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Natural Resource Stewardship and Science

Assessment of Natural Resource Conditions In and Adjacent to Biscayne National Park

Natural Resource Report NPS/BISC/NRR—2012/598

ON THE COVER
Coral reef in Biscayne National Park
Photograph by NPS South Florida/Caribbean Network

Assessment of Natural Resource Conditions In and Adjacent to Biscayne National Park

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December 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Harlem, P. W., J. N. Boyer, H. O. Briceño, J. W. Fourqurean, P. R. Gardinali, R. Jaffé, J. F. Meeder and M. S. Ross. 2012. Assessment of natural resource conditions in and adjacent to Biscayne National Park. Natural Resource Report NPS/BISC/NRR—2012/598. National Park Service, Fort Collins, Colorado.

NPS 169/117834, December 2012

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Executive Summary

This report is an assessment of the conditions of natural resources in Biscayne National Park (BNP) based on the compilation, review and evaluation of existing information on the Park's natural resources. This review evaluates threats and stressors, and is intended to improve understanding of BNP resources to help guide Park management to address the identified threats, which are supported by enhanced data collection, research and assessment efforts.

The report is focused on broad resource components, namely terrestrial resources and aquatic systems including: wetlands, canals, bay waters, marine/reef areas and ground waters. Biotic and abiotic resource components are considered in the review.

The objectives of the assessment are to:

- Provide a review/compilation of existing information on BNP natural resources.
- Provide a list and description of threats/stressors to these resources.
- Develop a semi-quantitative ranking of the threats to resource components and the extent of existing information.
- Identify research needs based on information gaps and degree of threat to the resources.

There are many threats to the resources of BNP and many gaps in our knowledge of the functioning of the Biscayne Bay ecosystem. In this report, we identified and evaluated various threats to specific natural resources and color-coded their strength using a stop-light format. To enhance the assessment further, the state of the knowledge for individual threats was complemented with a four-letter code to indicate whether the knowledge base is good, fair, poor or only inferred. Existing problems with a good knowledge base are candidates for management actions, while problems with less certain understanding are candidates for monitoring and research. Given our understanding of the state of the natural resources of BNP, we highlight the problems that deserve research priority.

The U.S. Congress designated Biscayne National Monument on October 18, 1968 to protect the central and southern portions of Biscayne Bay. In 1982, the monument was expanded and dedicated as Biscayne National Park. The Park is located south of the city of Miami (25°39'N, 80°50'E) in South Florida. The Park covers approximately 172,000 acres, most of which are covered by water, either in Biscayne Bay proper or offshore of the northern extension of the Florida Keys. It includes estuarine ecosystems with extensive seagrass meadows in the bay proper and extensive coral reef areas offshore of the Keys. BNP also includes terrestrial ecosystems on the Keys (mainly hardwood hammocks) and mangrove forest along the mainland shoreline. Except for its developed western boundary, BNP is surrounded by protected areas: to the east by the Florida Keys National Marine Sanctuary (FKNMS), to the south by the FKNMS and Pennekamp State Park, and to the north by the extension of the Biscayne Bay Aquatic Preserve. BNP waters, Biscayne Bay Aquatic Preserve and Barnes and Card Sounds (part of FKNMS) are designated Outstanding Florida Waters. The Park is within the National Oceanographic and Atmospheric Administration (NOAA) designated Essential Fish Habitat

(EFH) for spiny lobster, snapper, grouper, and the seaward waters are in the EFH for corals. All of BNP is within the NOAA-designated Habitat Areas of Particular Concern (HAPC) for the same groups and within the penaeid shrimp HAPC for the Biscayne Bay portion of the Park.

The major threats (not in order of importance) to natural resources in BNP are:

- Overfishing generally and for specific indicator species.
- Acidification as a result of increasing atmospheric CO_2 and its potential impacts on aquatic organisms, particularly corals.
- Atmospheric deposition of anthropogenic particulates with associated pollutants and possibly pathogens.
- Nutrient enrichment resulting in modifications in community structures and potentially negative impacts through harmful algal blooms.
- Microbial contamination due to increased anthropogenic inputs caused by urban development.
- General pollutant loadings to the Park, with particular emphasis on potential ecotoxicological effects of present day pesticides and herbicides, pharmaceuticals and personal care products, marine-derived pollution (e.g., antifouling agents) and canal-derived, sediment-bound pollutants.
- Current water management practices including hydrological modifications, with emphasis on plans for enhanced freshwater delivery (discharge), timing and the associated salinity gradients and pollutant loadings.
- Deposition of marine debris.
- Habitat loss and fragmentation due to urban development, particularly for the urban environments near the Park.
- Concerns about the resilience and buffer capacity of Park natural resources with the ever-increasing visitor use, especially boating and fishing.
- Increases in diversity and abundance of exotic/invasive species for terrestrial and aquatic environments.
- Climate change and associated sea-level rise.
- Potential effects of existing and expanded power plants adjacent to the Park (e.g., thermal, water and radiological pollution).

Anthropogenic threats and stressors are significant for BNP, and their effects can be implied but not accurately predicted. With the ever-increasing urbanization of the Miami metropolitan area, the threats are imminent. Water quality (WQ) is likely to change in response to these growing human populations in South Florida and the changing policies for managing freshwater resources in the watershed of BNP. It is well established that changes in water quality will lead to changes in the benthic communities in Biscayne Bay and potentially in the marine/reef environments seaward of the barrier islands. Steps should be taken to test hypotheses about water quality. Benthic community relationships and a synthesis of existing and new information needs to be developed to predict outcomes for planned changes in the quality or quantity of water entering the Park. The relationships between altered water quality, including the ecotoxicological effects of associated emerging pollutants of concern, such as pharmaceuticals and personal care products, and the diseases of marine organisms, also need examination.

The terrestrial environments of BNP, which is better known for its marine resources, include hardwood hammocks (broadleaf forest comprised of tropical upland trees) and coastal wetlands. The latter comprise the entirety of mainland BNP, while the former characterize a diverse mixture of communities on the barrier islands that form the eastern rim of Biscayne Bay. These contrasting terrestrial ecosystems are underappreciated and critical components of the broader BNP landscape. The coastal wetlands should be considered critical primarily for their interactions with surrounding marine ecosystems, though their role in buffering nearby urbanized areas from storms is probably considerable. The significance of BNP hardwood forests lies in their contribution to biodiversity in light of the diminished regional extent of tropical hammock vegetation and, consequently, these ecosystems deserve more research focus and support than they presently receive.

Currently, local human impacts are the primary concern; however, the accelerating rate of climate change may soon overtake local impacts in importance. Research should be directed toward understanding how climate change will impact the populations of marine organisms in the benthic communities and the wetlands, in Biscayne Bay and the marine/reef zones of BNP, and also how climate change could alter the relative dominance of species in all communities.

Park management practices and strategies need to be continuously enhanced to understand and mitigate visitor use of Park resources. Of particular concern are threats from boating, as well as fishing and diving. The resilience and buffering capacity of Park resources to visitor use, and the potential increase in visitor numbers, must be assessed and management plans adjusted accordingly.

Acknowledgements

This is Technical Report #T-481, Florida International University, Southeast Environmental Research Center, Miami, Florida (SERC Contribution #T-481). The project was supported by the National Park Service under Cooperative Agreement #H5000 06 0104, Task Agreement #J2380 07 0089 to Florida International University.

The authors thank the following individuals for data or material assistance in the preparation of this document: Richard Alleman (SFWMD), Elsa Alvear (NPS), Sarah Belmund (NPS), John Karl Bohlke (USGS), Amanda Borque (NPS), George Burgess (FMNH), Alan Cressler (USGS), John Cristensen (NOAA), Joana Fernandez de Carvalho (FMNH), Daniel Gann (FIU), Alicia Garcia (FIU), Ed Johnson (NOAA), Kristen Keteles (NPS), R. Robin Lewis (LES Inc.), Barbara Lidz (USGS), Diego Lirman (UM-RSMAS), Frank Marshall, Tammy Mayfield (FL DOT), Cliff McCreedy (NPS), Vanessa McDonough (NPS), Gary Milano (M-D DERM), Steven Miller (UNC Wilmington), Danielle Mir-Gonzales (NC Div. of Water Quality), Ted Morris (USAF Ret.), Matt Patterson (NPS), Emily Phillips (USGS), Joe Prospero (UM-RSMAS), Christopher Reich (USGS), Amy Renshaw (NPS), Pablo Ruiz (FIU), Marcia Steelman (M-D DERM), Ed Swakon (EAS Engineering), Harold Wanless (Univ. of Miami), G. Lynn Wingard (USGS) and Brian Witcher (NPS).

Introduction

The U.S. Congress in the FY 2003 Appropriations Act instructed and funded the National Park Service (NPS) to assess environmental conditions in watersheds where national park units are located. The objective of the assessments is to document existing and potential threats to habitat and biological integrity, and to provide guidance for future research and data collection.

This report assesses the condition of the natural resources of Biscayne National Park (BNP) and evaluates the threats and stressors that act on the natural resources. BNP occupies the central and southern portions of Biscayne Bay, a shallow estuary adjacent to the Miami metropolitan area. It has experienced significant degradation in estuarine conditions as a result of land use changes and the conversion of natural drainages to managed canals in the watershed.

The assessment covers resource groups in terrestrial, freshwater and coastal-bay-marine areas within and adjacent to BNP. A regional scope is necessary given the profound transformations experienced in the watershed and forecasted changes in the Comprehensive Everglades Restoration Plan (CERP), which is intended to restore some natural conditions from pre-intervention times.

Considering the abundance and richness of scientific information on BNP, this assessment is based exclusively on compilation, synthesis and exhaustive analysis of pre-existing data, without collection of new data. The objective of the assessment is to provide park managers and researchers:

- A descriptive summary of BNP natural resources.
- A synthesis of the status of the resources.
- Identification of information gaps and research needs.

This report is structured in five sections following guidelines and formats applied in similar studies in other National Parks (e.g., Vaux et al., 2008).

Park Description

This section includes a comprehensive description of BNP, highlighting relevant pre-modification dynamics and summarizing the fundamental characteristics of its resources. We document the areal extent and diversity of the BNP landscape and protected areas surrounding the park.

Resource Characterization

In this section, information is presented on a select group of attributes associated with generally accepted measures of resource conditions that best characterize the physical, chemical and biological resources of BNP.

Assessment of Threats

In this section, selected threats are described and the knowledge base and extent of the problems are ranked.

Assessment of Resource Condition

Given the diversity of resources and variety of metrics used to evaluate their conditions in the literature and this analysis, a homogeneous quantitative scale to evaluate those resources is unrealistic. Approaches adopted by other investigators (e.g., Mitchell et al., 2006; Kahl et al., 2000; Vaux et al., 2008), and fully described later in this report, were used.

Conclusions and Information Needs

Conclusions derived from this study lead to the identification of information gaps and topics where research is needed to characterize threats and enrich the knowledge base to understand ecosystem functioning and impact of stressors. This will help managers in the process of decision-making.

Park Description

The U. S. Congress designated Biscayne National Monument in October 18, 1968, to protect the central and southern portions of Biscayne Bay. In 1982, the monument was expanded and dedicated as Biscayne National Park. The park is located on the southeast coast of South Florida. Most of BNP's 172,000 acres are covered by water in the bay proper and the offshore along the northern extension of the Florida Keys. It includes estuarine ecosystems with extensive seagrass meadows in the bay proper and large coral reefs offshore from the Keys. Additionally, BNP also includes terrestrial ecosystems on the Keys (hardwood hammocks) and mangrove forest along the mainland shoreline. Except for its western boundary with the city of Miami, BNP is surrounded by protected areas On the south and east is the Florida Keys National Marine Sanctuary, which includes Card and Barnes Sounds; Card Sound to the south is an aquatic preserve and BNP waters, Biscayne Bay Aquatic Preserve, and Barnes and Card Sounds have been designated Outstanding Florida Waters and are also Essential Fish Habitats, designations that add a higher level of regulation and protection.

Size and Location of Park Lands

Figure 1 shows the location of Biscayne National Park. Figure 2 shows the general areas under management at the park and Table 1 shows the acreage by area. The majority of the park is Biscayne Bay.

Table 1. Area under management.

Province	Area (hectares)	Area (acres)
Atlantic Ocean	28,243	69,790
Biscayne Bay	37,398	92,412
Card Sound	520	1,285
Inland water bodies	31	77
Land	3,103	7,668
Total	**69,295**	**171,232**

The park is adjacent to protected lands and submerged bottoms with the exception of the western mainland shore where many developed and developable properties exist. The largest property is Homestead Air Reserve Base, a military reservation located NW of the park headquarters. Conservation lands (Figure 3) adjacent to the park include:

- The Florida Keys National Marine Sanctuary, which includes the marine areas east of the park as well as the portion of Card Sound to the south.
- Biscayne Bay Aquatic Preserve, which includes bay water areas located north of the park and managed by the state.
- John Pennekamp Coral Reef State Park, which shares its northern border with the park, and Bill Baggs State Park on the south end of Key Biscayne.

Figure 1. Location of Biscayne National Park southeast of Miami, showing topography and bathymetry. Terrestrial areas are coded from dark green (lowest) to dark brown (highest). Marine areas are coded light blue (shallowest) to dark blue (deepest).

- County and municipal parkland in many locations on or near the western park boundary.
- Miami-Dade County Environmentally Endangered Lands Program (EEL) plots along the western shoreline of the park or scattered across the uplands near the park.
- Other publicly owned lands near or in the watershed to the west of the park.

Figure 2. General distribution of areas under park management.

All other adjacent lands are zoned for commercial or residential use, including the large area used by Florida Power and Light for the nuclear plant cooling canals just southeast of park headquarters. The area of conservation land categories within five miles of the park boundary are presented in Table 2. The names of features in and around BMP are shown in Figure 4.

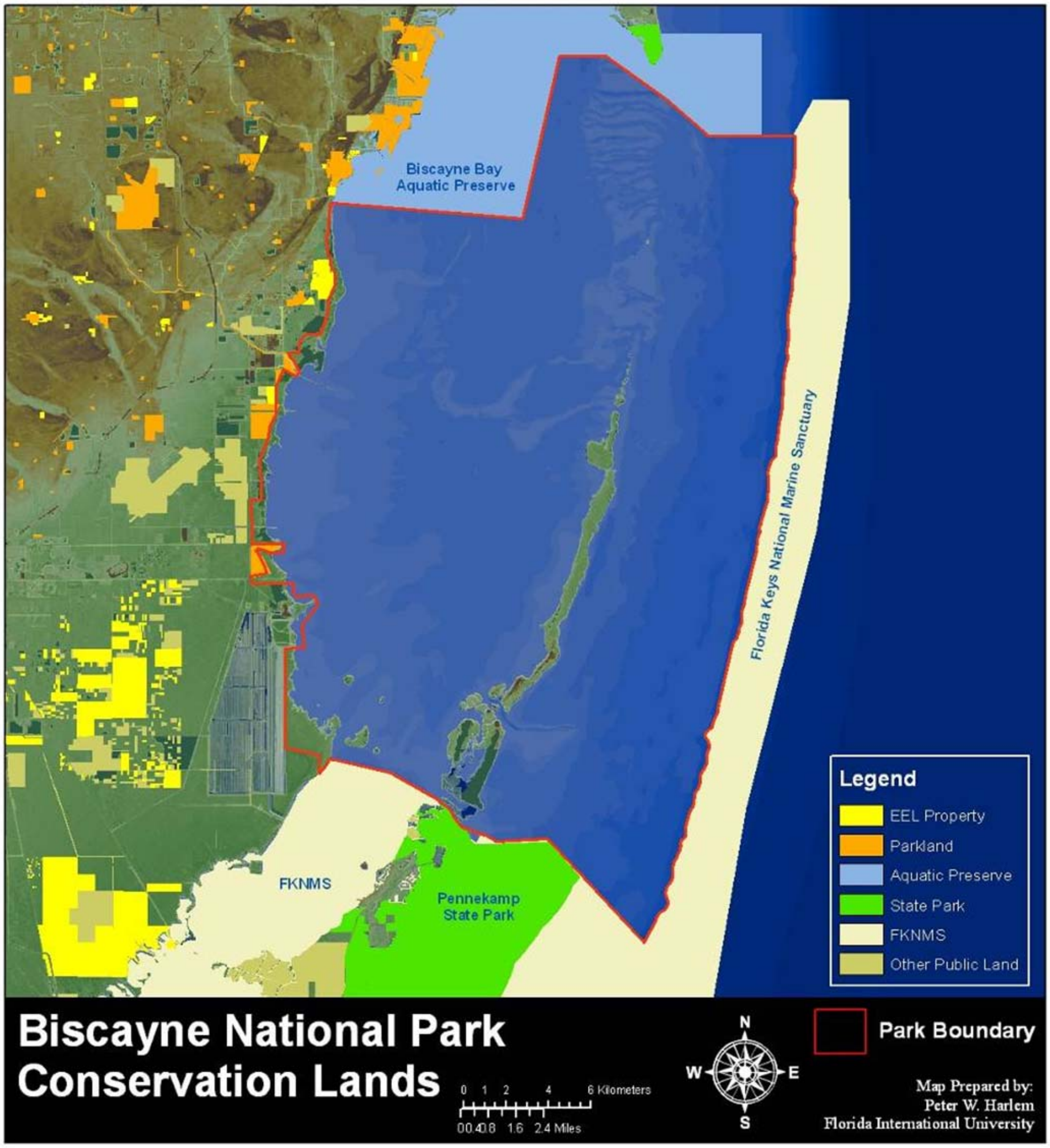


Figure 3. Conservation lands near Biscayne National Park. Environmentally Endangered Lands **(**EEL) properties are part of the Miami-Dade Environmentally Endangered Lands program, and FKNMS is the Florida Keys National Marine Sanctuary. Parkland includes city and county parks; Other Public Land includes property under government control, but not necessarily set aside as conservation land.

Table 2. Public lands within five miles of Biscayne National Park.

Type	Area (hectares)	Area (acres)	Comment
Environmentally Endangered Lands	1,345.7	3,325	County - preserved
Parkland	2,074.7	5,127	County and Municipal
Aquatic Preserves	13,952.5	34,477	State –marine only
State Park	5,991.4	14,805	State

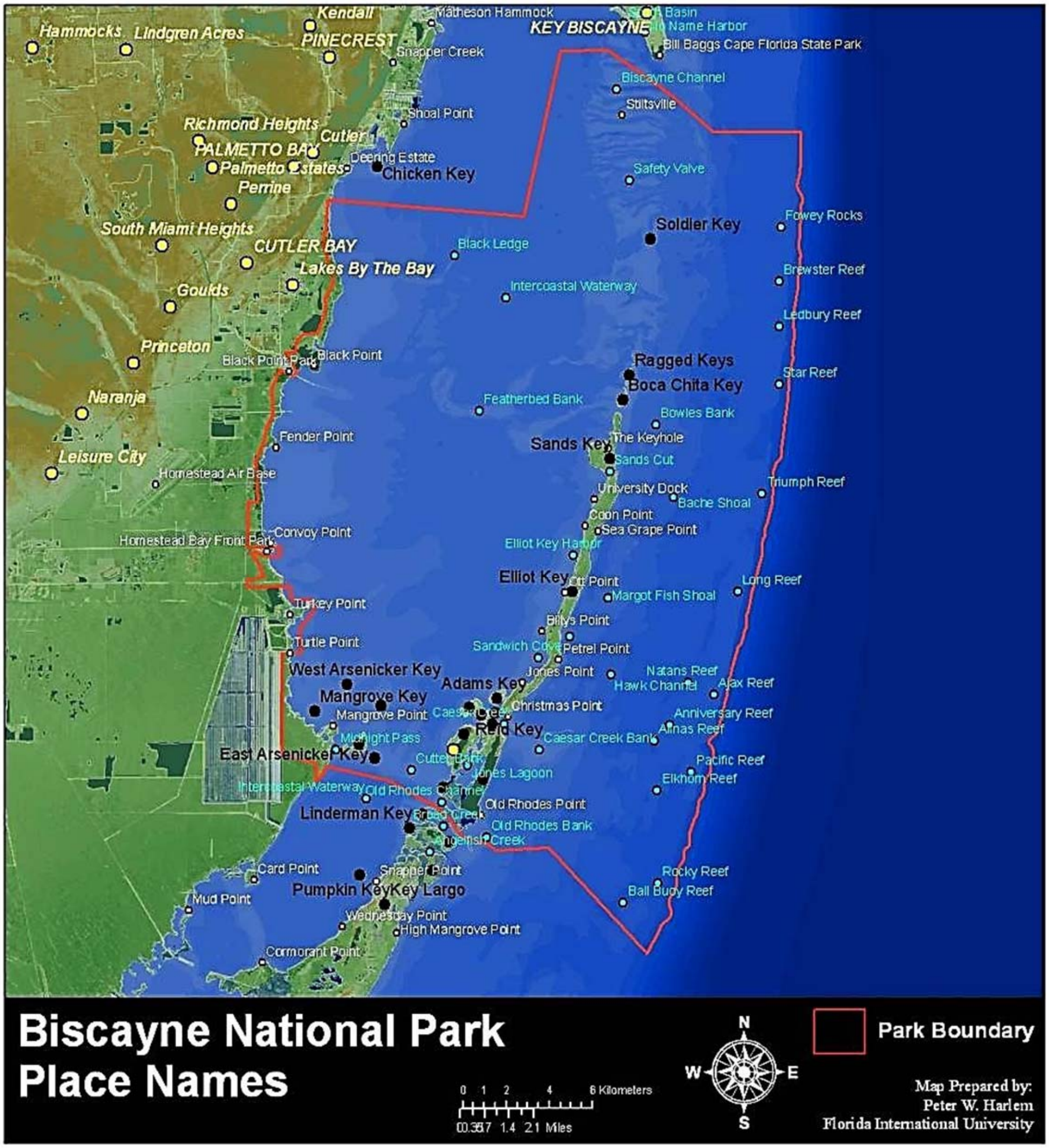


Figure 4. Named features in Biscayne National Park and surrounding areas.

Upland, Freshwater, Wetland, Coastal, Bay and Marine Systems

Biscayne Bay is defined by its geology. Specifically, the surface expression is a shallow depression in bedrock, produced by erosion and sedimentation through one or more changes in sea level acting on a suite of marine and fresh water deposits, dominated by limestone. Three major physiographic provinces, and the Biscayne Bay basin itself, are present in BNP and its surroundings: the Atlantic Coastal Ridge developed on the resistant Miami Limestone to the west; the southern slope, locus of Holocene sedimentation; and the High Coral Keys developed on the wave-resistant Key Largo Limestone to the east. Bedrock in all provinces has been subjected to severe weathering, leading to the development of mature karst topography where solution features (sinkholes, caves, microkarst, etc.) are abundant and relief is controlled by differential resistance to erosion. This fundamental setting is responsible for subsequent development and distribution of habitats and the ecosystem framework.

BNP is located primarily over a two subparallel marine basins – Biscayne Bay is the larger basin; Hawk Channel forms the eastern third of the park and is located seaward of the rocky keys, which divides the two basins. A small amount of land occurs along the western shoreline and on the rocky keys. Much of the bottom of Biscayne Bay is rocky or covered with a thin veneer of skeletal sands and mud, except for the thicker mud-bank called the "Safety Valve" found leeward of a submerged rock trend. Thick peat, mud, sand and marl deposits are found along the western shoreline and a few places on the islands. Seaward of the keys, Hawk Channel has sufficient sediment in most places to support a grassy-covered bottom, and is dotted with hardbottom areas and patch reef complexes; it is fringed seaward by a barrier platform reef system.

Freshwater freely entered the bay by surface flow from the west or northwest before drainage modification and urban development, and infiltrated water moved through two aquifers in the upper layers. Surface flow passed from the eastern Everglades to the bay via shallow valley structures (sloughs) oriented southeast in the Miami Limestone called "transverse glades" (TG, Figure 5). North of Miami, the TGs terminate in streams; several northeast of the park were evolving into streams, while those west of the park fed water to many of the largest tidal creeks. The northern bay was significantly fresher historically because, in addition to water it received from the ground and from runoff, its four short rivers connected directly with the eastern Everglades and combined with poor circulation until the opening of Bakers Haulover Inlet in 1924.

The southern bay combined an estuarine zone along the western shoreline, dominated by surface and groundwater flows, with a large body of marine water in the park area, entering through the many tidal channels cut through the limestone north and south of the upper Keys. A small coastal plain of carbonate mud, freshwater marl and peat, with small quantities of fine quartz sand, lies eastward of the limestone ridge and forms BNP's mainland shoreline. Incised with numerous extinct freshwater streams and tidal creeks, this sediment package widens considerably west of Turkey Point. The coastal plain supported marl forming prairies and was fringed by peat forming mangrove swamps running as a fringe along the coast.

The eastern margin of Biscayne Bay is defined by a linear elevated rock ridge made up of coralline limestone (Key Largo Formation), generally interpreted as an extinct reef. This Pleistocene reef is well exposed in the northern Keys where it rises to about 18 ft. In the northern bay this structure dips below the sediment cover, except off of Fisher Island and Virginia Key. It is just below the surface on the ocean side of the Safety Valve mud banks emerging only at Soldier Key. This subsurface aspect protects the Safety Valve and the northern beaches where present, such as at either end of Key Biscayne. Along the southern bay, the limestone is emergent and forms the middle and northern Florida Keys. Channels through the structure formed before the Holocene control the location of inlets and present tidal channels. Older, extinct reef structures seaward of the keys are lower in elevation, run in bands roughly paralleling the current shoreline and most have modern reefs growing on them. The living platform reefs offshore of the keys are separated by Hawk Channel, a depression filled with carbonate sediment and possibly fault-controlled.

Figure 5. General morphology of Biscayne National Park and adjacent upland derived from 2002 LiDAR and other sources. Note the many transverse glades passing over the limestone Miami Ridge. These were historic pathways for water flow from the Everglades to the coastline and fed the Southeastern Saline Everglades (SESE) coastal plain.

Drainage practices over the last century or more have eliminated most of the freshwater inputs, except for frequent point-source releases of water from the canal system to reduce interior flooding and small quantities of groundwater and rain (McPherson et al., 1976, Duever et al., 1994). Now, the rivers are controlled and a system of canals is in place with at least one major canal in each hydrologic basin (Figures 6 and 7); the runoff has been reduced to a trickle, and groundwater head has been lowered. Appendix A Table A1 shows the basin areas and proximity to BNP. North Biscayne Bay had frequent “freshets” with massive fish kills prior to opening Bakers Haulover inlet, which changed the salinity regime from estuarine to marine. In the southeastern portion, farming in the 1920s and 1930s converted most of the marl surfaces to agriculture. Recently, much of the coastal property in private hands is being converted at a rapid rate into suburban residential and exurban economic zones, even though this land was prone to inundation in the past and is now threatened by sea-level rise.

Limestone bedrock is exposed in the park in many locations and most of it displays karst features (Thornberry-Ehrlich, 2005). On the reef tract, sinkholes have been identified and some of the transverse submerged channels through the reefs could be interpreted as karst features along joint or fault trends (Kramer et al., 2001). On the Keys, the entire upper surface is controlled by the karst aspect of the Key Largo Limestone with microkarst surfaces and many facies changes which affect vegetation patterns (Ruiz et al., 2008).

Much of south Biscayne Bay bottom is bare bedrock or barely covered by a sediment veneer which may come and go with storm cycles. This surface displays circular depressions (sinkholes) filled with seagrass growing over fossil mangrove peat (Zieman, 1972) reflects the karst history of the Miami Limestone prior to submergence. Other striking features are dendritic patterns which seem to be drowned stream channels etched into the limestone surface. These can often be traced from extinct freshwater streams along the coast, with branches coalescing into wider sinuous segments which ultimately extend to breaks in the barrier islands. One group, located north of Featherbed Bank, is trending to a location under the Safety Valve, and a second main group converges on tidal passes south of Elliot Key.

Sediment within Biscayne Bay is generally thin and mostly formed of biogenic carbonate (Wanless, 1976). The Safety Valve banks are the thickest accumulation of fine carbonate mud in the park and are geologically quite peculiar and little studied. The banks are protected from ocean attack by a thick rind of sand, coarse shell and coral fragments on the seaward margin and by the Key Largo ridge which lies under the margin edge. Behind this protection, they are mostly soft mud and support a dense pattern of seagrass and biota. At the north end of BNP, mud, which has been transported south from the break in Rickenbacker Causeway, accumulates along the deep axis where depths can reach more than four meters. To the east, a thin sediment package overlies the limestone to the coast, but closer to Black Point this thins until bedrock is exposed. Quartz sand bodies (common to the north) are scarce in the park, except as deltas at the mouths of former streams where they support dense mangrove forest structures which also extend up the former creeks. Featherbed Bank and No Name Bank are examples of relict sand structures which can be emergent at lowest tides. Longshore, drift-derived, sand beaches are found northeast of the park from Matheson Hammock south to Chicken Key, although these are now eroding as their supply of sand has been cut off by many dredged holes along that coastline.

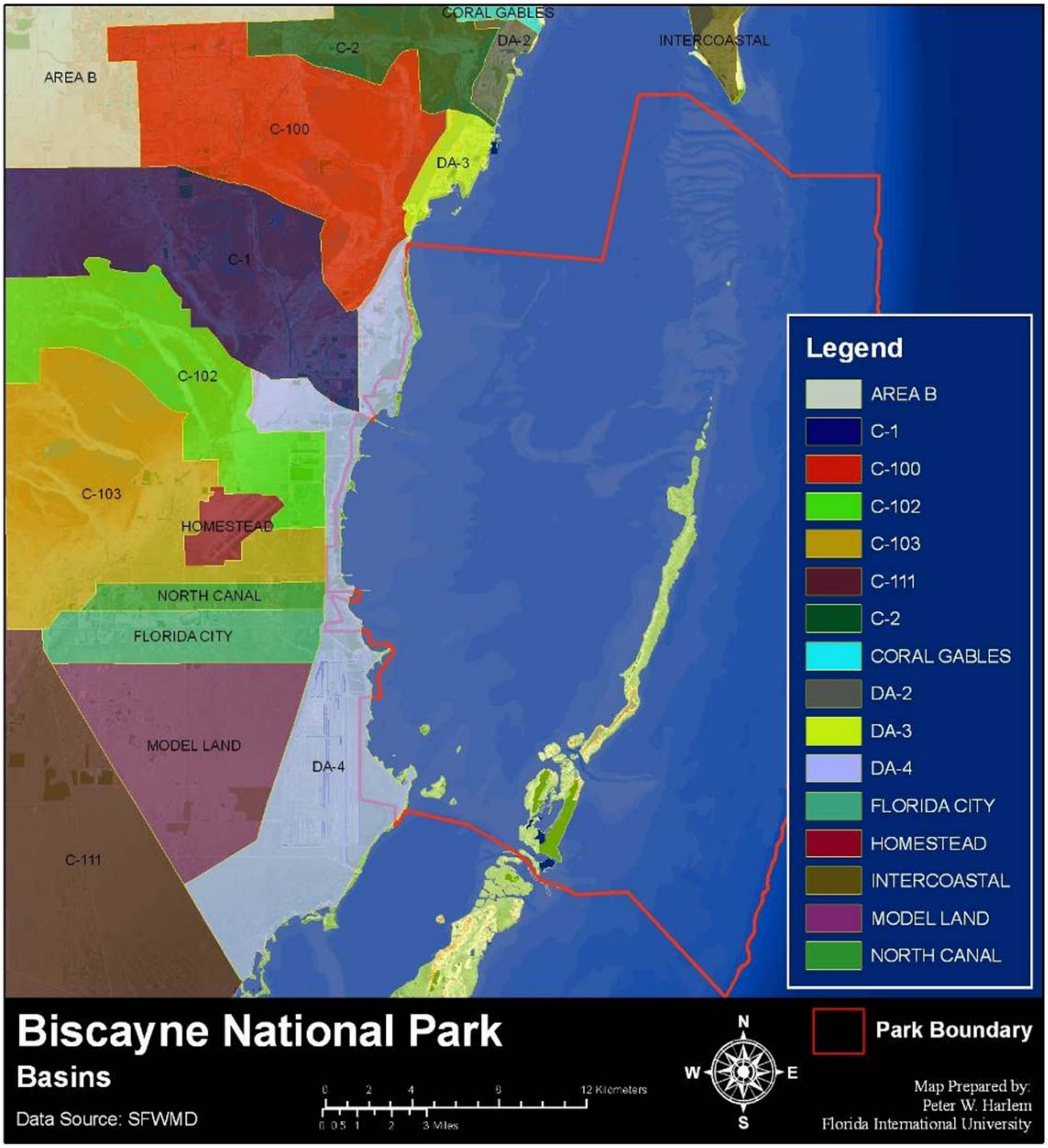


Figure 6. South Florida Water Management District management basins west of Biscayne National Park. These basins are used to control flooding and salt water intrusion, but have only a crude relationship to the natural drainage basins determined by geomorphology.

Biscayne Bay is separated into sub-basins by sediment banks. The area north of Featherbed Bank is the main basin of central Biscayne Bay and is generally deeper than any others in the bay. Recent work suggests this depression may be fault controlled as there appears to be one trending from Black Point toward Key Biscayne (Cunningham, 2008). The southern basin south of Featherbed is shallower, but deepens toward Elliot Key and to the south, where it is separated

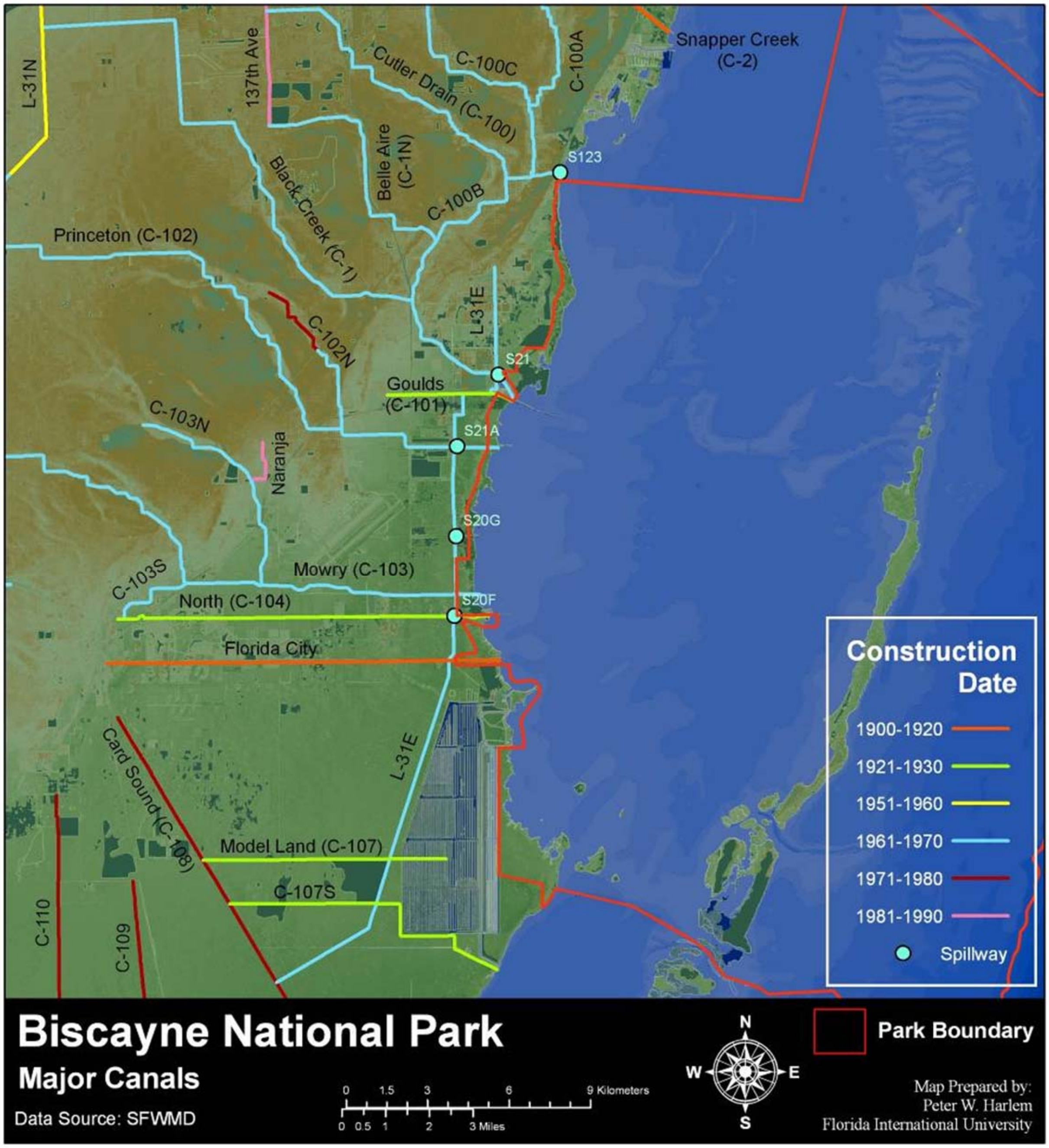


Figure 7. Major freshwater canal inputs and their relative completion date.

from Card Sound by a large carbonate sediment bank which provides a substantial divide between the bay and the sound.

Perhaps the most famous and most visited areas of the park are its fringing reefs and extensive network of patch reefs off Elliott Key. Coral hardgrounds and patch reefs occur in Biscayne Bay (Lirman et al., 2003), mostly on hardbottom in the southern bay near the upper Keys (Figure 8). These are areas with adjacent seagrass beds or seagrass patches growing in rounded karst holes

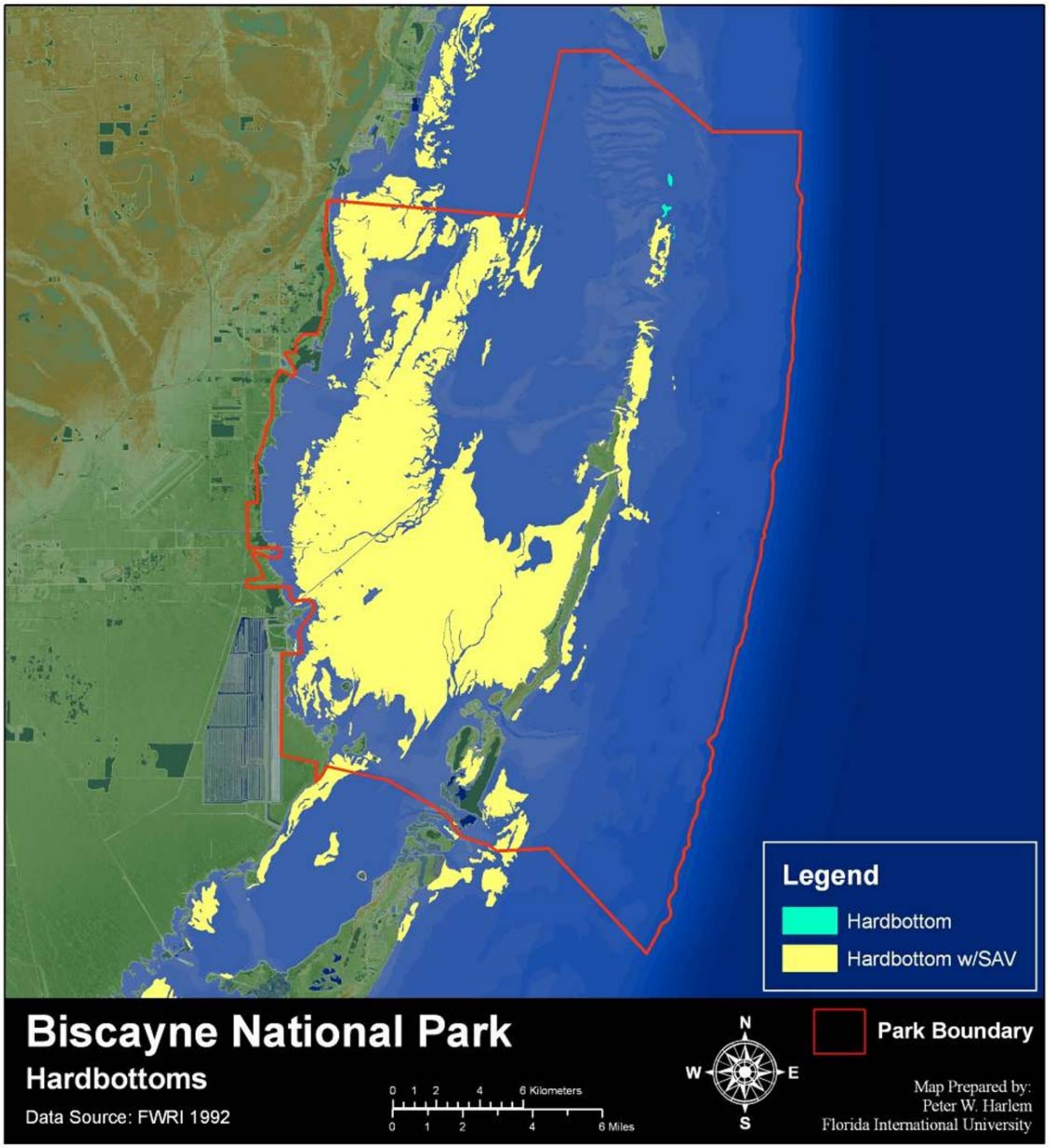


Figure 8. Hard bottom substrate mapped by the Florida Wetlands Research Institute. Hard bottom areas are the home of many animal and plant species adapted to bare bottoms with shifting thin sediments. Many solitary or small-head hard corals and gorgonians and many attached benthic plant species, such as important calcareous blue-green alga, live in areas of normal marine salinity. SAV = submerged aquatic vegetation.

in the upper limestone layer; they provide food and other benefits to the animals living on small bioherms. Hardbottoms are also the home of sponges, which were harvested extensively in the past (Munroe, 1930). Table 3 shows the total area of bare bottom and hardbottom substrates in the park and the adjacent bottoms to five miles from the park boundary.

Table 3. Bare bottom substrates in or adjacent to Biscayne National Park (BNP). Categories defined by FWRI (1992). Percent is compared to total benthic area. Ha = hectares.

Bottom Type	Area (Ha) in BNP	Area (Ha) 5 mile buffer	Percent (BNP/ 5 mile buffer)
Bare substrate	2,499.3	4,345.8	3.71/3.87
Hardbottom	26.1	26.1	0.04/0.02
Hardbottom with seagrass	17,590.1	19,558.0	26.14/17.4

Offshore of the barrier islands/Keys, the sea bottom is the home of both extensive patch reefs, particularly seaward of Elliot Key (Figure 9), and bank margin reefs which extend for long stretches along the eastern edge of the park (Figure 10). Table 4 summarizes the acreages of these features. The reefs are frequently visited by fisherman and by recreational divers, and are perhaps the most important asset to the park because of that attention; they also provide managers with a sympathetic ecotone readily identified with this unique park. Coral reefs are considered worldwide to be a major indicator of the health of the oceans the local environment. However, the considerable environmental stresses on the reefs are mostly from a variety of large-scale processes, many of which are not responsive to local management solutions.

Table 4. Offshore reef areas in and around Biscayne National Park (BNP). Categories defined by FWRI (1992). Percent is compared to total benthic area. Ha = hectares.

Bottom Type	Area (Ha) in BNP	Area (Ha) 5 mile buffer	Percent (BNP/ 5 mile buffer)
Patch Reef	940.7	1,165.7	1.40/1.04
Platform Margin Reef	2,876.5	4,047.2	4.28/3.6

Other reef-related resources are historical shipwrecks, other sunken vessels, or other debris (wreck related or the result of dumping). These perform as hard substrate for reef-forming organisms and are part of the archeological resources within the park. Artificial reefs are not allowed within the park but several are located offshore of the eastern park boundary. They are known by the diving and fishing communities and are utilized by both quite extensively, often traversing park waters to access the sites (Figure 11; see Appendix A Table A2 for brief descriptions).

Legislative Background and Management Objectives

In 1916, the National Park Service Organic Act was passed by Congress which created the Park Service and gave it its purpose:

> ....to conserve the scenery and the natural and historic objects, and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

Figure 9. Patch reefs as mapped by Florida Wildlife Research Institute (1992). The area seaward of Elliot Key has one of the highest densities of this reef type in the Florida reef tract. Note the significant drop-off of reefs north of the Keys, where the mobile sediments surrounding Key Biscayne cover much of the bottom area. Patch reefs inside Biscayne Bay are not shown.

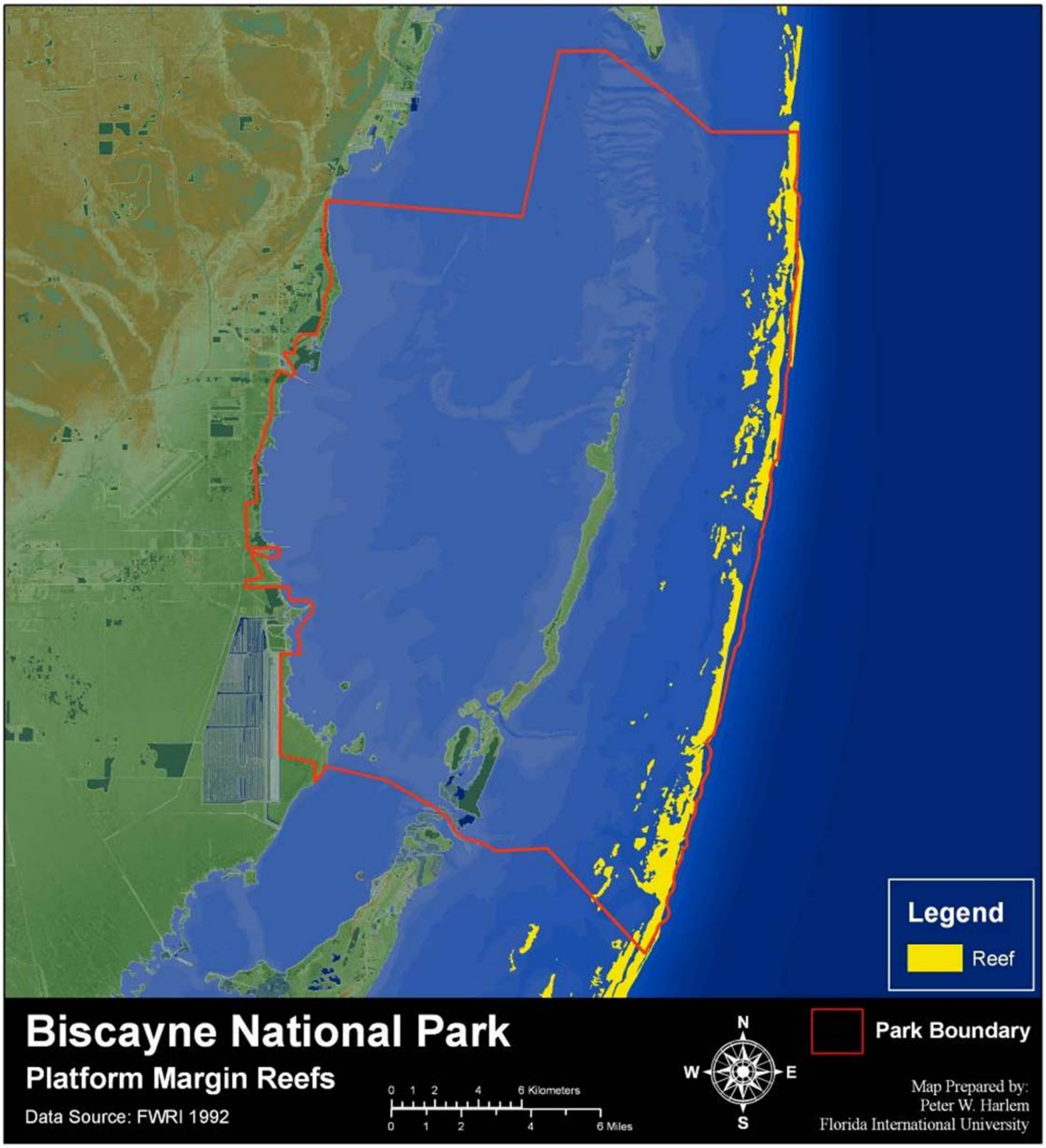


Figure 10. Platform margin reefs located along the eastern margin of Biscayne National Park (FWRI, 1992). Forming almost a continuous barrier along that side, breaks in the reef reflect geological attributes such as drowned stream valleys.

Figure 11. Location of significant artificial reefs adjacent to Biscayne National Park. Data are from numerous sources, including online reef-diver listings and NOAA lists, none of which are complete by themselves.

Biscayne National Park was created under U.S. Code Title 16, Conservation Chapter, Subchapter LIX-E. Section 410gg of that act specifies:

> In order to preserve and protect for the education, inspiration, recreation, and enjoyment of present and future generations a rare combination of terrestrial, marine, and amphibious life in a tropical setting of great natural beauty, there is

> hereby established the Biscayne National Park…in the State of Florida. The boundary of the park shall include the lands, waters, and interests therein as generally depicted on the map entitled "Boundary Map, Biscayne National Park", numbered 169-90,003, and dated April 1980, which map shall be on file and available for public inspection in the offices of the National Park Service, Department of the Interior.

Detailed aspects of running and managing the park are covered in the Code of Federal Regulation under Title 36 (Parks, Forests, and Public Property) in which Chapter 1 covers the National Park Service. Details of managing BNP proper are covered in the Superintendent's Compendium (National Park Service, 2004), which lists various uses and prohibited uses, among other details.

Other Federal laws enforced in the park include the Endangered Species Act, Clean Water Act and traditional law enforcement. Agencies including NOAA National Marine Fisheries Service and Fish and Wildlife Service have jurisdiction over aspects of park resources. State laws governing fishing and diving, West Indian manatee protection zones and others, are enforced by Florida DNR, Florida Fish and Wildlife, and park staff.

Biscayne National Park General Management Plan

The last comprehensive planning effort (general management plan) for Biscayne National Park was completed in 1983. Population and development near the park has greatly increased since 1983, visitor uses have changed and stresses on park resources have increased. Each of these changes has profoundly impacted the integrity of park resources and quality of visitor experience, and will have major implications for future management of park resources. In 2000, the NPS began the planning process in order to clearly define goals for resource conditions and visitor experiences to be achieved in the park, and determine what kinds of visitor facilities, if any, would need to be developed.

This planning process is conducted pursuant to the National Environmental Policy Act and NPS policies in order to ensure consultation with interested stakeholders and adoption by the NPS leadership, after an adequate analysis of the benefits, impacts, and economic costs of alternative courses of action. Public scoping meetings were held in 2001 and 2003, and continued with public scoping workshops on possible sizes and locations of a marine reserve zone in 2009, and release of the Draft General Management Plan/Environmental Impact Statement, followed by more public meetings in 2011.

Alternatives

The draft plan has five alternatives, including the National Park Service preferred alternative for future management of Biscayne National Park. The alternatives, which are based on the park's purpose, significance, and legal mandates, present alternative ways to manage resources and visitor use and improve facilities and infrastructure.

<u>Alternative 1</u>

The no-action alternative consists of a continuation of existing management and trends at Biscayne National Park, and provides a baseline for comparison in evaluating the changes and impacts of the other alternatives. The National Park Service would continue to manage the park as it is currently being managed. Existing operations and visitor facilities would continue, and no new construction would be authorized, other than what has already been approved and funded. Current law, policy and plans, would continue to provide the framework of guidance. The important impacts of continuing existing management conditions and trends would include no new impacts on natural resources, no adverse effect on cultural resources, a continuation of adverse effects on visitor experience, a continuation of adverse effects on park operations and no new impact on the socioeconomic environment.

Alternatives 2-5

Alternatives 2-5 are action alternatives and they share common features, such as the introduction of Nature Observation Zones in terrestrial areas of the park, and increase non-combustion engine use zones and slow speed zones to increase boater safety and reduce impacts on sensitive shallow areas by reducing vessel groundings. These areas include the waters surrounding Jones Lagoon, the Featherbeds in the bay area of the northern part of the park and along the mainland shoreline. The action alternatives reduce the Legare Anchorage. This area originally provided boaters with visual landmarks to mark the protected area, where stopping, anchoring and entering the water is prohibited. Due to modern GPS technology, an equal amount of protection can be achieved with a smaller area delineated by latitude and longitude. Action alternatives 3 and 5 propose access by permit zones in order to provide opportunities for solitary recreation in which the permit would be purchased by boaters. Action alternatives 3, 4 and 5 propose a no-take marine reserve zone, intended to provide visitors who snorkel and dive a unique opportunity to experience a healthy, natural coral reef community. The marine reserve zone is 10,522 acres in alternatives 3 and 4, and 21,812 acres in Alternative 5.

Alternative 2

Alternative 2 would emphasize the recreational use of the park, while providing for resource protection as governed by law, policy or resource sensitivity. This concept would be accomplished by providing a high level of services, facilities and access to specific areas of the park. Alternative 2 introduces Nature Observation Zones on terrestrial portions of the park, and proposes zones such as Non-Combustion Engine Use zones in shallow seagrass areas vulnerable to vessel groundings. Alternative 2 is expected to have beneficial impacts on fisheries and submerged aquatic communities, negligible to minor adverse impacts on state listed species and wetlands, no adverse effect on archeological resources, historic structures or cultural landscapes, both beneficial and adverse effects on visitor use and experience, adverse impacts on the park’s operations budget and beneficial impacts on the park’s facilities and beneficial impacts on the socioeconomic environment; it is unlikely to adversely affect federally listed species.

Alternative 3

Alternative 3 would allow all visitors a full-range of visitor experiences throughout most of the park, and would use a permit system to authorize a limited number of visitors to access some areas of the park. Management actions would provide strong natural and cultural resource protection and diverse visitor experiences. Alternative 3 is expected to have beneficial impacts on fisheries and submerged aquatic communities, negligible to minor adverse impacts on state listed species and wetlands, no adverse effect on archeological resources, historic structures or cultural landscapes, both beneficial and moderate adverse effects on visitor use and experience, adverse impacts on the park’s operations budget and beneficial impacts on the park’s facilities and beneficial impacts on the socioeconomic environment; it is unlikely to adversely affect federally listed species.

Alternative 4

Alternative 4 is the National Park Service preferred alternative and would emphasize strong natural and cultural resource protection while providing a diversity of visitor experiences. Some areas would be reserved for limited types of visitor use. The marine reserve proposed in this alternative would be 7% of the park's waters and 30% of the park's reef tract, leaving 93% of the park's waters open to fishing, including 70% of the park's reef tract. Alternative 4 is expected to have beneficial impacts on fisheries, and submerged aquatic communities, negligible to minor adverse impacts on state listed species and wetlands, no adverse effect on archeological resources, historic structures or cultural landscapes, both beneficial and adverse effects on visitor use and experience, minor adverse impacts on park operations and both beneficial and adverse impacts on the socioeconomic environment; it is unlikely to adversely affect federally listed species.

Alternative 5

Alternative 5 would promote the protection of natural resources, including taking actions to optimize conditions for protection and restoration. A permit system would be used in some parts of the park. Other areas would have limited numbers of visitors, manner of access and recreational activities to provide certain experiences. Alternative 5 is expected to have beneficial impacts on fisheries and submerged aquatic communities, negligible adverse impacts on state listed species and wetlands, no adverse effect on archeological resources, historic structures or cultural landscapes, both beneficial and adverse effects on visitor use and experience, minor to moderate adverse impacts on park operations, and both beneficial and adverse impacts on the socioeconomic environment; it is unlikely to adversely affect federally listed species.

Plan Finalization

Over 18,000 comments from individuals, other federal agencies, tribes, organizations and businesses were received on the draft plan. Over 90% of the comments were in favor of alternatives containing a no-take marine reserve zone. This zone received considerable attention, including Congressional hearings in April 2012, on concerns of marine industry groups and fishing interests. NPS will consider changes to incorporate in a Final General Management Plan/Environmental Impact Statement. The final plan will include letters from governmental agencies, substantive comments on the draft document and NPS responses to those comments. Following distribution of the Final General Management Plan and a 30-day no-action period, a Record of Decision will be issued to document the NPS alternative selection for implementation. An approved plan does not guarantee adequate funds and staff for implementation.

Park Visitation

Visitation to BNP has grown from 78,000 in 1972 to 600,000 annual visitors (Figure 12) with monthly totals varying from 30,000-100,000 (Figure 13). Tent campers are most common in the spring months (Figure 14), while boat overnight stays are highest in October (Figure 15). Not included in the data are research visits, walk-ins from ground access points along the shoreline or overflights by aircraft.

Figure 12. Annual recreational visitation to Biscayne National Park.

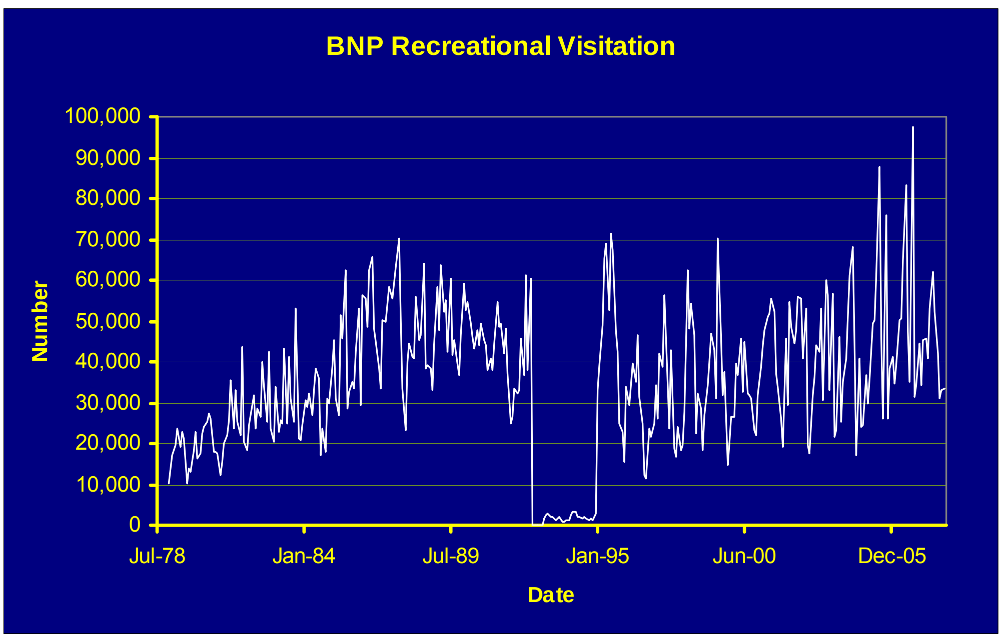


Figure 13. Recreational visitors to Biscayne National Park (BNP) by month. The sharp dip after Hurricane Andrew in 1992 and slow recovery is clearly visible. Data from NPS Public Use Statistics Office covers the1979-2007 period, except for the post Hurricane Andrew period Aug./1992-Dec./1992, for which data is not reported. Usage did not return to normal levels until 1995.

Of most concern are the users who come by boat because of the marine nature of the park. Without a boat, most of the resources cannot be viewed or enjoyed, a result of the small land footprint including islands, which also must be accessed by boat. Boater usages include fishing (mostly public but also commercial bait fish, finfish, crab and shrimp), scuba or snorkel diving,

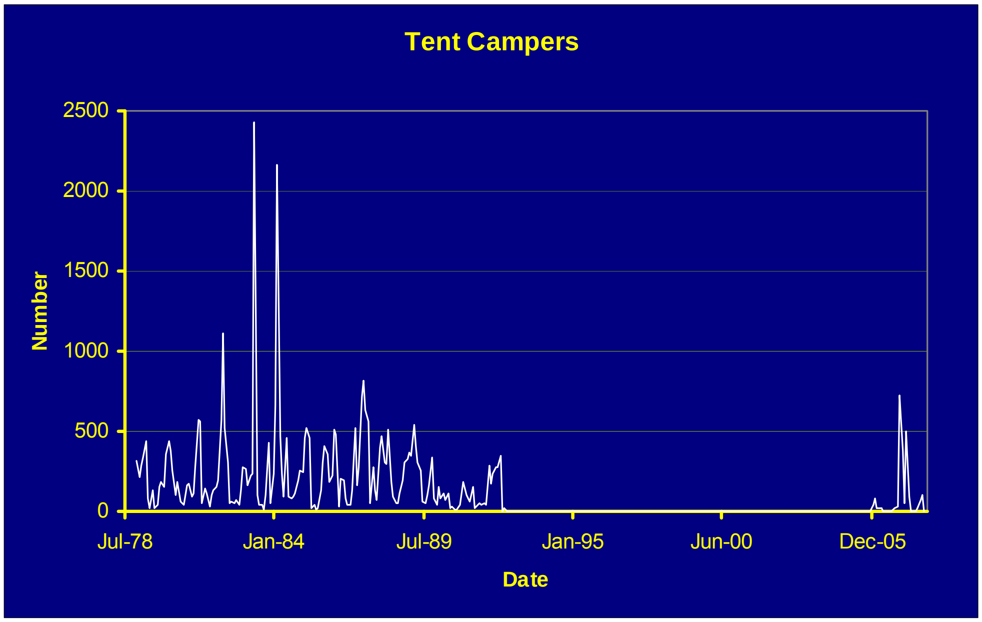


Figure 14. Tent campers in Biscayne National Park by month. Peak periods tend to be in the months March-May. Data from NPS Public Use Statistics Office covers 1979-2007; however, no data was reported for the period from August 1992, when Hurricane Andrew devastated the area, to January 2005.

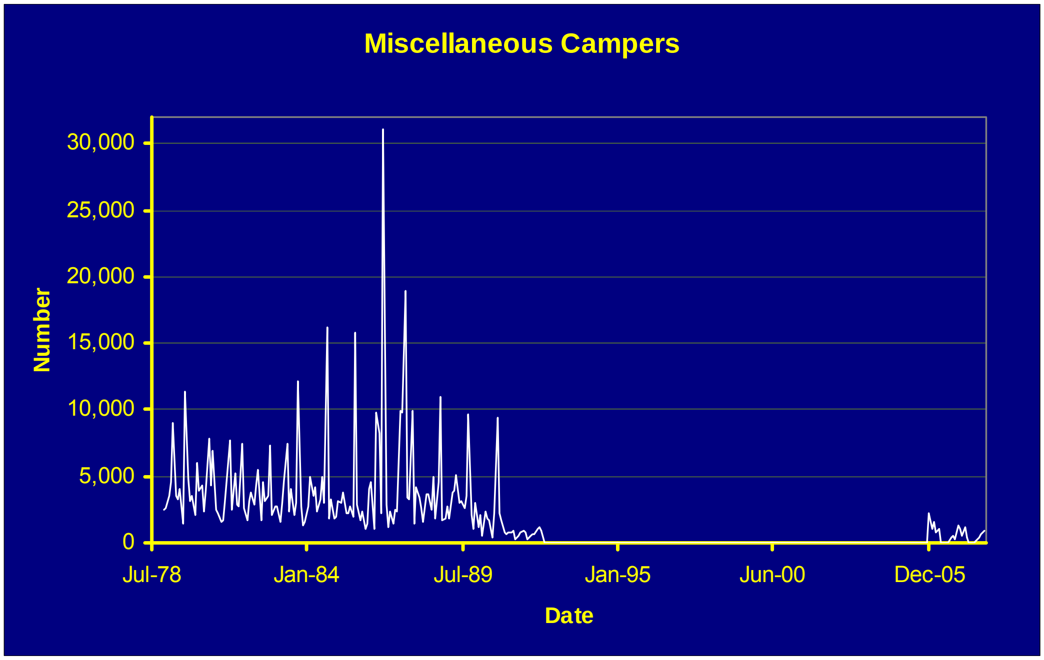


Figure 15. Miscellaneous campers in Biscayne National Park. These are mostly overnight stays in vessels. Peaks tend to be in the week surrounding the Columbus Day Regatta. Data from NPS Public Use Statistics Office covers 1979-2007, but with no data reported for the period from August 1992 to January 2005.

traversing or just to spend quality time away from the stress of urbanization. Several times a year, special events occur which attract visitors, fisherman or competitors in nautical events. These can be especially busy periods.

Small numbers of aircraft are used for research flights or military sorties; landing in the park requires permission in advance. Others use the airspace over the park for viewing it or as a place to practice flying techniques over a largely uninhabited area. Military users are normally only passing through BNP airspace, but in the past Biscayne Bay has been used for training (e.g., bombing in WWII and astronaut recovery in the 1960s). Exact numbers of overflights are unknown but could be extracted from FAA radar records or by studying filed flight plans.

Ground use includes visitation to park headquarters, either as a destination or to gain access to park boats to Elliot Key and the reefs; casual users of access points along canal levees (mostly for fishing); and the hardy souls who can handle the rigors of traversing the coastal mangroves for recreation (birders and plant enthusiasts) or research. After September 11, 2001, many of the levee roads leading to the park boundary have been closed for security reasons, which have made long walks to the bay necessary to reach it for viewing or fishing. This precludes handicapped visitors and may have decreased visitation for little or no gain; it should be revisited.

Vessel registration data is available from the Florida Department of Transportation, which shows the total number of vessels registered in Miami-Dade County to vary from approximately 56,000 in 2000 to 62,000 in 2007. Monroe County registrations were between 27,000 and 28,000 for the same period (Figure 16). Registrations in Miami-Dade increased by 1,561 vessels between 2006 and 2007, and in Monroe they declined by 598 over the same period. Monroe numbers peaked in 2005 and have declined since then; this is probably attributable to storm losses, particularly in late 2005. Miami-Dade registrations have been increasing steadily in recent years.

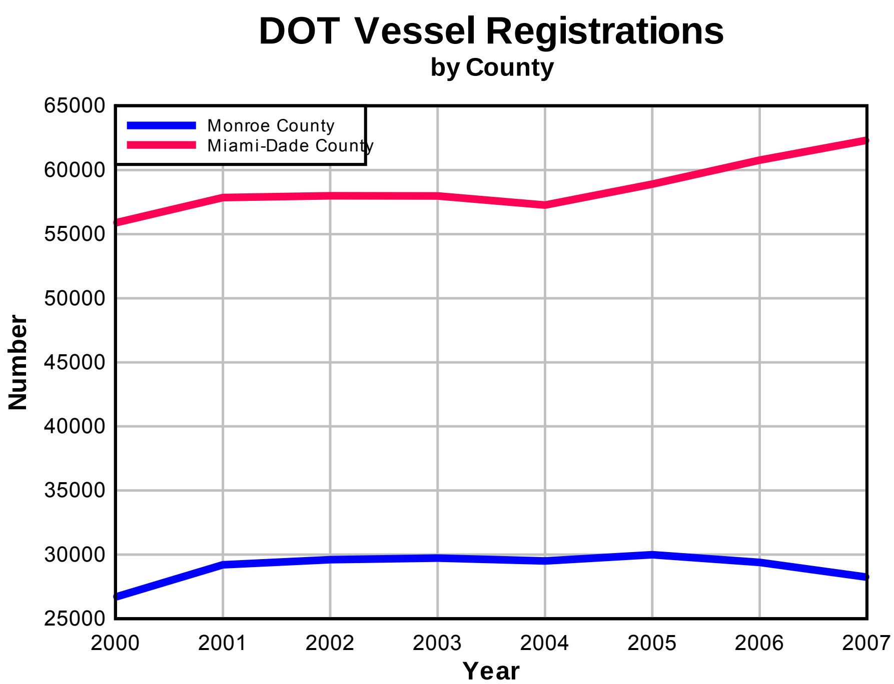


Figure 16. Department of Transportation vessel registration in Miami-Dade and Monroe Counties by vessel class for years 2000-2007.

Figure 17 shows the vessel registrations by type for the two counties nearest to BNP. All types except Class A-2 (12-16 ft) are increasing in Miami-Dade County with Class 2 (26-39 ft) boats increasing the most in recent years. In Monroe, all registrations are either holding steady or in

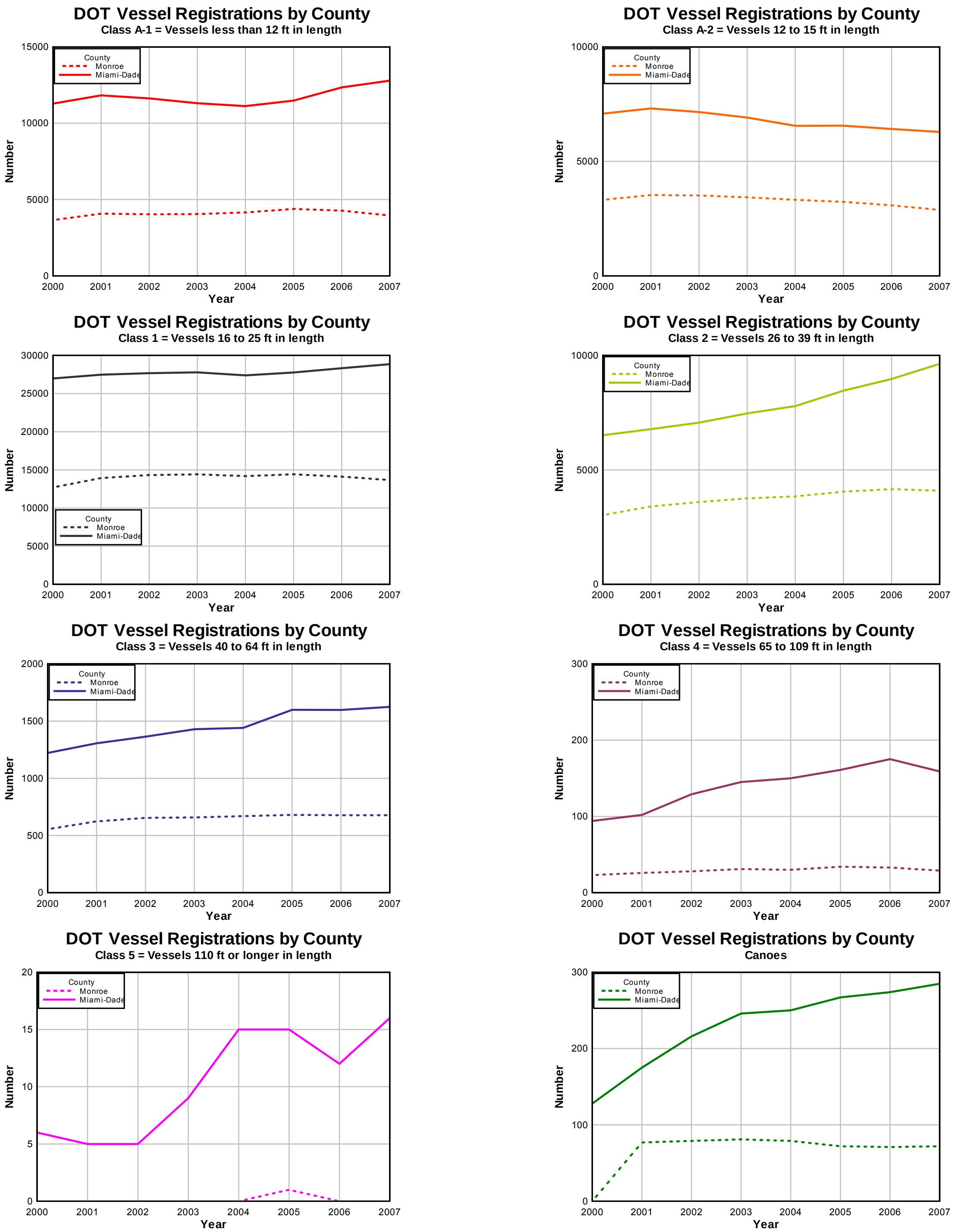
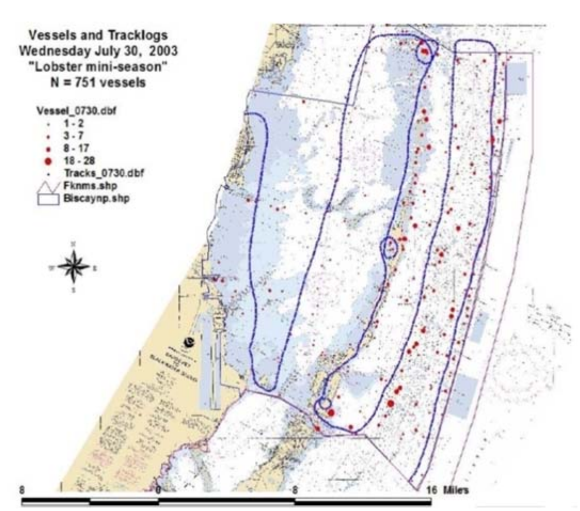
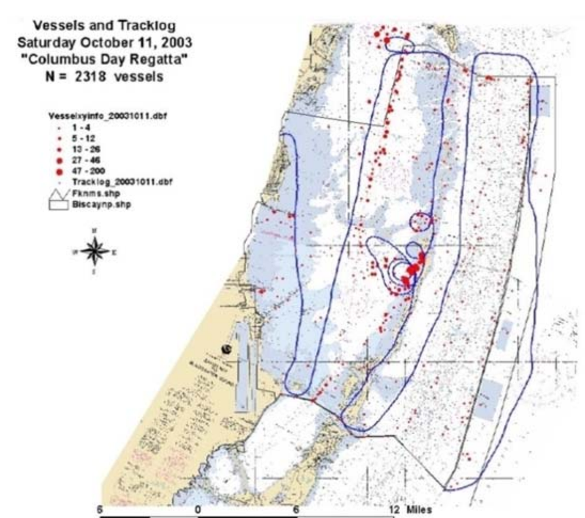


Figure 17. Vessel registrations by type of vessel. Solid lines are Miami-Dade County and dashed lines are Monroe County. Clearly, Class 1 vessels in the 16-25 ft are most common and the majority are trailered prior to entering the water. Note that vertical scales vary.

slight decline. We expect these trends to reflect the growing population of Miami-Dade and the growth control exercised in Monroe County.

Determining the actual number of vessels using the park is not easy, since boats are not always registered locally. Vessels enter from the ocean and other vessels traverse the Intracoastal Waterway longitudinally without stopping within the park. Ault et al. (2005) attempted to determine a metric for estimating the number of boats actually using park waters, and found that a census of the number of trailers at adjacent marinas approximated (R^2=0.943) the number of boats in the park determined by over-flights. They collected a year's worth of data in 2003-2004, and produced maps showing both high usage and low usage periods. The highest use was during the Columbus Day Regatta weekend, with other vacation days and special events like the Lobster Mini-Season producing larger turnouts (Figure 18). The mean daily boating usage by season varied in the range 240-420 with the most usage in the springtime and the least in winter (Table 5). Figure 19 shows the variability over a year.





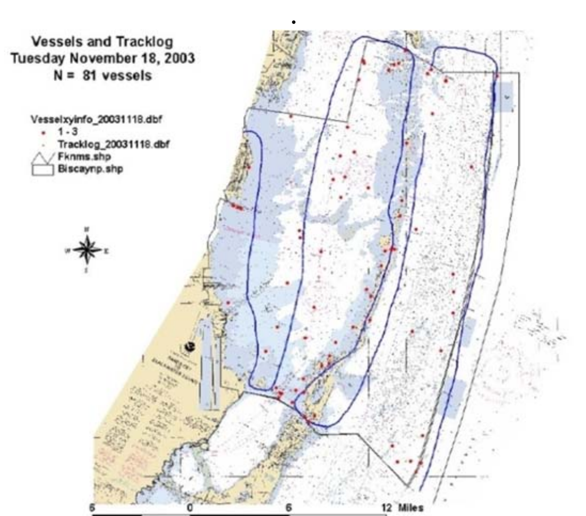


Figure 18. Examples of boater use of Biscayne National Park (from Ault et al., 2005). Top left shows boats (red dots) using the park waters during the Lobster Mini-Season in July 2003, when 751 boats were counted and many were using the offshore areas to hunt for lobsters. Middle image show the boating pattern on a typical day during the annual Columbus Day weekend when 2,318 boats were counted. Concentrations along the west side of Elliot Key and vessels traversing the Intracoastal Waterway are evident. The bottom image shows a typical day in November when usage is relatively low (81 vessels) and boats are distributed more evenly.

Table 5. Mean number of boats in Biscayne National Park on days surveyed in 2003-2004 (Ault et al., 2005).

Season	Mean # of Boats Observed
Spring	416.8
Summer	361.9
Fall	365.8
Winter	243.0

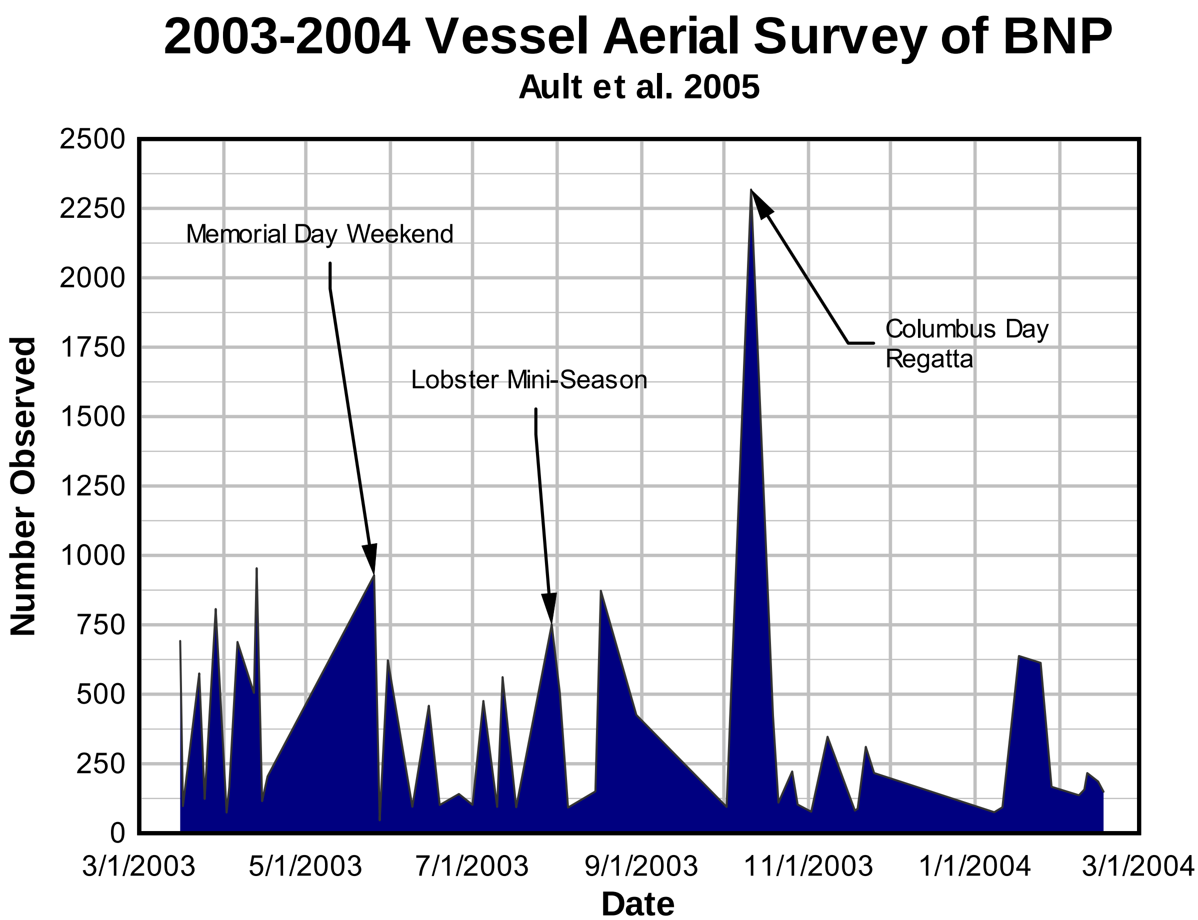


Figure 19. Observed boat usage in Biscayne National Park (BNP) during 2003-2004 (Ault et al., 2005).

Natural Resources of Biscayne National Park

Biscayne National Park comprises a diverse suite of physical environments. Terrestrial upland on the mainland and Keys provide diversity in plant life and important elements of the food chain. Freshwater storage and delivery by surface runoff and groundwater provide the elements for estuarine conditions in some areas. Coastal marshes provide habitat and food for important animal and plant communities, as well as buffer the coastline from storm effects; Biscayne Bay and Card Sound are outstanding water bodies with diverse habitats and inhabitants and recreational assets of high value. The marine environment seaward of the Keys is home to broad seagrass meadows and a portion of the living reefs of Florida, an unparalleled asset.

Physical Resources

To the west of the park, a ridge of limestone rises above the coastline, ultimately intersecting the shore northwest of the Park to form the cliffs called Silver Bluff. Except for a large contribution from precipitation, most of the natural freshwater entering the Park originated in the Everglades to the west of the ridge. Historically, water would flow overland through shallow transverse glades (TG) and rivers crossing the ridge, or as groundwater flow along the coast and in the bay after passing through the ridge or under it (Meeder and Harlem, 2008). Subsequent alteration of the surface drainage into canals began in the late 1890s (Caloosahatchee Canal, west of Lake Okeechobee) and adjacent to the Park (Miami Canal, Florida City Canal), and continued with Snapper Creek canal in the early 1910s (Stewart, 1907; King, 1917). Many additional canals and ditches were installed to make more dry land arable for farming, including parcels along the shoreline.

Natural sheet flow to the bay shore had to pass over a coastal plain marsh system dominated by sawgrass and brackish water grasses (the white zone) with tree islands (Ross et al., 2000), and then into the mangrove shoreline fringe forests which included many small tidal creeks (Meeder et al., 1999). Once drainage canals were installed, sheet flow was controlled and channelized resulting in point sources for most of the freshwater delivery and associated pollutants. Construction of the L-31E levee and associated canal for storm protection eliminated sheet flow to the bayshore. Because of lowering of the water table in the Everglades over the years, groundwater head and saltwater intrusion can only be maintained by control structures on the canals (Meeder et al., 1997). Flow to the park is severely curtailed by decreased Everglades storage, and stage and flow generally only occurs now when there is a significant wet season event that requires opening of the structures to alleviate urban flooding. The canal water and what remains of the connected groundwater flow are affected by pollutants picked up from the urbanized ridge and surrounding agricultural fields.

Freshwater entering Biscayne Bay mixes with marine water and portions return with the tide. Tidal renewal times are short because of limited freshwater discharge (Meeder et al, 1999). Water entering the estuarine zone exchanges with bay and offshore areas because there is sufficient tidal flushing to move and mix the limited amounts of runoff in relatively short time (Caccia and Boyer, 2005; Wang, 2003). Dredged holes, such as boat channels and marinas, however, are sediment sinks, and transported sediments are deposited in the deep bottoms. Canals normally have little suspended sediment, but what is there may be allochthonous sediments derived from surface runoff, re-suspension from canal bottoms as well as atmospheric deposition. Pollutants attached to sediment, or as part of the dissolved load, such as trace metals and organics, can accumulate in bay environments and potentially in marine organisms. With a predicted extreme rise in sea level, oceanic forces can be expected to increase, and tide and wave driven processes will be ascendant causing the redistribution of contaminated sediments.

Climate

Rainfall in BNP is bimodal with peaks in summer (June) and fall (September-October) ranging from 102-165cm yr^{-1}, with more rain occurring over the coastal ridge on the mainland than over the barrier islands (Schmidt and Davis, 1978). Maximum rainfall is affected by the occurrence of tropical storms and hurricanes, which can greatly alter the amounts over any particular area and also affect regional variability (Duever et al., 1994). There is also a 7-year cycle and 3.5 harmonics in precipitation rates (H. Briceño, personal communication.) The dry season usually runs between December and March. Changes in aquatic chemistry, and the ecosystem's response to those changes, have been recently documented for Florida Bay (including Barnes and Card Sound) as responding to long-term precipitation cycles (Briceño and Boyer, 2009) driven by global meteorological forcing. Preliminary exploration of Biscayne Bay water chemistry indicates that park waters also follow those global trends with additional modulation by water management deliveries. Chemistry of rainwater also seems to affect soil processes especially the pH, which controls the mechanisms of dissolved organic matter and nutrients released to streams.

Extreme climatic events, like hurricanes, are frequent in South Florida, and in recent years the frequency, as well as the energy, of storms has been increasing in the North Atlantic (Landsea, 1996; Briceño and Boyer 2009). Winds, seawater surge and precipitation are coupled with larger than usual deliveries of freshwater by the SFWMD to Florida Bay to avoid flooding of urban and agricultural areas. These, in turn, result in sudden "freshets" and nutrient enrichment leading to algal blooms, especially in areas with restricted circulation. Rainfall also transports particulates to the surface waters. These particulates may be from local and distance sources, as South Florida receives transported dust from Africa which has been shown to affect water quality once it enters the water cycle (Prospero, 1999a). The effects of changing climatic conditions on park natural resources have not been clearly discerned and require an additional research effort.

Geology and Soils

The geology of south Florida (Figure 20) is the result of a net regional subsidence spanning more than 180 million years, along which marine and freshwater constructive (sedimentation) and destructive (erosion) processes have alternated. At the same time, the rise and fall of sea level, driven by eustacy and/or climatic fluctuations, has also left important imprints on the rock record and the landforms, especially during Pleistocene times. This slow subsidence, caused by the continuous opening of the Atlantic and the separation of North America from Africa and Europe, has kept a close pace with shallow water sedimentation to render over 18,000 feet of Cretaceous to Quaternary age sedimentary rocks (mostly limestones, dolomites and evaporites) deposited in a large carbonate platform (Klitgord et al,, 1988). Cenozoic sea levels fluctuated over one hundred feet above and below the actual sea level.

During the Paleogene the shallow platform was isolated from the mainland by the deep Gulf Trough or Suwannee Strait (Chen, 1965) where strong marine currents did not allow siliciclastic input from the continent to reach the submerged Florida carbonate platform located to the south, and the terrigenous sediments coming from the north were transported eastward by the currents.

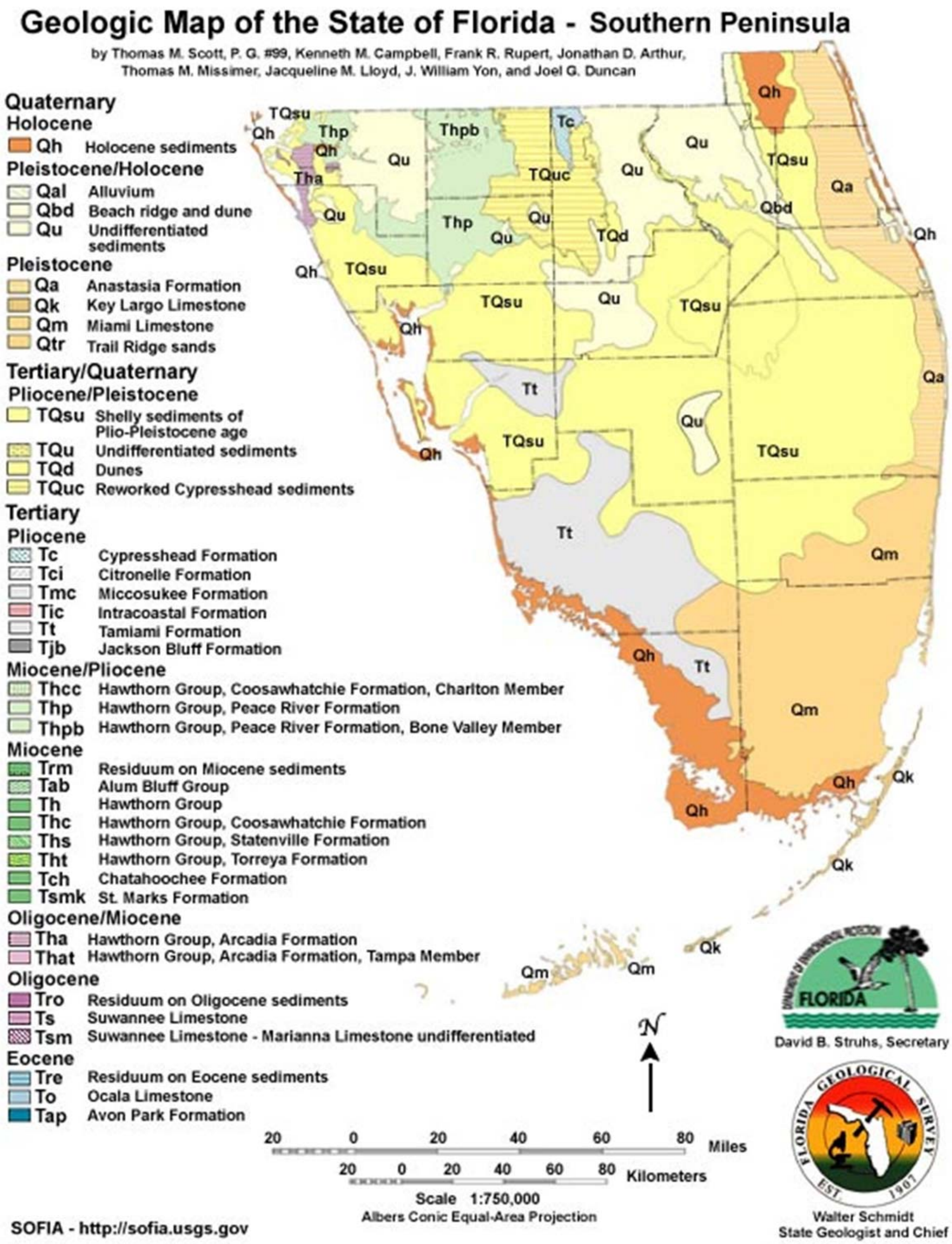


Figure 20. Generalized geologic map of South Florida (Scott et al., 2001).

By early Miocene, under more subtropical climate and with the Appalachian Mountains already uplifted, substantial volumes of sediments were produced which finally filled the strait and connected the shallow platform to mainland, creating the route for siliciclastic material to move across the platform and progressively encroach the carbonate sedimentation southward. During the Neogene sediments deposited on Florida were mostly quartz sands, silts and clays with subordinated carbonate accumulation (Bond and Scott 1994; Pinet and Popenoe, 1985). In southern Florida, most sediment was calcium carbonate rich with some quartz sands which provided nuclei for carbonate ooids to develop extensively as bars in high energy environments.

The Cenozoic stratigraphic profile is shown in the north-south cross section of Figure 21, where the onlaping of units from the south is evident. Although the sedimentary section is practically un-deformed by tectonism, there are large and open structures, mostly as result of original geometry and distribution of topographic highs and basins, as shown in Figure 22

Ginsburg (1987) proposed a structural control of the morphology of southeast Florida, arguing that the striking feature of terrestrial and submarine morphology of Southeast Florida is the family of arcuate trends that are convex towards the southeast. From northwest to southeast, these trends are:

- The southern extension of the Atlantic Coastal Ridge composed of oolitic limestone of the Lake Pleistocene Miami Formation

- The Upper Florida Keys, a chain of islands composed of the Late Pleistocene Key Largo Limestone

- The break in slope of the Florida Reef Track marked by discontinuous living reefs, rocky shoals, and piles of coral rubble.

- The Pourtales Escarpment of the Late Tertiary that marks the edge of the Pourtales Terrace in depths of 360-540 m.

- The Mitchell Escarpment in depths from 720-1,000 m that is probably early Tertiary.

The Cenozoic section in South Florida, relevant to the present study, is represented by those units outcropping within the watershed downstream from Lake Okeechobee (Figure 20) and those lying underground, which constitute the shallow aquifers. The outcropping units are the Plio-Pleistocene shelly sediments (TQsu), which include the formerly named Fort Thompson and Caloosahatchee formations; and the Quaternary Miami Limestone (Qm) and Key Largo Formations (Qk). Besides these units, also the subsurface Miocene Hawthorn Group, the Pliocene Tamiami Formation and the Pleistocene Anastasia Formation bear significant importance, but for brevity are not discussed.

<u>Stratigraphy</u>
The stratigraphy of the upper units of Southeast Florida is discussed in turn, starting with the Miocene and moving upward to the recent.

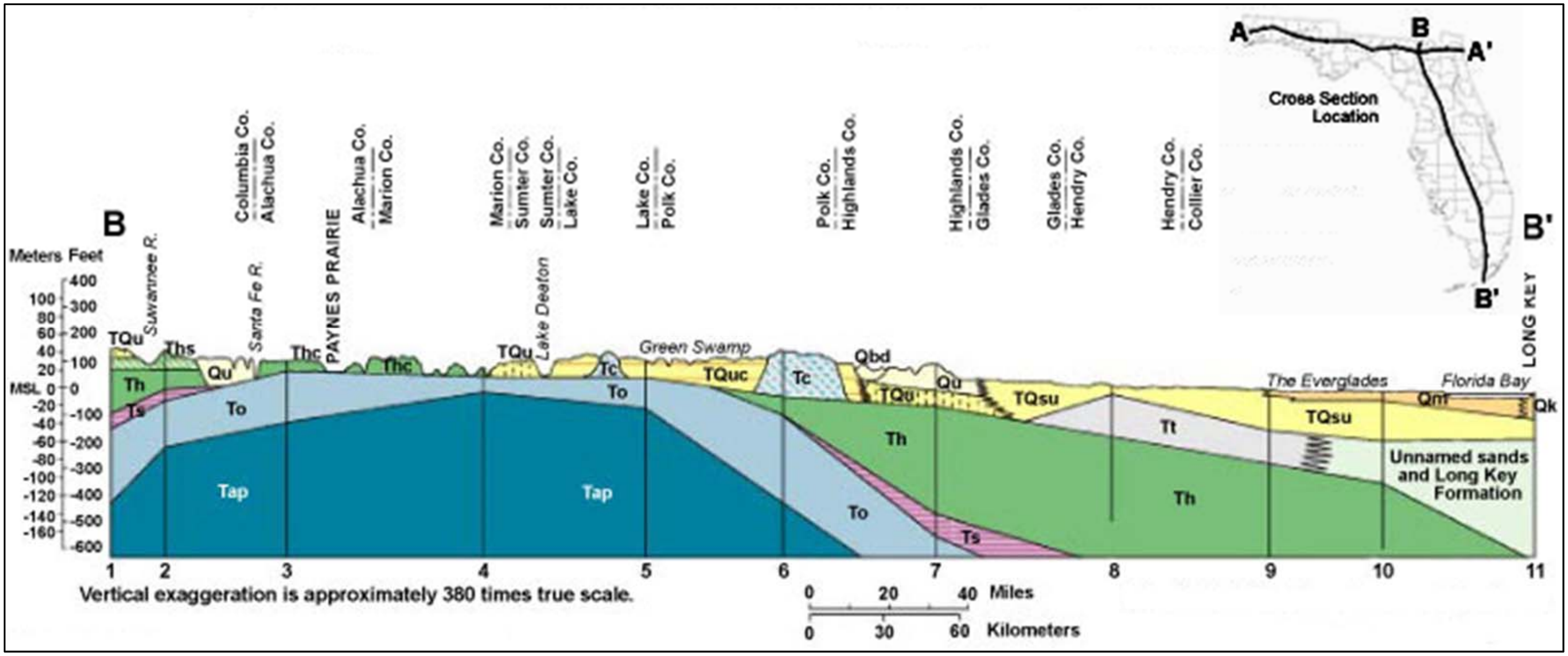


Figure 212. North-south (B-B') generalized geologic cross-section of the Florida Peninsula (modified from Scott et al., 2001-see Figure 20 for color codes)

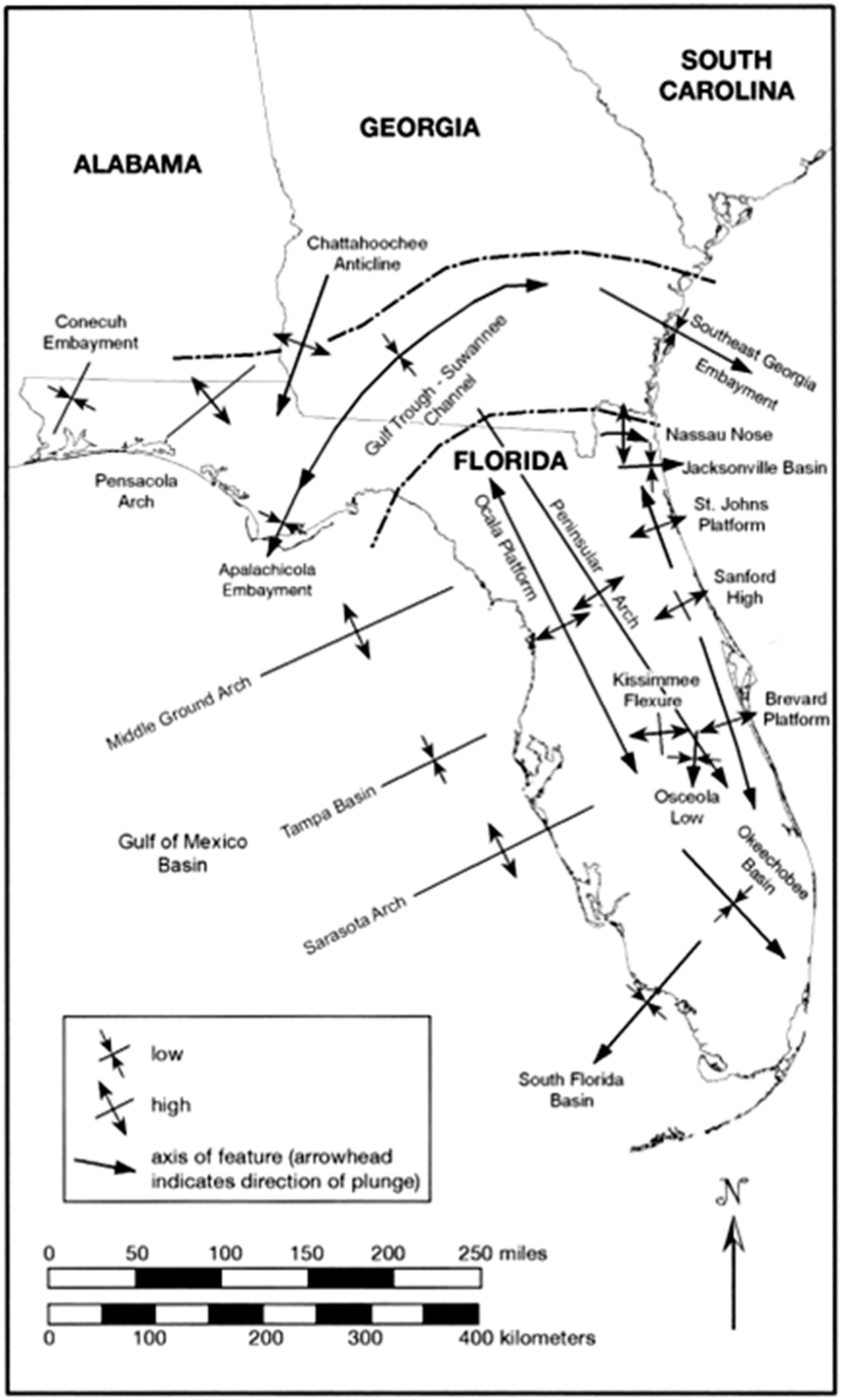


Figure 22. Major structures in the Florida Peninsula (after Bryan et. al, 2008)

Miocene
The Miocene Epoch lasted from 23.8 million years ago (Ma) to 5.3 Ma. In south Florida, it is represented by the Hawthorn Group. The Hawthorn Formation is a complex unit consisting of carbonates and siliciclastic sediments interbedded and intermixed, deposited in inner shelf, nearshore environments. It represents the significant change in sedimentation processes at the end of the Miocene and beginning of the Neogene. The Hawthorn does not reach the surface in south Florida but is important for the lower aquifer. The Long Key Formation of transitional age from Miocene to Pliocene is found in cores in the Upper Keys. This formation is made of siliciclastic sand layers accumulated in outer- to inner-shelf environments (Guertin et al., 1999).

Pliocene
The Pliocene Epoch followed the Miocene and lasted from 5.3 Ma to 1.8 Ma, and, in south Florida, is comprised of the Tamiami Formation and the Caloosahatchee Formation. Both outcrop in southwest Florida, particularly in the Caloosahatchee River basin but neither have surface expression in the park region. The Tamiami Formation, estimated to be 6 Ma (Hoffmeister, 1974), varies from sandy limestone to near pure sand, and parts of the upper Tamiami are cavity-riddled and hydraulically porous. The Tamiami has been interpreted as bay like to nearshore shelf environments with differential and fluctuating sea levels with proximity to southward flowing rivers (Peck et al., 1979) and includes a major reef trend in southwest Florida (Meeder, 1990). The Caloosahatchee (Marl) Formation is comprised of shell beds interlayered with sand and silt deposits, which are generally thin and are not thought to extend far from the southwestern side of Lake Okeechobee or along the Caloosahatchee River.

Pleistocene
The Pleistocene Epoch ran from 1.8 Ma to approximately 0.01 Ma (~10,000 years ago) and was a period of intense shifts in sea level caused by cyclic changes in the earth's ice cover. Pleistocene limestone forms the bedrock in much of southeast Florida, and is represented by the Fort Thompson Formation, the Key Largo Formation and the Miami Formation. The Fort Thompson outcrops to the NW, near Lake Okeechobee (Figure 23), and forms the basin of the great lake and Everglades. It lies below the Miami and Key Largo Formations at BNP and has been interpreted as a series of sea level fluctuations producing alternating marine and freshwater shell, sand and lime mud facies typical of shallow coastal environments (Figure 24). The Key Largo Formation (Figure 25) is dominated by reef facies and is the outcropping of limestone which forms the Florida Keys, including most of the islands within the park (Figure 26). The Miami Formation, contemporaneous with the Key Largo, forms the low ridge along the park's west side (Figure 27) and the bottom floor of much of Biscayne Bay; its oolitic sand (Figure 28), carbonate sand and burrowed mud facies are interpreted as marine inner-shelf deposits influenced by high tidal fluctuations during oolite formation. As the principal geomorphological control in, and adjacent to, the park (Meeder and Harlem, 2008, Harlem and Meeder, 2008), the karst surface of this marine unit has the greatest effect on the park's resources (Figure 29).

Holocene
The Holocene Epoch runs from the end of the Pleistocene more than 10,000 years ago to today. The Holocene is characterized by soils on the terrestrial landscape and sediment deposits in the coastal estuaries, bays and offshore, and includes the recent modifications done by man.

Figure 23. Outcrop of Fort Thompson Formation beds. One meter high outcrop just west of extinct Lake Flirt on the Caloosahatchee River canal includes a lower marine shell-rich layer and an upper, shelly, freshwater, gastropod-rich marl. Fort Thompson underlies the Miami Limestone in Biscayne National Park and is tens of meters thicker under the park (P. Harlem).

Figure 24. Hand specimen of Fort Thompson freshwater marl facies. The gastropods are a mixture of *Helisoma*, *Planorbis*, and Hydorbiid varieties and the matrix is lime mud (John Meeder sample, photo P. W. Harlem).

Figure 25. Canal cut bank through the Key Largo Formation on North Key Largo. Branching coral head (*Montastrea cervicornis*?) is plainly visible in the lower center. The rocks of the Florida Keys are made from this extinct Pleistocene reef complex including those within Biscayne National Park (P. W. Harlem).

Figure 26. Aerial view of Key Largo Formation on Elliott Key. The facies, or diagenetic, control on vegetation is evident in the vegetation patterns. The small patch of hardwoods located at right center is growing on the highest part of the outcrop while the mangroves on the left are growing on the lowest. The bare, epikarst halo around the hardwoods is too hostile for either community to utilize, and appears to be made of well-cemented fragments of branching corals. Note the presence of intertidal zonation (color patterns) even though the entire profile is nearly flat (P.W. Harlem).

Figure 27. Outcrop of the Miami Formation on the Charles Deering Estate. This is the crossbedded facies predominantly composed of ooid grains and illustrates the commonly seen water table cave at the base of the outcrop. Such karst features are very common in this limestone. The Miami Formation outcrops west of the park, forms the bottom of Biscayne Bay and interfingers laterally with the Key Largo Limestone along the west side of the Keys (P. W. Harlem).

Figure 28. Oolitic facies of the Miami Formation. This slab section shows well-developed clear calcite cement holding the white ooids together, making this particular layer more resistant to weathering. These indurated layers alternate with softer, less cemented ones, and make the cross bedding easy to see in most outcrops of this facies. At the top the ooids have popped out showing the moldic porosity for which the formation is well known (P. W. Harlem).

Figure 29. Water filled cave in Miami Limestone formed in the bioturbated facies. The facies can comprised ooids and biogenic sand grains (bryozoan and mollusc fragments, pelloids, etc.) and most layering was destroyed by heavy burrowing by invertebrates after deposition. The cavernous porosity of the Miami Limestone is poorly researched and not understood by most workers studying water issues in Miami-Dade. Photo taken in "Razor Rock Cave," Charles Deering Estate, a short distance from the National Park (A. Cressler, USGS).

Holocene sediments and soils provide the habitat for most plant species, and many important animal species, in the park. The dominant Holocene sediment in the park is biogenic sand and mud comprised of any number of biologically derived components (i.e., *Halimeda* plates, mollusc fragments, cohesive pelloids, coral fragments, foraminifera and other invertebrate tests). Muddy carbonate sediment is a common matrix component and derived from the breakdown of skeletal sands and calcareous alga, such as *Acetabularia* and *Penicillus*. Quartz sand is the third most likely sediment and is derived from terrestrial sources usually transported to the region by longshore drift and submarine currents, and perhaps by wind. Figure 30 shows the sediment regimes as shown by Wanless (1976), Figure 31 shows median grain size (Carnahan, 2005), and the depth to bedrock map (Figure 32) provides a generalized idea of sediment thickness when compared to bathymetry (Figure 33).

Geomorphology

Most of the landforms of modern Florida formed during the Quaternary when, during high sea level, carbonate sedimentation reached its peak, coral reefs grew and beaches formed and extended, as did dune fields. The land area was reduced, forcing the coastal ecosystems to migrate landward onlaping onto fresh water environments. At low sea level, the shoreline migrated seaward, expanding the land mass. Weathering, mass movement in steep areas and fluvial transport played a major role in the modification of landforms. Under this framework, coastal ecosystems also migrated seaward, which sometimes restored estuarine conditions. In Southeast Florida, these cycles of sea level rise and fall have generated critical landforms that have controlled the persistence and distribution or disappearance of ecosystem assemblages. Biscayne Bay, Florida Bay and surrounding landforms are the result of the dynamics of these

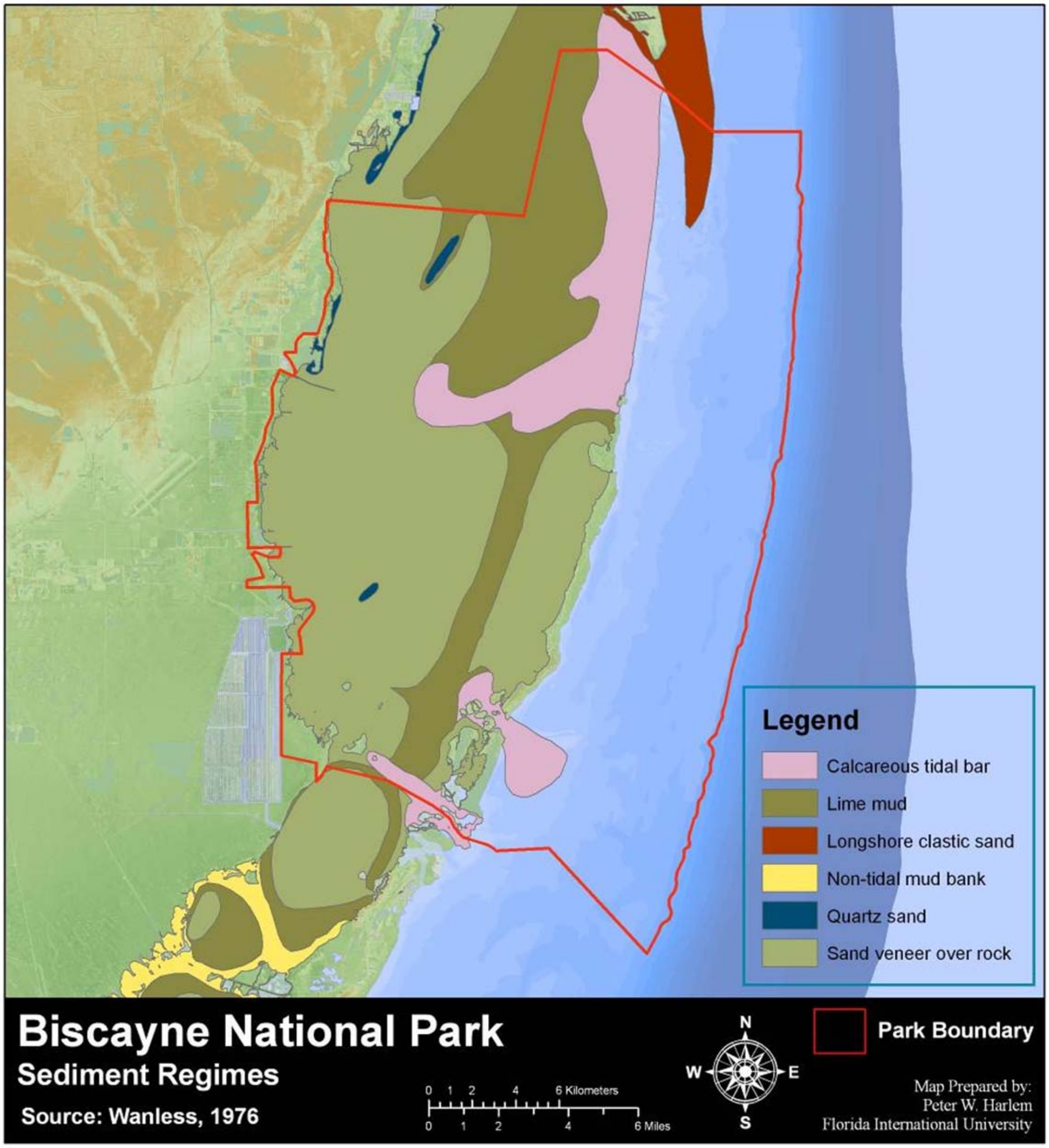


Figure 30. Sediment regimes within Biscayne Bay as described by Wanless (1976). Mud deposits are restricted primarily to the deep axis of the bay and the margins of the two sounds to the south of the park. Calcareous tidal bars of carbonate sand and mud form the shoals at Safety Valve, Featherbed Bank and Caesar's Creek, while quartz sand deposits comprise several small features in the bay as well as shoreline deposits along the mainland. Quartz and carbonate sand derived from the beach at Key Biscayne form a submerged spit at the north end of the park.

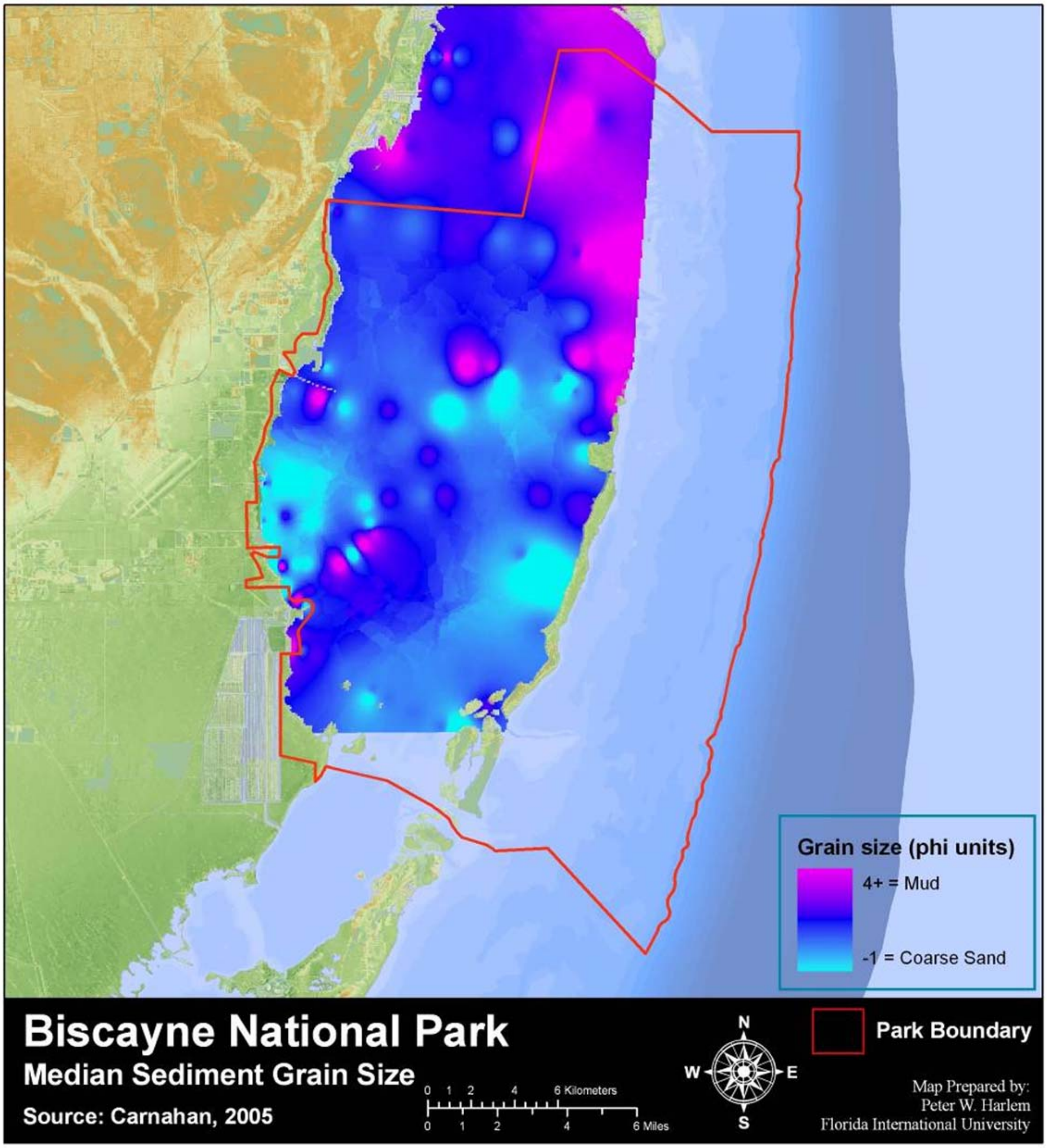


Figure 31. Median grain size distribution from Carnahan (2005). Data were mapped using inverse distance weighting interpolation of values taken during coring program. Not counting the terrestrial portion, the park has more mud at the north end and more fine or coarse sand to the south and west. The coarse sand value near the center of Elliott Key may be the result of winnowing by boat waves visiting the NPS dock facility.

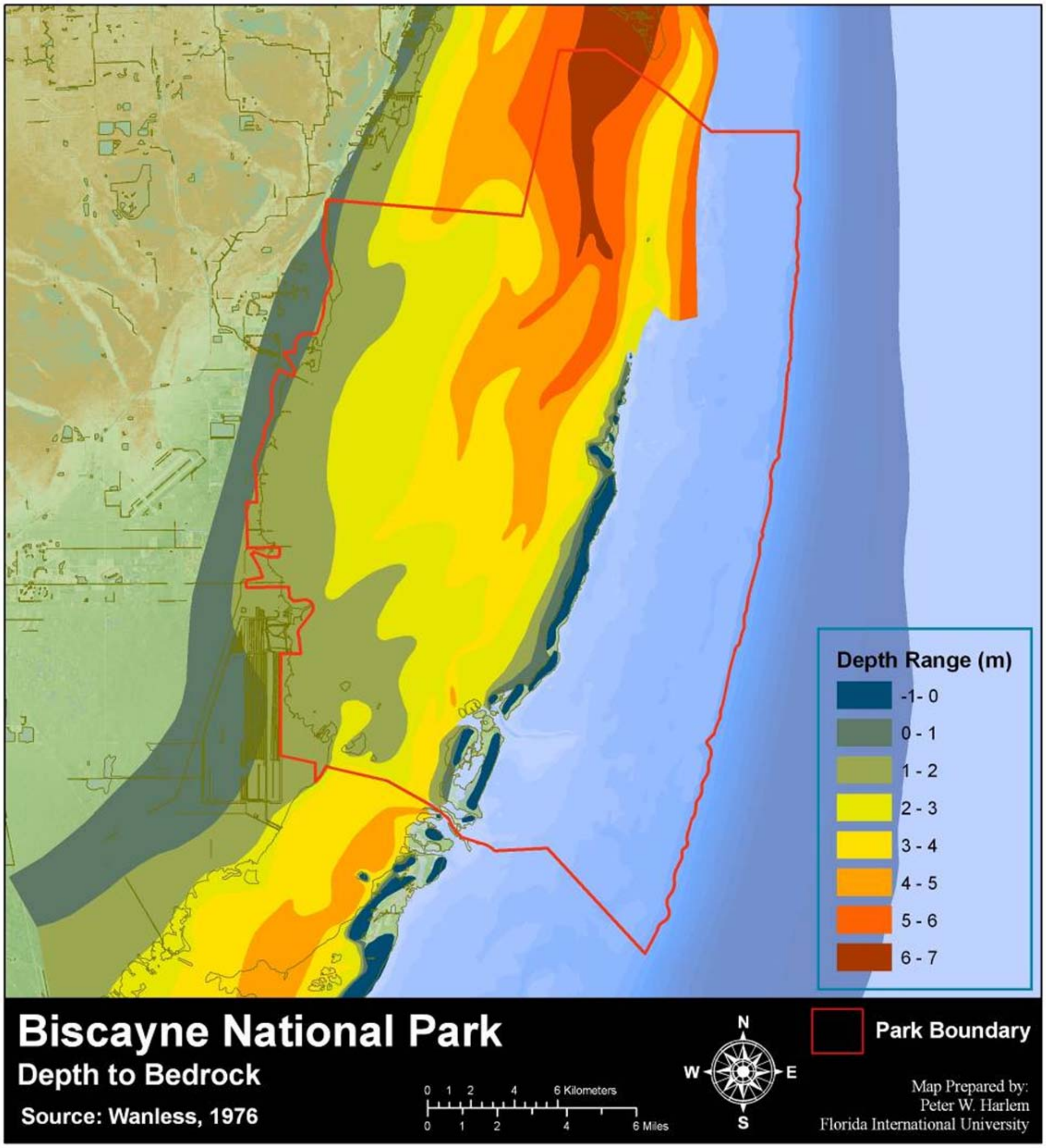


Figure 32. Depth to bedrock as mapped by Wanless (1976). Bedrock dips to north and south away from a high region around Turkey Point. The deepest point is under Key Biscayne and at least two valley-like structures extend south into the bay portion of the park. These can be associated with recent historical drainage features suggesting that the bedrock topography is post-depositional and produced by fluvial or karst processes.

Figure 33. Bathymetry of Biscayne National Park from NOAA nautical charts. The central axis of the bay is uniformly deep, except where crossed by shoal sediments such as at Featherbed Bank. Deeply cut tidal channels bisect the rise formed by the Key Largo Limestone along the trend of the Keys.

cycles, which are also accompanied by different climatic conditions. Figure 1 shows the topography (derived from LiDAR) of the region, and Figure 33 shows the current bathymetry as shown on nautical charts.

The Biscayne Bay basin dates to at least 4,200 years BP based on basal peat dating (Meeder, personal communication) and began filling with marine waters approximately 3,200 years ago as sea level rose and flooded southern Florida (Wanless et al., 1994). Sea level is still rising and has been accelerating. Data from Key West recorded since 1913 indicates sea level has been rising at 0.15+/-0.03 cm/yr before ca. 1925 and 0.23+/-0.01 cm/yr afterwards (Maul and Martin, 1993). The rate is expected to increase in the coming years (Miami-Dade Climate Change Advisory Task Force, 2008).

Soils

The National Park Service has so far not prepared maps of the soils of any of the major parks in Florida, including BNP. However, historical soil maps, which show the park soils, include the Soil Conservation Service soil survey map from 1947 (USDA, 1947, Figure 34) and a very general map (Leighty et al., 1954) derived from it which lumps many types in crude “associations.” The current Miami-Dade County soil map (USDA, 1996, Figure 35) does not include the land inside the park, apparently for jurisdictional reasons.

From the data available and from numerous studies which reported on soil conditions, it is clear the park has three principal soil types. Marl (carbonate mud) is the dominant soil type west of the park, with peat dominant along the park’s mangrove fringes (Gaiser et al., 2006b; Ross et al., 2001). The marl can vary in the content of silt or fine sand included. The main component is fine-grained mud, derived either from transport onshore during storms and high tidal events, or produced epiphytically by algal mats in the former wet grass prairies which used to occupy the inland coast. The latter process has been lost as the coast has been denied fresh water runoff (sheet flow) resulting in mangrove expansion in a change to peat formation. The former process is ongoing and may increase as sea level rises and bay sediments are subjected to higher erosive forces.

The second major soil type in the park is peat, derived from the small amounts of leaf detritus combined with root biomass of mangrove forests. This is the common soil along the fringe of the coastline and now to the edge of L-31E, along former freshwater streams and seeps and on most of the islands. The amount of peat produced is a function of the biological processes of the trees, and high productive areas can become elevated (Meeder et al., 2002). Mangrove peat accumulation is rapid enough in some places to compensate for the mangroves’ ability to dissolve subjacent rock by acidic pore water, a process that can provide for additional peat storage (Zieman, 1972).

The third major soil type in BNP are Folists, which develop under hardwood hammock vegetation on the barrier islands. Folists are organic soils (Histosols) that develop in well-drained, upland settings that combine relatively high, aboveground production with some level of recalcitrance to decomposition (Coultas, 1977). Detailed descriptions of Folists have been published from Hawaii and the Florida Keys (USDA, 2000; Ross et al., 2003). Soils in BNP hammocks are shallow, generally <30 cm deep. Total moisture-holding capacity is very limited, and nutrient supply depends on efficient recycling. The nature of these soils suggests that the

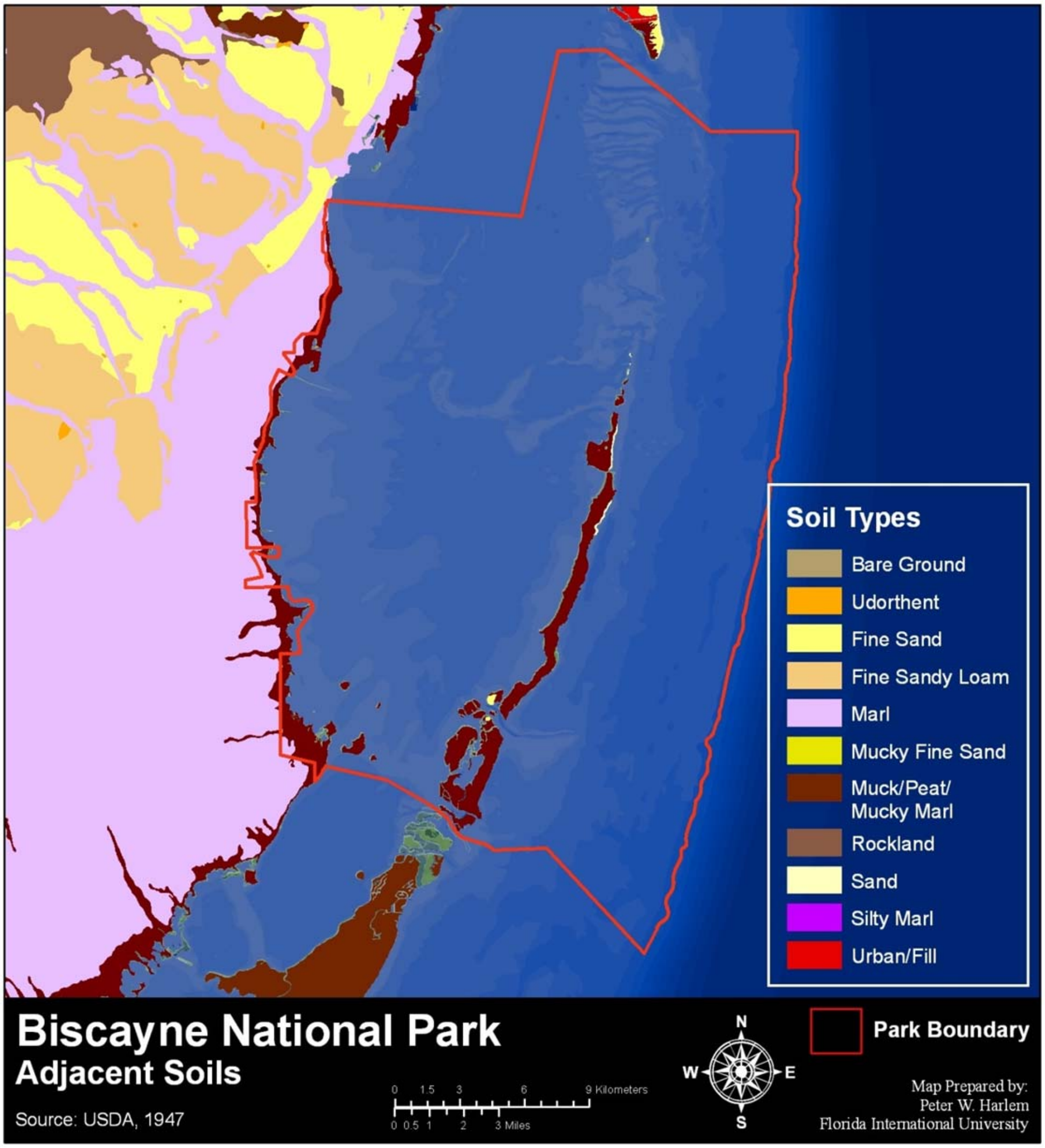


Figure 34. Soil map of Biscayne National Park and vicinity. Some details in the original data are not visible because of general categories used in production of this map. Mangrove peat areas are not differentiated and detail on the Keys within the park is clearly wrong, as much of the upland there is rocky (USDA, 1947).

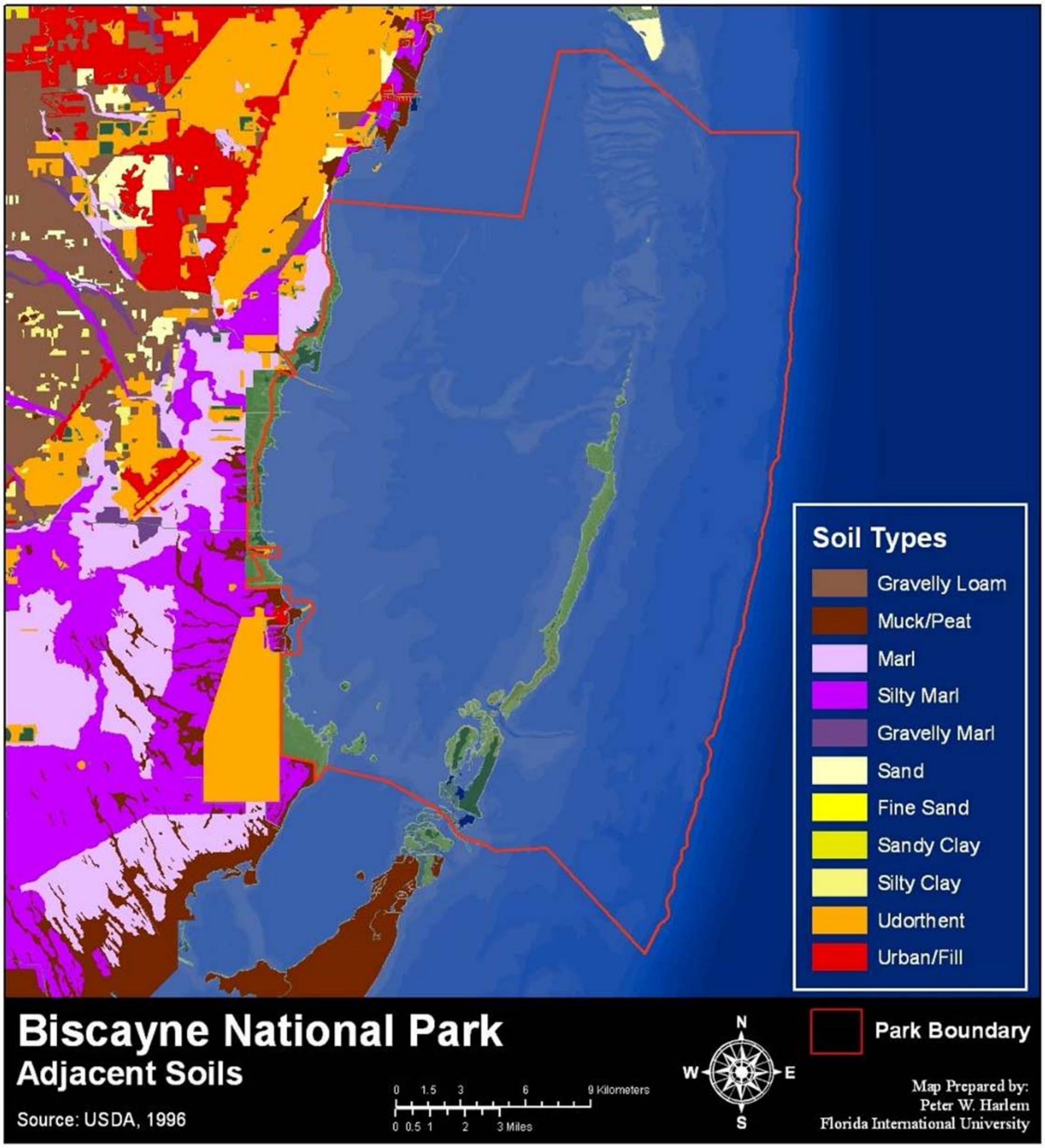


Figure 35. Generalized soil map showing detail of basic types adjacent to Biscayne National Park (USDA, 1996 based on 1986 survey). The source data does not show the soils in Biscayne National Park.

hardwood hammock ecosystems may potentially be damaged by disturbances that consume soils or open the forest canopy for long periods (e.g., fires, insect or disease outbreaks) or from sea level-driven salt water encroachment into the shallow rooting zone.

Fine grained quartz sand is an important component in only a few locations. Quartz sand is present by longshore transport from the north or from weathering the limestone, of which it is a minor component. It forms sandy soils on top of the ridge and some of that has been transported downslope to the bayshore, particularly where former freshwater streams entered the bay. Wanless (1976) identified small sand deposits at the bayshore that have now been associated with each of the headlands along the western bayshore, each of which has a strong relationship with former streams (Meeder et al., unpublished manuscript).

The park also receives dust in small quantities (Prospero, 1999) which contributes minerals and is the source for iron rich soils such as the Redland soils, which give name to that region of south Miami-Dade. Accumulation in the park is minor but it contributes iron and sulfur to pore waters forming hard reddish layers of iron-rich calcite associated with cemented rootlets that are in contact with the limestone. This is a form of calcrete and is transitional from soil to rock in classification.

Lowering of Everglades' water levels has produced significant oxidation of peat soils in that region resulting in the lowering of ground levels over large areas (Davis, 1943; McVoy, 2011). As most of the soil adjacent to BNP is marl or peat, which remains wet, this is assumed to be less of a problem, although soil loss due to farming practices might be important. In fact, many coastal farms have now been converted to residential properties with required fill pads to elevate them above storm tide datum. This conversion has brought large amounts of soil to the coastal real estate properties that have been engineered. For example, the Shoma property, located at the northwest perimeter of the park, was extensively raised with transported fill.

Freshwater Systems
Water is the most important ecosystem component; its quality is an indicator of the health of BNP. Freshwater from rain feeds the surface uplands, wetlands and Biscayne Bay (Figure 36). As much as 95% of rainfall is returned to the atmosphere by evapotranspiration (Duever et al., 1994; Ross et al., 2002). The surplus water in uplands becomes groundwater. Most surplus water in wetlands runs directly into the bay by sheet flow or channelized flow. Only minor amounts of water falling on the coastal ridge may flow into canals. Almost all canal water comes from the Everglades or from groundwater stored within the coastal ridge. Figure 37 shows the upland morphology to the west of the park and shows the linear depressions crossing the ridge called "transverse glades." These wet, marsh or prairie-like depressions (Figure 38) were important pathways for historical flow across the coastal ridge, which is now kept dry by canal operations (Meeder and Harlem, 2008). Current water management basins (Figure 6) are based on an inherited system of haphazardly placed drainage features now operated for flood control, farm hydration and aquifer protection, and has little relation to the natural drainage systems which used to feed surface and groundwater to Biscayne Bay prior to development.

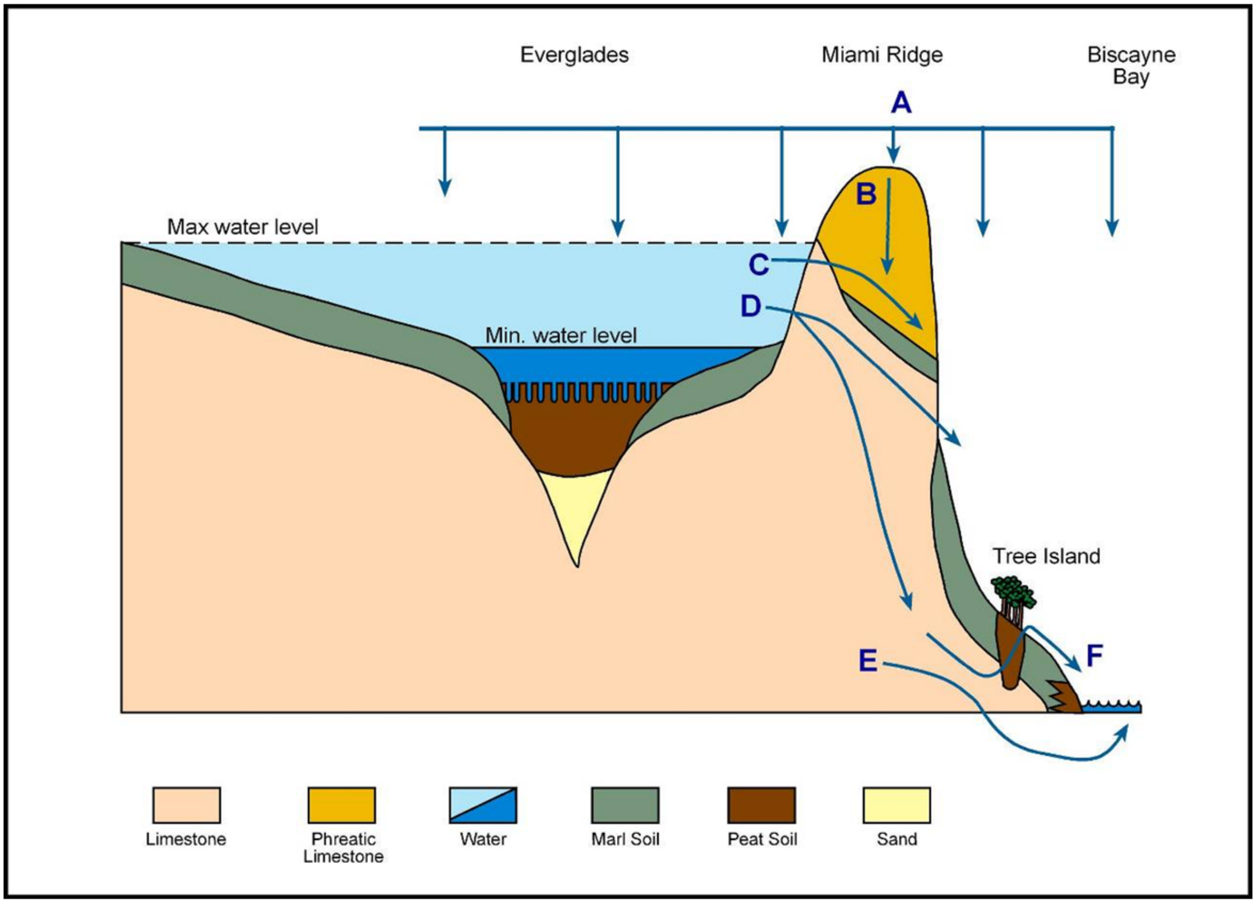


Figure 36. Stylized cross-section across Everglades to Biscayne Bay. Freshwater entered Bay by A: rainfall and surface runoff, B: groundwater recharge from elevated ridge, C: via transverse glades perched on marl, D: springs feeding coast, E: groundwater to offshore and F: groundwater seeps in coastal marl (at tree island). Lowering of Everglades water levels below historical minimum elevations reduced or eliminated C and D. Lowering head reduced groundwater flows (D and E) leaving A and B as only unmodified delivery. Cross section modified from McVoy (2011): flow details after (Meeder and Harlem, 2008).

Drainage Systems

Current management of surface waters utilizes canals, coastal structures and weirs (Figure 39) to move water rapidly as needed, for flood control, to maintain drinking water supplies, control salt water intrusion, and provide water for irrigation. Major canals bring water to the coast and release it via the structures on schedules determined by local managers. Smaller canals, irrigation ditches, mosquito ditches and linear borrow pits provide lateral connectivity, which is largely uncontrolled. The borrow pit for the L-31E levee is an example. Figure 7 and Figure 40 show the location of the major canals and ditches leading to, or near, BNP. Table 6 lists the major canals entering Biscayne Bay and if they are connected directly to BNP. Mosquito control ditching going back to the 1920s, levee or road construction with linear borrow ditches and alteration of natural streams have produced a modified coastline with little resemblance to historical natural flow (Figure 40).

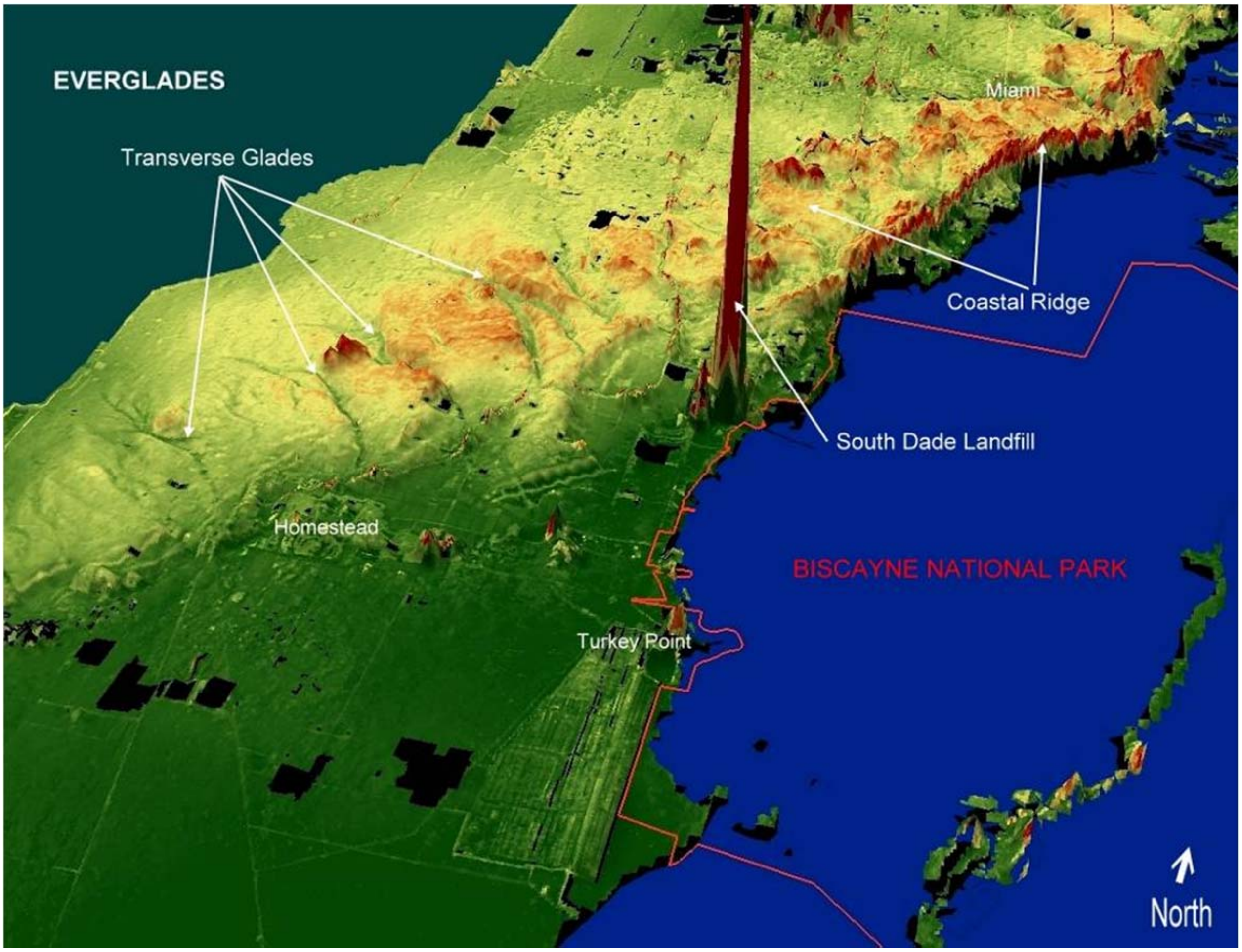


Figure 37. 3D LiDAR terrain image of west side of Biscayne National Park clearly shows the transverse glades. Historically, these structures performed the traditional role of streams cutting through the limestone ridge. A significant portion of Everglades' waters passed through these structures to feed freshwater to the SESE coastal plain marshes or directly into the bay via coastal streams (Meeder and Harlem, 2008; Meeder and Harlem, unpub.). Vertical exaggeration is 500 times (LiDAR from USACE).

Open Water Bodies

Open water bodies in the park include a small number of natural water filled sinkhole ponds on the Keys and small open water areas in the mangrove tidal creek systems (Figure 39). Anthropogenic water bodies include unconnected ditches or pot holes, most derived as borrow for roads, levees, or irrigation dikes over the years. Deep rock mines are confined to areas just west of the park boundary (Figure 41) with others several miles to the southwest in the former Model Lands. The open mines remove water from the ground by increasing the area available to evapotranspiration and those nearest to the park have contributed to saltwater intrusion (Meeder, personal communication).

Streams

Natural streams connected directly to the eastern marshes of the Everglades used to exist on the mainland shore of the park. Several streams flowed through TGs and connected surface waters in the Everglades to Biscayne Bay, including the Miami River, Little River, Arch Creek(s) and the Oleta/Snake Creek complex (Table 7). The TGs nearest the park had marl bottoms, which

Figure 38. Grass and marl transverse glade (TG) at Princeton, Florida in 1911. The general morphology shared by most of these structures is evident as are the elevated rock margins supporting pine woodlands. TGs were only dry for a short period of the year, but as Everglades water levels dropped, they were converted to agriculture to produce crops for ever increasing periods of the year. Current drainage practices allow home construction in low lying areas (Wagner Free Institute via McVoy).

Figure 39. Water control structure (S-20F) at Mowry Canal (C-103). This adjustable weir controls water levels to the west of the park and when opened on schedule, or to relieve interior flooding, pumps large quantities of water into the nearshore of Biscayne National Park. Adjacent farms and residential areas contribute significant pollution to the canal (P. W. Harlem**).**

Table 6. Major canals entering Biscayne Bay. BNP = Biscayne National Park.

Canal	Name	Length (m)	Connected to BNP?*	Control Structure
Arch Creek	Arch Creek	2,854	N	
C-1	Black Creek	7,414	Y	S21
C-2	Snapper Creek	20,353	N	S22
C-3	Coral Gables Waterway	12,183	N	
C-6	Miami River	32,180	N	S26
C-7	Little River	13,516	N	S27
C-7 Extension		5,141	N	
C-8	Biscayne Canal	14,938	N	S28
C-8 Extension		5,764	N	
C-9	Snake Creek	6,824	N	S29
C-9 Extension		24,764	N	
C-100	Cutler Drain	15,086	Y	
C-100A		11,223	N	S123
C-100B		3,083	N	
C-100C		10,625	N	
C-101	Goulds Canal	4,658	Y	
C-102	Princeton Canal	25,556	Y	S21A
C-102N		6,688	N	
C-103	Mowry Canal	25,648	Y	S20F
C-103N		8,955	N	
C-103S		3,234	N	
C-104	North Canal	30,286	N	
L-31E**		13,786	Y	
Military Canal	Military Canal	3,492	Y	S20G

* Y=yes, N=no: May be connected indirectly to outlet canals by ditches or other canals.
** L-31E levee includes a borrow canal which connects several other canals together.

allowed surface flow from the west to the east; the flow exiting the glades along the east side of the ridge fed many other small freshwater streams (Meeder et al., 1999). Black Creek is the largest of this type and is shown on almost all historical maps, sometimes with the name “North Creek,” (Figures 42-43) implying it was a known pathway for travel into the Everglades from Biscayne Bay, at least in the wet season.

A third historic stream type, found along the western coastline, emanated from springs at the base of the ridge or in the middle of the coastal plain. These sometimes start at a tree island seep,

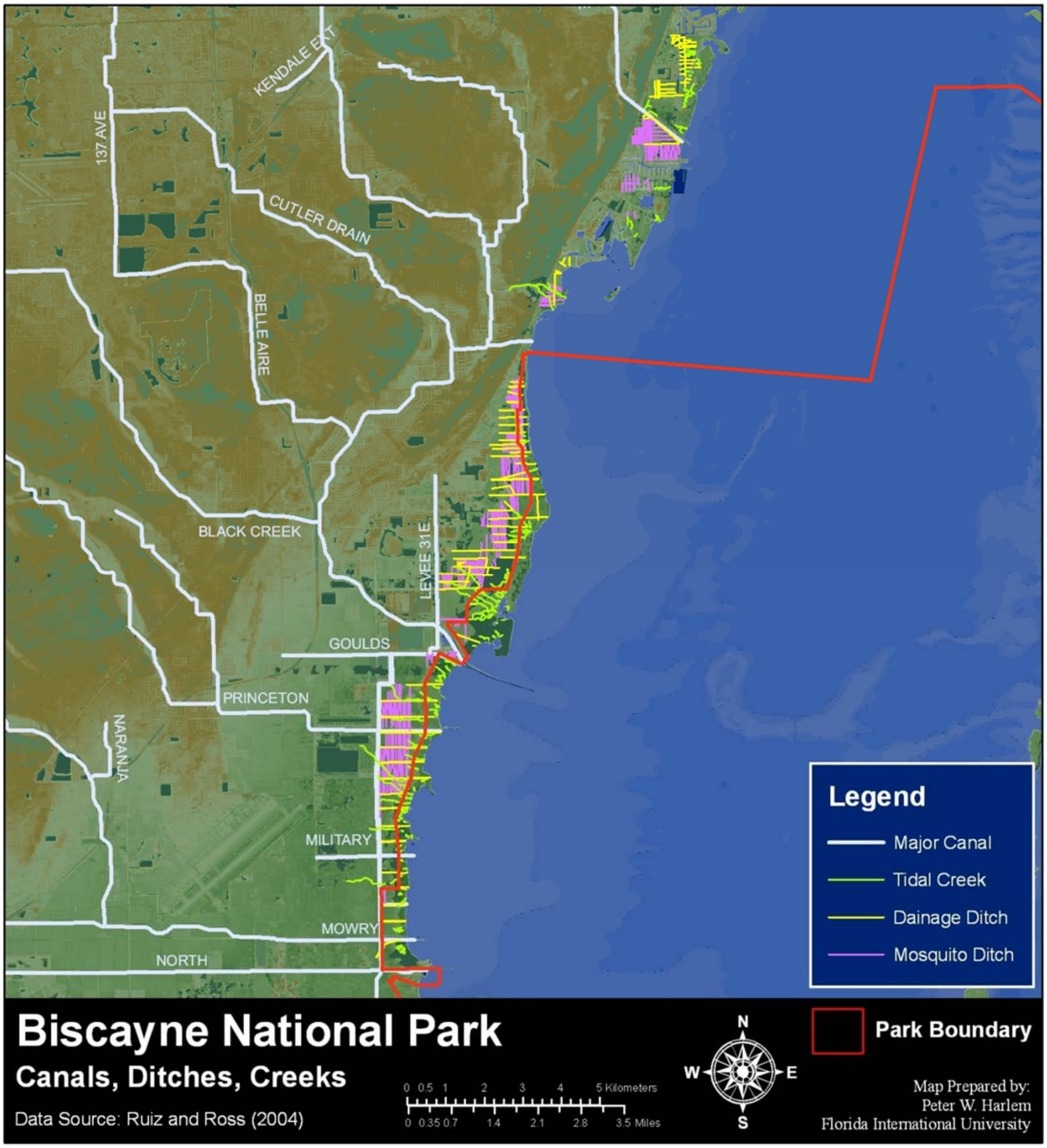


Figure 40. Canals, ditches and tidal creeks along the mainland shore of Biscayne National Park. Data from Ruiz and Ross (2004).

where penetration through the marl soil taps into the shallow aquifer. Figures 44-47 are examples of this type of stream along the western margin of the park.

The larger freshwater streams from the coastal plain are associated in some cases with bedrock depressions in the bay. Stream-like patterns in the bay's rock bottom, and holes in patterns identical to tree island patterns on the coastal plain, suggest that water has been moving from the Everglades by the coastal stream network for thousands of years. This has important implications for the past history of the Everglades, as well as Biscayne Bay (Figure 48).

Figure 41. Aerial photos of Sands Key showing dolines formed in Key Largo Limestone. The photomosaic on left is from the first aerial coastline survey by Coast and Geodetic Survey in 1928. It includes interpretative marks (black outlines and alignment circles) from the originals. The white arrows on the right image (2006, FLADOT) show a large (~160 m) and two smaller dolines (42 and 15 m). The sinuous band across the island is an elevated rock feature with hardwood hammock vegetation with numerous smaller dolines. The green arrow is a dredged channel dug that connects to the large doline. The red arrow points to an area of significant erosion in the tidal channel margin since 1928, which has changed the flood delta morphology; above that, there appears to be more mangroves on the south shore.

Figure 42. Aerial photo of large limestone mines (rockpits) located just west of the park boundary along L-31E levee. The older northern example is approximately 1,425 x 177 m in dimension; the larger one (owned by CEMEX) is about 1,355 m x 1,165 m and has recently been closed out. Miami-Dade DERM has been monitoring water quality in this pit for some time (FLADOT, 2005).

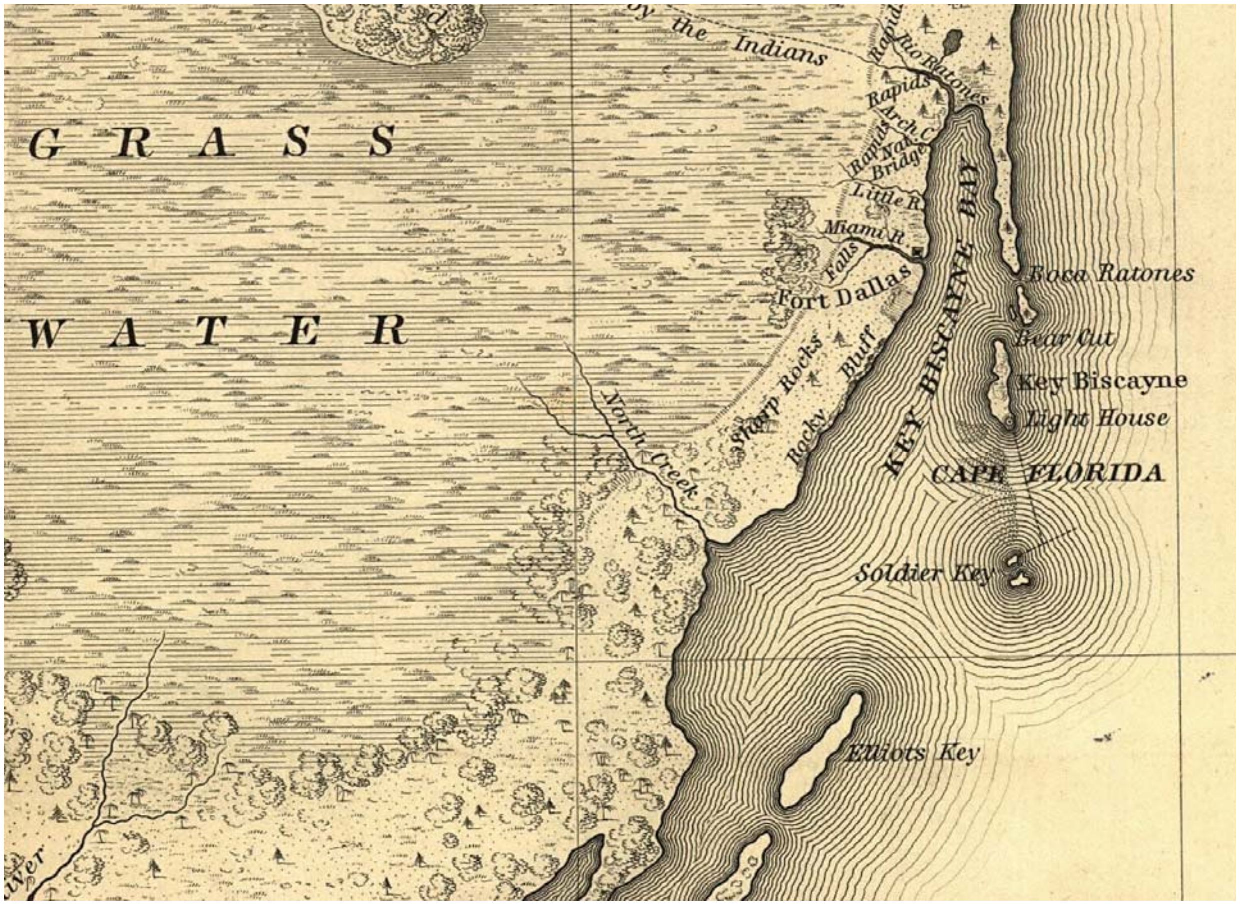


Figure 43. Historic map showing Black Creek**.** This military map by General Zachary Taylor, published in 1838, clearly shows a stream named North Creek passing through the ridge in the position now occupied by Black Creek. Numerous other maps of the 1800s show this stream, usually unnamed. While no description has been discovered from the period, it seems likely the creek was known as a pathway into the Everglades during high water. Black Point is a more recent feature and only appears on late 1800s maps. Note also the twin islands at Soldier Key where we now only have one (National Archives).

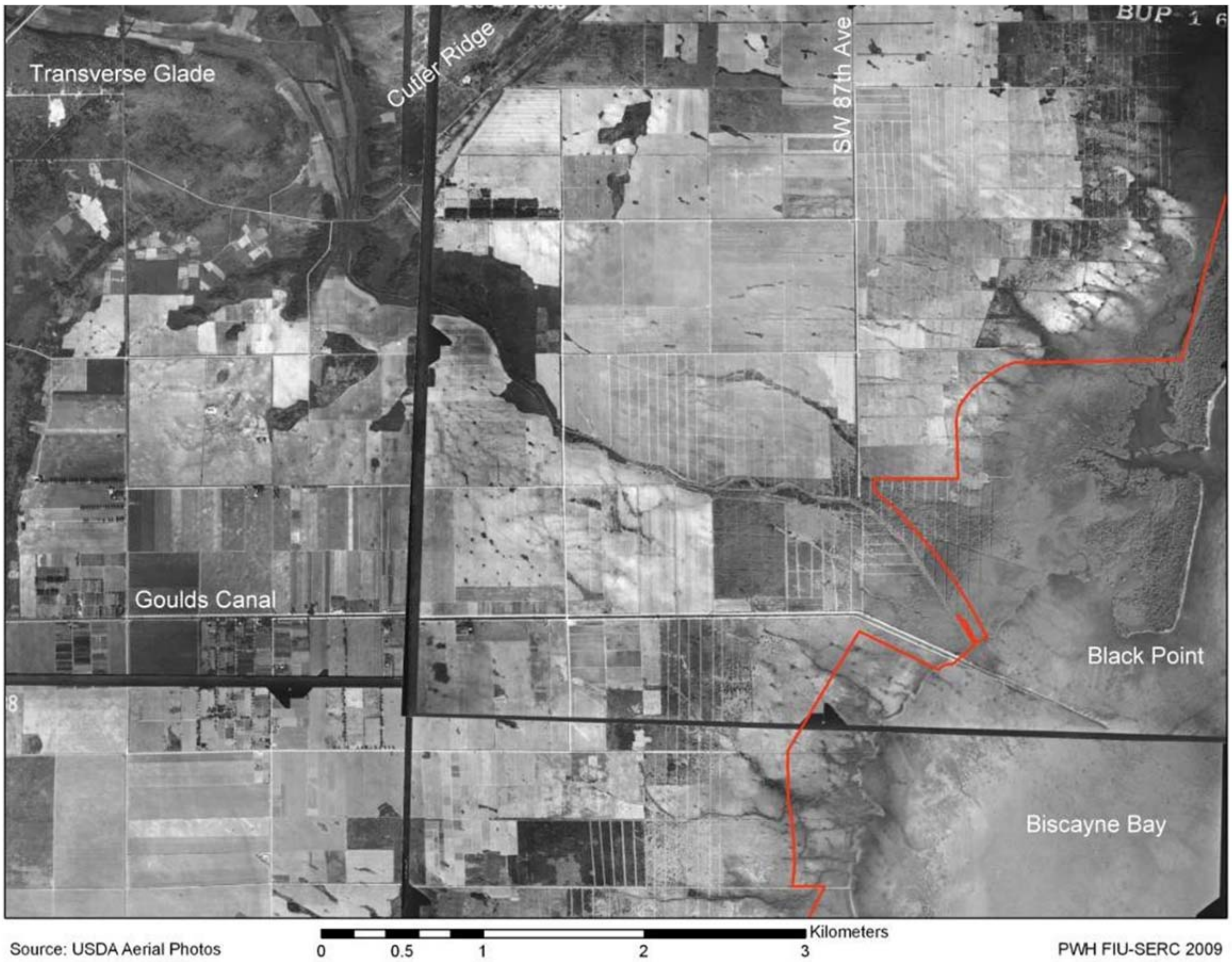


Figure 44. Aerial photomosaic of Black Creek taken in 1938 by U.S. Department of Agriculture. The creek emanates from the transverse glade complex, which cuts Cutler Ridge at the upper left and discharges southeasterly into the low, unfarmed, tree covered area. Farm fields are light grey as without significant vegetation, the marl soil in the fields has high albedo. The mangrove fringe is narrow along the shoreline except at Black Point. Note many other small creeks. The lower portion of Black Creek was already channelized by this time and Goulds Canal in place. Park boundary is shown in red. The current south Dade landfill is located on the distal end of this system.

Figure 45. Photomosaic of Fender Creek (1938). Two extinct streams are shown in this 1938 image, neither of which have official names but are referred to here as “Fender Creek” and “Historic Creek” (Meeder et al., 2002). Both originated in the lowland, east of the transverse glade belt, from a combination of surface runoff and groundwater seeping up to the marl prairie, which was heavily farmed at this time. The farming has eliminated evidence of the upper stream channel making the origination point of both streams difficult to determine. Note the many smaller streams and tidal creeks along the coast and the thin mangrove fringe, which was natural along this coast until recently (USDA images).

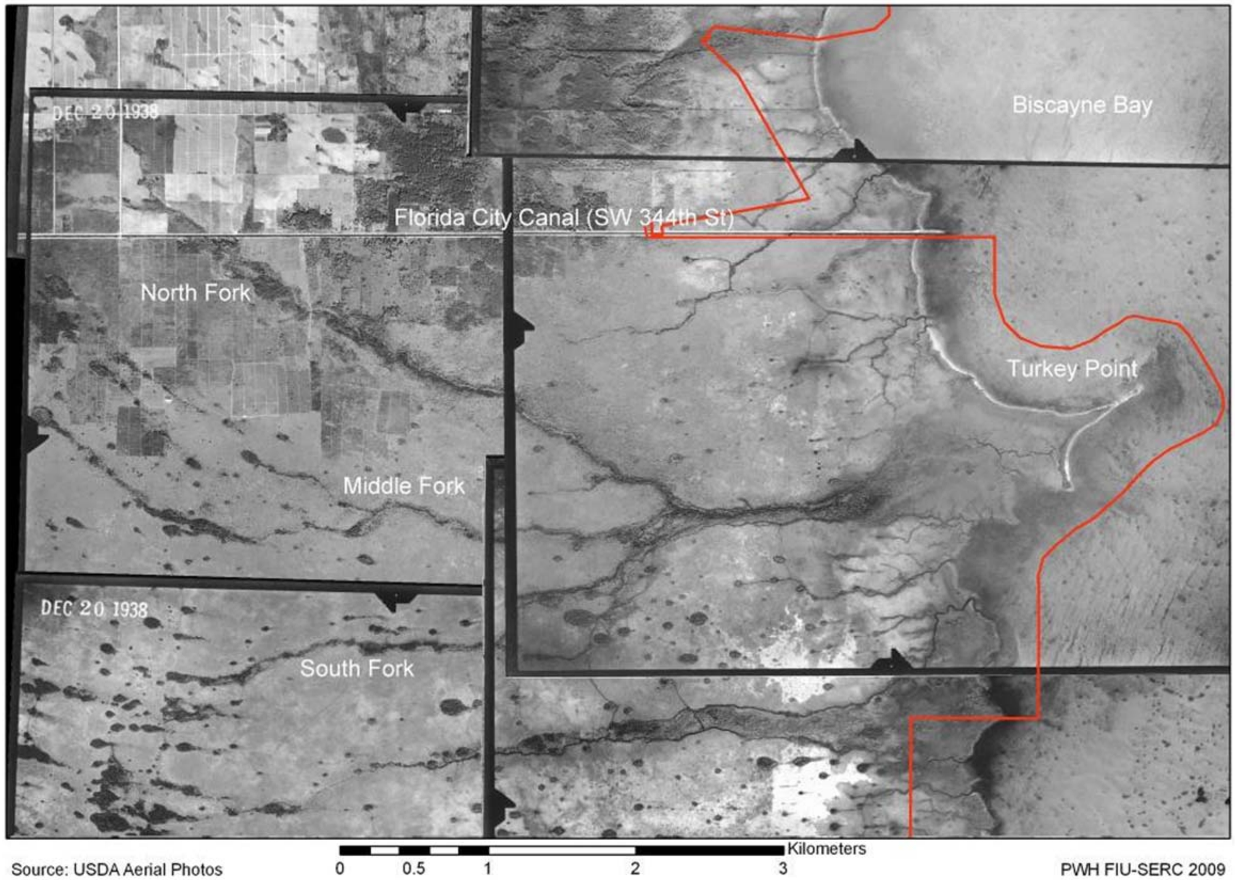


Figure 46. Photomosaic of Turkey Creek (1938). Turkey Creek (unofficial name) had three main feeder channels, the north fork being the dominant one. As the conjoined stream approached the coast, it became braided before entering the coastal mangrove forest occupying the outlet delta (Turkey Point). Most of the larger freshwater streams on this coast are associated with protruding headlands (Meeder, et al., 2003). This area is now occupied by the FPL nuclear power plant and its cooling canals (USDA images).

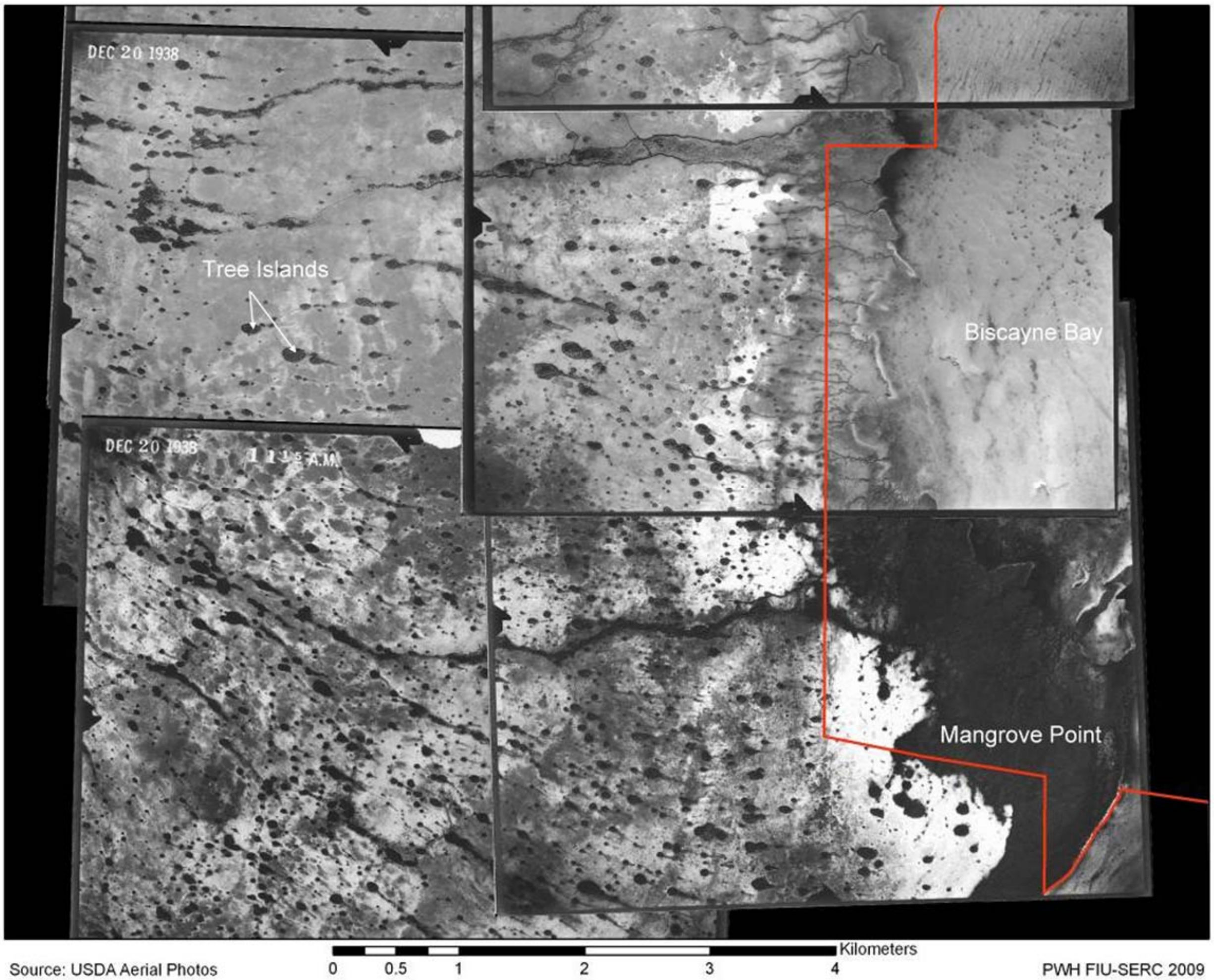


Figure 47. Photomosaic of Mangrove Creek (1938). This was the dominant system on this part of the coast. The stream crossing the lower frames (Mangrove Creek – unofficial) originates at tree islands and travels to the large mangrove forest at Mangrove Point. Note how the channel follows the surface drainage to the southeast until half way to the coast, where it turns to enter the bay perpendicular to the coastline. The stream reaching the coast at top (no name) differs in having two small perimeter channels which migrate away from each other as the coast is approached; this provides a low interval filled with mangrove. Both creeks were destroyed during the construction of the cooling canal network for Turkey Point Power Plant (Figure 80) (USDA images).

Table 7. Major historic freshwater steams entering Biscayne Bay. BNP = Biscayne National Park.

Stream	Type	Headwater	Flow to BNP?	Comment
Snake Creek	River	Everglades	N	Empties into Dumfoundling Bay
Oleta River	River	Everglades	N	Connected to Snake Creek
Arch Creek	River	Everglades	N	Twin channels, north one through limestone arch
Little River	River	Everglades	N	Empties into North Biscayne Bay
Miami River	River	Everglades	N	Major stream with karst springs adding flow (Gaby, 1993)
Snapper Creek	Stream	Transverse Glade Spring	N	Creek portion from base of ridge only. Inland portion went subterranean before reaching coast (Stewart, 1907)
Cutler Creek	Stream	Transverse Glade	N	Karst collapse feature
Black Creek	Stream	Transverse Glade	Y	"North Creek" in 1838
"Fender Creek"	Stream	Seep	Y	Seep part of delta of transverse glade
"Historic Creek"	Stream	Seep	Y	Seep part of delta of transverse glade
"Turkey Creek"	Stream	Seep	Y	Seep part of delta of transverse glade
"No Name Creek"	Stream	Seep	Y	Seep part of delta of transverse glade
"Mangrove Creek"	Stream	Seep	Y	Seep part of delta of transverse glade

Wetlands

Wetlands dominated the historical coastal lands of southern Biscayne Bay. These were predominantly marshes and prairies with abundant sheet flow in the wet season but drying out sufficiently in the winter months to produce fires (Egler, 1952). Early settlers tried to farm the coastal wetlands where winter drying was sufficient to allow a short growing season. Early coastal modifications with dikes and ditches were attempts to extend this season. Unfortunately for the farmers, the coast is very low and prone to frequent marine inundations by extreme tides and storm events, and easily subjected to saltwater intrusion. Lowered water levels in the Everglades source area, resulting from coastal drainage measures, reduced the freshwater output to the coast to a mere trickle, causing a collapse of the easternmost farms and inducing a march of mangroves to the west, which continues today and is now accelerating as sea level rises. Figure 49 shows an example of this progression.

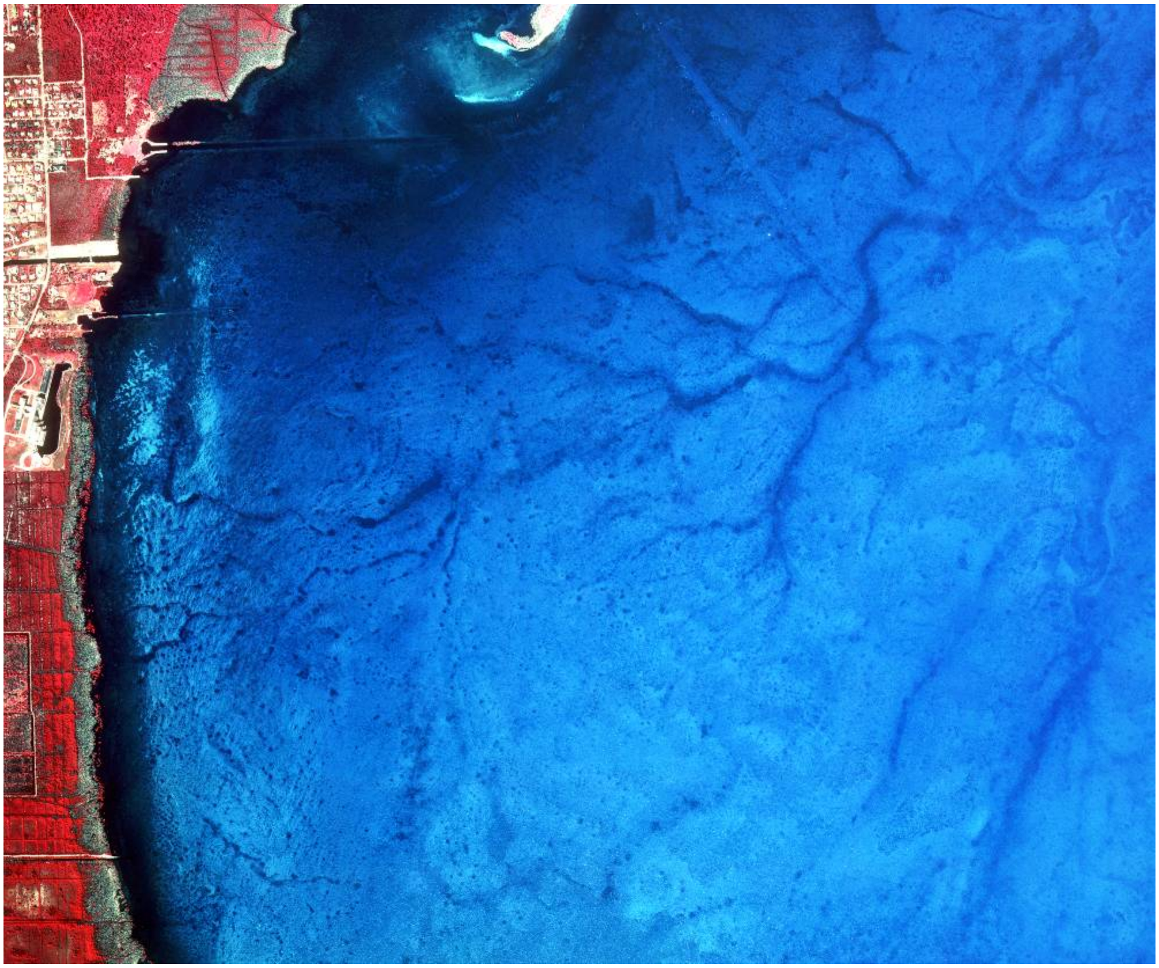


Figure 48. Drowned stream courses shown by relic karst depressions and valleys in the bay bottom. This example at the north end of Biscayne National Park (Deering Estate at upper left) is one of two very large dendritic patterns in the bedrock surface, which had to have been formed when sea level was lower and this area was part of the coastal plain with sediment cover and vegetative environments similar to those observed today. Where sediment cover is thin enough, it is possible to trace some of the features to the end of historic stream courses or tidal creeks. Associated with these are many thousands of dolines (sinkholes) frequently filled with marine grasses growing over drowned deposits of mangrove peat. The holes form lines along the drowned stream courses or are parallel to the coastline, suggesting relic shorelines (USGS, 1996 IR image).

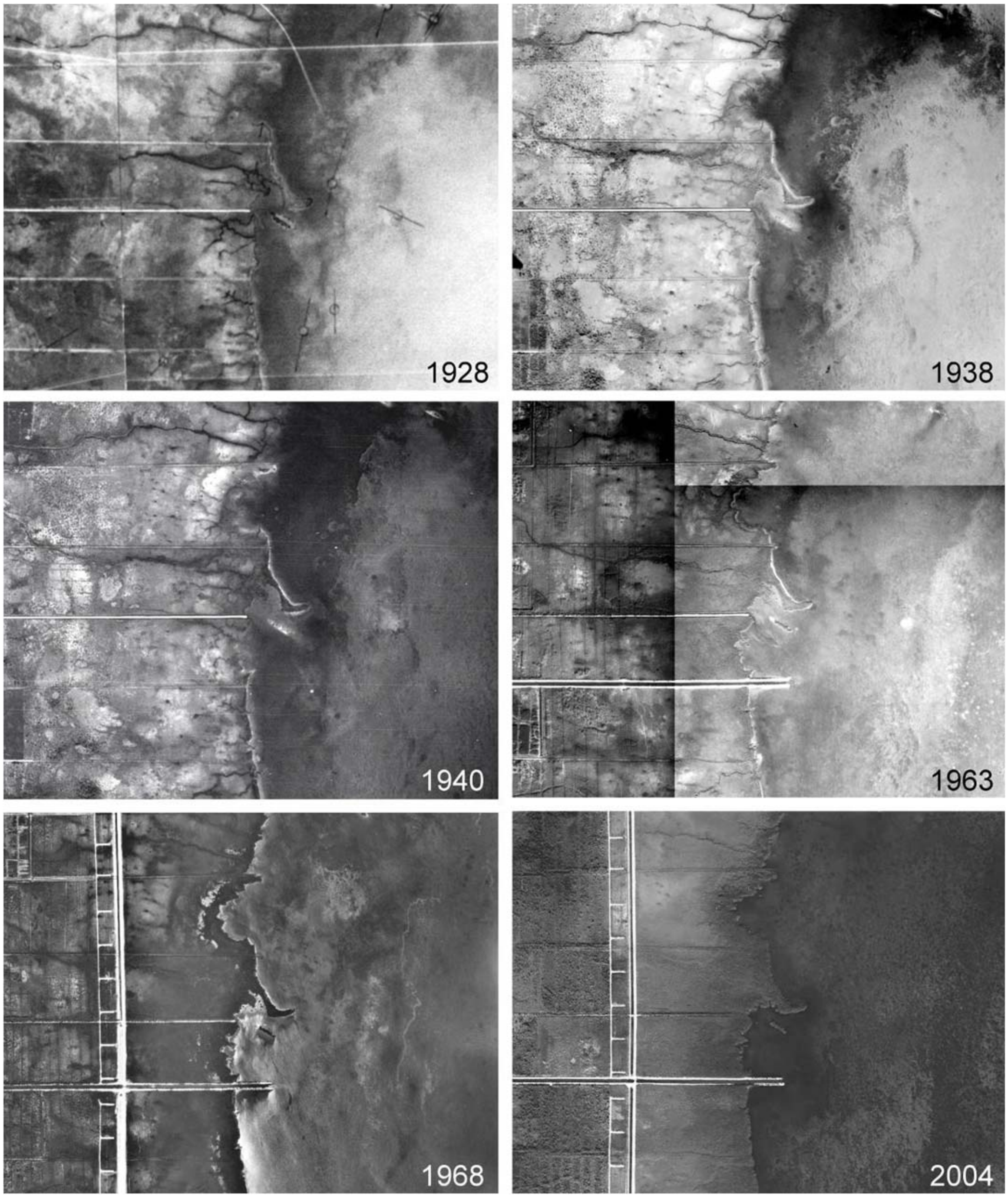


Figure 49. Coastal marsh changes as shown by sequential aerial photos. The area shown is centered on the “Historic Creek” (Meeder et al., 2002) south of Fender Point. Narrow mangrove fringe in 1928 changes to mangrove, covering all the area east of L-31E canal/levee after construction in mid 1960s. Streams and tidal creeks appear stable in early pictures. By 2004, terrestrial trees, exotics and farming over many years have changed the area west of the levee. The ephemeral nature of the algae and seagrasses growing offshore in the bay can also be seen (NOAA, USDA, USDA, USDA, FLADOT, USGS images respectively).

Groundwater

Freshwater on the barrier islands and Keys is restricted to rainfall surplus, which enters the ground from above. Lenses of freshwater are thin, temporary and mostly nonexistent; even the surface of the groundwater is brackish due to the narrow configuration of the islands and the high porosity of the Key Largo Limestone. Interstitial soil water may be fresh in the most elevated parts of the islands (e.g., more than 2 m above sea level) due to spatial separation from the underlying brackish lens. Fresh water may accumulate during the wet season in some protected interior basins, depending on the nature of the sediments.

Groundwater on the mainland side of the park is an important contributor of freshwater to Biscayne Bay (Figure 36). Springs entering the bay directly, or along the shoreline, were known and used by historical visitors and early settlers. Terrestrial springs are less relevant now because of curtailment of flow with lowering of the Everglades water table, which has eliminated or reduced the flows to a trickle. However, there are still springs flowing to the bayshore or the bay itself. NOAA and University of Miami scientists identified several springs in the bay near the Charles Deering Estate at the northwest corner of BNP south of Turkey Point (Figure 50). Several springs studied in detail flow intermittently, and even reverse flow with the tide (Atlantic Oceanographic and Meteorological Laboratory, 2006). Several of this report's authors have been to an active spring at the rock edge just north of the mansion at The Deering Estate and another spring still flowing brackish water at the original outlet of Snapper Creek (north of the park). There, a mixed freshwater/mangrove swamp exists along the bayshore, supported by water leaking out of the rocks and into the back side of the mangrove forest.

Groundwater also enters the bay beneath nearshore sediments or directly through the rocky bottom. Many groundwater inputs are reported to contain pollutants and many studies of upland groundwater conducted over time by USGS and others shows the ease with which groundwater quality is negatively affected by human processes. Seepage through the sediment in the bay was documented by Meeder et al. (1997) and Mir-Gonzalez (2007) using seepage meters constructed for the purpose. Bellmund et al. (2008), in a discussion of NPS salinity monitoring, point out the significant role groundwater has on seasonal salinity patterns even at mid-bay, and how it affects salinities for a period after the wet season has officially ended. Such flow clearly is less than it would have been when the regional water table was much higher.

Seasonal releases of freshwater from the canals for farming requirements also impacts the groundwater levels along the coast, and the irrigation systems and canal network convert large volumes of water to point delivery instead of slow seepage from the rock aquifer. These can involve very large volumes of water (Meeder et al., 2002, 2003). Renshaw et al. (2008) recently calculated that an average of 2.14 billion gallons (65,800 ac-ft) of groundwater are released each year from the C-102 (Princeton) and C-103 (Mowry) canals during the drawdown period when levels are lowered to dry wet farm fields. Drawdown starts on October 15 with a 0.8 ft lowering, is modified to 0.4 ft on December 30, and extends at that level until April 30. The drawdown impacts the park by lowering groundwater levels on the west side coastline, which affects the habitat for pink shrimp, juvenile seatrout, redfish and snook among others, and increases nearshore salinity allowing predatory marine species to invade the estuarine zone. It also impacts the Biscayne Aquifer increasing salt water intrusion. This practice continues in spite of radical changes to more urban uses in recent years which have led to major reductions in row crop farming (Renshaw et al., 2008).

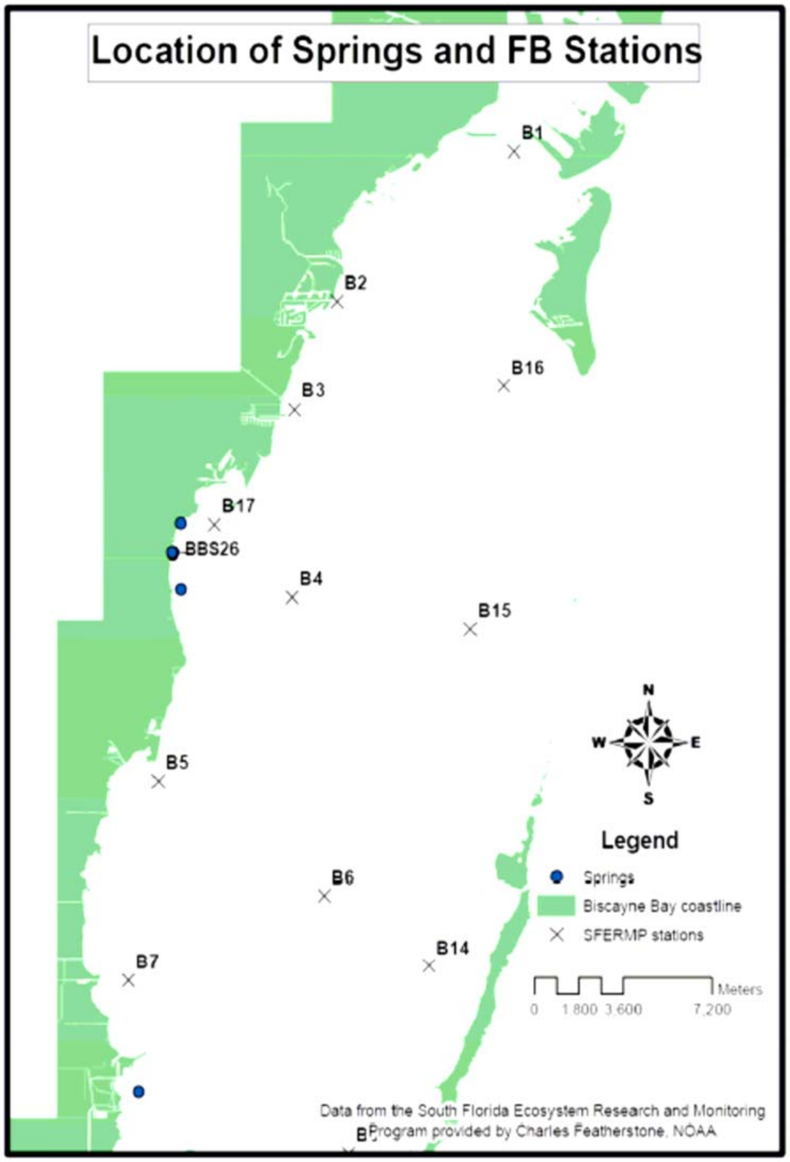


Figure 50. Location of active springs (blue dots) along the shoreline of Biscayne Bay, identified by NOAA in 2006. Points labeled with letter B are controls used to compare spring water quality to background. Other active springs are known (Atlantic Oceanographic and Meteorological Laboratory, 2006, figure A8).

Coastal/Bay Systems

Biscayne Bay is a shallow subtropical lagoon situated as a topographic basin, resting between the Atlantic Coastal Ridge and offshore reef and barrier island system; it historically functioned as an estuary. BNP occupies a subset of the bay and is a marine park strongly influenced by oceanic water. The Florida Current to the east flows strongly northward; both it, and eddies from it, enter the park, frequently bringing new water to the offshore areas and into Biscayne Bay. Tidal flushing between offshore areas and the bay is excellent, particularly at the north park boundary where the mud bank structure, the Safety Valve, is dissected by many tidal passes. Caesar's Creek and other geologically controlled cuts through the limestone Keys in the southern portion of the park, provide tidal exchange south of Featherbed Bank. Some tidal exchange occurs between the northern park boundary and the bay west of Key Biscayne, with effectiveness largely controlled by wind conditions. Therefore tidal exchange in the bay is generally very good with short residence times (ca. 1 mo), except along the mainland coastline where shallow water and poor circulation result in longer periods between flushing. Historically, rivers, streams, creeks, springs and seeps of freshwater along the mainland shoreline provided significant freshwater to the west side of the park, but drainage structures and practices have eliminated much of this flow, causing some researchers to erroneously suggest that Biscayne Bay is not an estuary. It remains an estuary, but one severely degraded in this respect. The quality of marine and remaining fresh waters is paramount to the biological health of the park's submerged ecosystems.

The geological formations and sediments of Biscayne Bay and the ocean seaward of the Keys provide support, habitat and material contributions to many organisms at all trophic levels. Some inhabit the rocky limestone shores of the Keys, the hardbottom sediment-free areas and the rocky bay shoreline northwest of the park. Some inhabit the sediments which provide protection and nutrients necessary for life at one or more life stages, and which act as soil where plant communities can thrive and expand. Others find what they need by attaching themselves to organisms which depend on those geologic elements. Still others come to the rocks or sediment to feed on what is there. Collectively, these components form the benthic communities of BNP.

The benthic environment is submerged, with the exception of those species living in the intertidal zone that have adapted to varying degrees of wetness (hydroperiod). It is affected by water movement, such as tides, wind driven currents and wave action, in the wave zone and in the water below. Water chemistry, its temperature and its all-important salinity determine which habitats will provide a suitable location for benthic community survival. Rainfall can affect salinity, as will freshwater flow from the land, so some park areas end up with salinity fluctuations which must be successfully adapted to. Water depth can be limiting; many species require sunlight for life functions and the less the light reaches the bottom in deeper water. Current-driven turbidity and nutrient-driven planktonic components in the water affect the light reaching the bottom, with shading a problem in areas with high levels of these components. This, too, can fluctuate frequently in some parts of the park. Large storms often affect the physical aspects of the benthos greatly and hence make severe demands on benthic organisms. Communities attached to the rocks must be able to stay attached in a storm-driven current regime and those living in or on the sediment must have a survival strategy for when the sediment erodes by the action of strong bottom currents or moves in to bury an area. The coastal/bay portions of the park are dominated by physical attributes and processes.

Marine Systems

Seaward of the Keys lies the marine portion of BNP. This area includes the fringing reefs growing on extinct reef material, the patch reefs behind the main reefs and the sediment-dominated trough generally referred to as "Hawk Channel" which runs between the reefs and the rocky keys. Marine climate and physical processes dominate this area where tidal currents and wave processes produce strong effects on the shoreline and benthos. Tides affect water depth and are the driver for coastal currents which can erode bottoms or move sediments. Large storms, particularly hurricanes, move large amounts of water quickly, which can have significant short term effects and can produce large waves, which have significant potential to produce damage to reefs, submerged vegetation and other communities dependent on the sea.

The proximity of the drop off into deep water of the Straits of Florida allows marine currents associated with the Gulf Stream and the stream itself to enter the park on occasion. This provides water exchange with inshore areas, and delivers transported materials, including larval forms of numerous species, which settle in the park. The currents can also remove suspended sediment and drive a net flow of such material out of the park and into the deep. Sediment packages are thin seaward of the reef and thicker behind the reef, which provides some protection from this type of erosion.

The marine climate is generally drier than that of the mainland, with rainfall levels higher on land. Aerosol deposition to the marine system occurs as it does on the mainland with the dust particles entering the coastal waters. Freshwater from the mainland was, and is, largely diluted to marine values by the time it reaches the marine areas of the park, but groundwater seepage from springs has been suggested to affect reef areas (Shinn, et al. 1994) and could as easily impact the backreef, if present. However, rainfall provides most of the freshwater delivered to this area.

The reefs are built upon past high grounds assumed to be extinct reefs and reach nearly to sea level in many cases. Except where passes occur, the reef provides a barrier to waves coming ashore during easterly wind events, which reduce the wave height striking the coast of the Keys and shallow adjacent bottoms. Without the reefs, the energy level landward would be higher. Because the tops are shallow and cause waves to break over them, reef areas export sediment frequently to adjacent areas with much of the seagrass covered sediment in Hawk Channel derived this way.

Biological Resources

The National Park Service Inventory and Monitoring Program define "Vital Signs" as physical, chemical and biological elements and processes of park ecosystems that represent the overall health and condition of the park. The South Florida/Caribbean network of the NPSIMP identified 41 vital signs of concern to the managers of the seven national parks in the region. Many of these vital signs are related to the benthic communities of BNP. Vital signs are nested within a hierarchical conceptual structure, defined by the NPSIMP. Level 1, the highest level of organization, groups the vital signs into five classes: geology and soils, water, biological integrity, human use and landscape pattern and processes. Within each of these categories, there are vital signs that are relevant to the conditions of the biotic resources of BNP; resource managers have suggested that the benthic vital signs are among the most important issues facing the parks in the region.

Vegetation

Vegetative communities in BNP include terrestrial, coastal and marine types, with the latter two dominated by submerged benthic vegetation.

<u>Terrestrial Vegetation</u>

The terrestrial environments of BNP are largely controlled by the geology and geomorphology of the surface. The islands in the park, particularly the Keys proper, are rocky outcrops of Key Largo Limestone on which the wide diversity of organisms grow and live. Patterns seen in the geology are reflected in the plant communities and either can be used to deduce details about the other. The rocky islands also display a complete suite of intertidal zonation patterns over wide areas because of the low elevations and slope, and these affect the resulting ecological communities as they adapt to varying rates of inundation.

On the mainland, the terrestrial plant patterns are controlled by elevation as well as attributes of the ground materials. Most of the rocky shoreline of Biscayne Bay is located to the NW of the park, where the Miami Limestone outcrops at the shoreline. Along the park boundary to the south and east of that limestone outcrop, the vegetation patterns reflect subtle differences in elevation and the amounts of moisture available. Moisture is controlled in part by the soil types deposited along the east side of the ridge and by current water management practices. Historically, naturally occurring springs, groundwater seeps, transverse glade-fed creeks and sheet flow controlled the freshwater delivery to the coast and had a large effect on the original vegetation patterns (Meeder et al., 2002). Tidal creeks along the coastline occur at regular intervals, cutting into the coastal soils and providing interior access to mangroves and facilitating the spread of other salt-tolerant species. Modification of the original delivery mechanisms by ditching, canal construction and levees has changed the freshwater delivery in many ways and the current vegetation patterns are a product of those changes; for example, the spread of mangroves landward shows the effect that can be invoked by relatively minor changes in the landscape.

Soil patterns can be used to determine past ecological history, as well as current depositional processes. The principal soils of the park are carbonate marl, formed in wet prairies along the coast or transported during large storms, and peat deposits comprised of detrital organic components produced by the vegetation. Mangrove peat is the most common of this type. Marl is important because of its ability to act as a barrier to water percolation which enables sheet flow of surface waters. Peat has both the ability to hold water interstitially and to compact with age, providing additional room for plant growth.

Along the SW coastline of Biscayne Bay the marl prairies of the interior are dotted with tree islands. These features are commonly growing over holes in the subsurface rocks, which allow connection to the groundwater below the marl soil. These landforms exhibit greater stature and productivity than the wetlands around them, and are primarily dominated by mangrove species near the coast. Occasionally, tree islands, including some upland component, may be found growing over protruding rocky remnants of the karst geology. These, too, enjoy the benefits of connection to the groundwater available in the porous limestone.

The shoreline of most of the upper Keys is rocky epikarst while the mainland shoreline of the park is dominated by sediment structures. The exceptions are numerous small islands of mangrove trees growing on shoals which are comprised of sand (carbonate mostly) or mud banks; these become nearly emergent during low tide. Residual quartz sand, deposited to the NE of the park by longshore drift, barely makes it into the park near Black Point, and quartz sand headlands occur near the outlets of former freshwater creeks along the west side of the park.

The vegetation patterns on the mainland have been rapidly evolving as water management and other modifications to freshwater delivery, as well as farming and development practices, impact the coastal zone. The Bay shoreline once had a narrow fringe of mangrove backed by a wide “white zone” gramminoid and marl-forming environment that is largely destroyed now. The mangroves have expanded to the west and now are the dominant habitat east of the L31E Levee, where saline water has become the driver.

The islands of BNP, and the narrow shoreline fringe on the mainland, are home to a diverse and complex series of vegetative ecosystems. While the park is 95 percent under water, the remaining 5 percent adds much to its diversity and includes many threatened or endangered plant species. On the rocky islands, the rock morphology and facies impart a strong control on the types of plants, which can survive and dictate patterns at larger scales. The low elevation, porous limestone and abundant seawater at the perimeter make fresh groundwater scarce or ephemeral, causing distress on many species. The dominant vegetation type on the islands is mangrove, but there are many hammocks of tropical hardwoods.

A limited number of physical variables, particularly elevation and groundwater salinity, are the primary determinants of the distribution of all terrestrial ecosystems within the Keys landscape (Ross et al., 1992). These two factors drive within-community processes as well. For instance, canopy height, structural complexity and species composition of tropical hardwood hammocks within the park are all strongly affected by elevation and distance to marine waters (hence salinity), with forests becoming taller, more close-canopied and diverse upslope and inland. Keys hammocks change in composition over time following stand-initiating disturbance, with deciduous species (e.g., *Lysiloma latisiliquum, Metopium toxiferum, Swietenia mahogani*) recruiting aggressively early in succession, and evergreen species becoming dominant later (e.g., *Krugiodendron ferreum, Eugenia confusa, Ateramnus lucida*) (Ross et al., 2003). Many of the most diverse Keys forests are mid-successional hammocks, with a deciduous upper layer and an evergreen subcanopy.

Early descriptions of the land environments of the park area include Romans (1775), who briefly visited the area during mapping for the British government. A detailed example of the maps made by Romans is provided in Frazier (1975), which shows the area along the coast just NW of BNP. De Pourtales (1877) visited the Florida Keys and Biscayne Bay region and made general observations of the flora he found at that time. Holden (1887) collected and described ferns in the Brickell Hammock area. He was one of many visitors to the region who wanted to sample the rare and unusual plants found here and nowhere else in the United States. Norton (1892) produced a guide to travelling in Florida, including Dade County, which, at that time, extended north to Jupiter. He gives interesting general descriptions of the vegetation around the Miami River, Coconut Grove and the upper Keys. Eaton (1906) described his trip to Miami and Homestead during a fern collecting expedition, including stops at local hammocks and to sites near Black Point. Small (1910), one of the more important observers at the time, described new species of flora found adjacent to Biscayne Bay. Gifford (1911) described the local vegetation and landforms around Biscayne Bay. Small (1913) described the plant communities growing on or adjacent to the limestone ridge. Phillips (1940) examined the plants of Castellow Hammock a few miles west of the coast.

Davis (1940) wrote the primer on Florida's mangroves with considerable descriptive material from Biscayne Bay and surrounding areas. His 1943 publication (Davis, 1943) for the State Geological Survey provides additional information about other plant communities in south Florida. Egler (1952) provided a complete description of the Southeast Saline Everglades (SESE), which comprised the mainland coastal plain east of the Miami Limestone ridge to the shoreline of what is now the park. Darling (1961) described ferns from various sites in Miami-Dade County near the park. Alexander (1967) examined the changes in a hardwood hammock (Davis's lime-sink hammock), located west of the park, over 25 years, and noted that lack of fire allowed the hammock to spread into adjacent pinelands. More recently, Molnar (1990) and Mack (1992) followed up on stand development in the same hammock, making this the longest and most complete local sequence of forest monitoring data. Psuty and Salter (1969) discussed the loss of tropical fruit orchards to urbanization on the pineland portions of the ridge.

Pool et al. (1973) examined the structure of mangroves in several locations near Biscayne Bay and compared them with mangroves in other tropical locations. Teas (1976) classified mangroves into five communities and discussed the effects of man on the swamps, speculating that the coverage of Biscayne Bay coastal mangroves had increased because losses to development were offset by the mangrove encroachment landward, induced by cutting off of freshwater flow. Gill and Tomlinson (1977) examined the root systems of mangroves using sites around Biscayne Bay. Little (1978) produced maps of the distribution of tree species in Florida. Appendix A Table A3 lists those native and naturalized species found within 10 km of BNP. Harlem (1979) mapped the mangrove environments of Northern Biscayne Bay with comparisons between 1925 and 1976 using aerial photography. Camilleri and Ribi (1986) examined DOC from mangrove leaves and its effect on invertebrate food chains. Sternberg and Swart (1987) examined how important south Florida plant species on the Keys used either salty or fresh waters found on those islands.

McFadden (1998) examined exotic vegetation on Key Biscayne with recommendations for management. Gordon (1998) discussed the invasive plant modification to the environment and addressed it. Ross et al. (1998) looked at the effects of Hurricane Andrew (1992) on two hardwood hammocks in BNP. Ross et al. (1999) analyzed the white zone vegetation landward of the mangrove fringe. Ross et al. (2000) reexamined the vegetation of the SESE to the Southwest of Turkey Point for historical changes since Egler's work. Ross et al. (2001) showed a technique to estimate above-ground biomass in BNP mangrove communities. Robles et al. (2005) gave an assessment of the condition of all the natural resources of BNP. Gaiser et al. (2005) examined the usefulness of diatoms as indicators of the health of coastal wetlands along the shoreline of BNP. Rutchey et al. (2006) produced vegetation classifications for use in the region. Ross et al. (2006) studied the effects of Hurricane Andrew in 1992 on the shoreline mangrove communities of Biscayne Bay. Zhang et al. (2006) used LiDAR mapping of a portion of the park coastline to determine the value of the technique in describing coastal vegetation structure. Possley et al. (2006) examined the effects of fire patterns and fragment size on diversity patterns in pine forests adjacent to the park. Ewe and Sternberg (2007) examined water uptake by the exotic *Schinus terebinthifolius* (Brazilian pepper) growing on the SW coast of Florida, and concluded that it was slightly salt-tolerant and better suited to mangrove transition zones than native species. Shamblin (2008) described the vegetation in the hardwood hammocks on the Keys in BNP.

Ruiz et al. (2008) produced a vegetation map of BNP using digital recognition software combined with LiDAR, which will become the standard for future vegetation mapping in the park. Included in this report (undergoing certification by NPS staff) is a table of areas that provides a summary of the detailed vegetation patterns. Red mangrove scrub and mixed mangrove forests dominated the mainland coastline inside the park; Soldier Key is dominated by mixed herbaceous dune; the Ragged Keys are dominated by modified land and mixed mangrove forest; Sands Key is split between mixed mangrove shrubland and forest and hardwood hammock; Elliott Key is dominated by hardwood hammock; and Old Rhodes and Totten Keys are dominated by red and mixed mangrove shrubland with hardwood hammocks. Appendices A4 and A5 show vegetation types in the park by acreage from Ruiz et al. (2008).

To provide clarity, the vegetation patterns in BNP, as mapped by Ruiz et al. (2008), are shown in maps produced for this report from their data layer. These are presented in Appendix B; each is followed by a summary table of areas and percent, sorted from most abundant to least abundant. Figures B1-B5 in Appendix B show the mainland areas of the park (north to south) while Figures B6-B10 in show the island vegetation by island or group of islands. Classification terminology follows the source material, which should be consulted for a full explanation.

Marine Plant Communities

The marine plant communities growing in the park area have been studied for many years, with many important species receiving extensive coverage. Communities studied include important intertidal zones on the rocky Keys and mangrove shorelines along the bayshore, bay resident benthic habitats of many types and those offshore of the Keys, including the reefs. Plants are important species in all these areas and in some, they dominate. For the species collectively called sea grasses, the amount of sediment is a major controlling factor as much of the bay portion of the park is bare rock or has a veneer of sediment too thin to support the root structure. Predation by herbivores can also control grass patterns with halos around patch reefs, for example, showing the balance between thin sediment and predation. Algal species more often are attached to the bottom or other objects (shells, other organisms). A quick review of pertinent literature follows.

Howe (1905) visited Biscayne Bay prior to drainage of the Everglades and made observations on the marine algae. He discovered *Acetabularia farlowii* in abundance but confined to the zone near low tide, and *Acetabularia crenulatum,* more abundant, but more common in deeper waters. With the birth of marine science and the advent of the University of Miami program on Virginia Key in the 1950s, new research on Biscayne Bay and reefs was undertaken. Smith (1957), for example, summarizes research being conducted at the Marine Lab (now RSMAS) on level bottom communities in Biscayne Bay and adjacent areas. Hopper and Meyers (1967) looked at the benthic nematode fauna within a *Thalassia* bed in Bear Cut. With 100 taxa collected, they reported four species as dominant, with population density fluctuating seasonally. McNulty and Lopez (1969) studied benthic polychaetes with emphasis on the production of gametes.

Roessler et al. (1973; Figure 51) produced the first attempt to map the complete benthic habitat in Biscayne Bay, showing the bottom types from Julia Tuttle Causeway, south to, and including, Card Sound, using general ecotones. This did not include the offshore areas and because of the collection method (towing an observer behind a boat), the maps present a snapshot of the benthos only and were intended to be a guide to the areas that presented the least problems if used as borrow pits for dredging. The map identifies six community types defined as: (1) the turtle grass or *Thalassia testudinum* community, (2) the Cuban shoal weed, *Halodule* (*Diplanthera wrightii* in report), community, (3) the sparse *Thalassia*, or green algae, community, (4) the hard sand-green algae community, (5) the barren sand areas, and (6) the mud-silt bottom community. A summary of spatial patterns from this source is given in Table 8.

Table 8. Summary of habitat areas inside Biscayne National Park as shown on Roessler map (Figure 51).

Community	Hectares	Acres	Percent
Barren Sand	1,327.5	3,280	3.4
Cuban Shoal Weed	2,451.8	6,059	6.3
Hard Sand, Green Algae	11,164.4	27,588	28.7
Mud-Silt	226.8	560	0.6
Sparse Turtle Grass, Green Algae	8,296.1	20,500	21.4
Turtle Grass	15,385.5	38,018	39.6
Total	**38,852.1**	**96,006**	**100.0**

Roessler's observations include the following:

- Sparse *Thalassia* and green algae-sand communities generally cover large portions of the bay with much of the *Thalassia* found growing in cracks or "potholes" in the rocky bottom. The various species of green algae dominated in areas where sediment is insufficiently thick to allow grasses.

- Hard bottoms and small rocks or shell fragments provide holdfast locations for green-algae, sponges and soft coral types.

- Almost barren sand occupies the surface of many of the channels in the Safety Valve and also Featherbed Bank in mid-bay. In the Featherbed area, small rock outcroppings were found to include attached sponges.

- Micro-algae coated, soft sediment (mud-silt) is found in southeastern Card Sound, and as part of a large muddy area at the north end of the park which they believed derived from high turbidity associated with urban and seaport areas north and northwest of the park.

- Trawl study data showed that the community associated with red algae (*Laurencia*, *Digenea*) had the highest abundance and greatest diversity of animals. This category was not mapped because it is not permanently attached to the bottom and moves around with strong currents from time to time.

- In 1976, the State of Florida with Miami-Dade DERM produced an aerial survey of the reef tract to map underwater habitats. They used a rarely-used, special Kodak film with enhanced ability to penetrate water. A team under Dr. Don Marszalek at the University of Miami produced 10 maps (Marszalek, 1984) covering the entire area offshore of the Keys which were extensively truthed by towed divers over a two-year period. Figure 52 shows an example of one of the images taken, but not used, in the reef-mapping survey and Figure 53 shows the northern three maps which overlap portions of BNP.

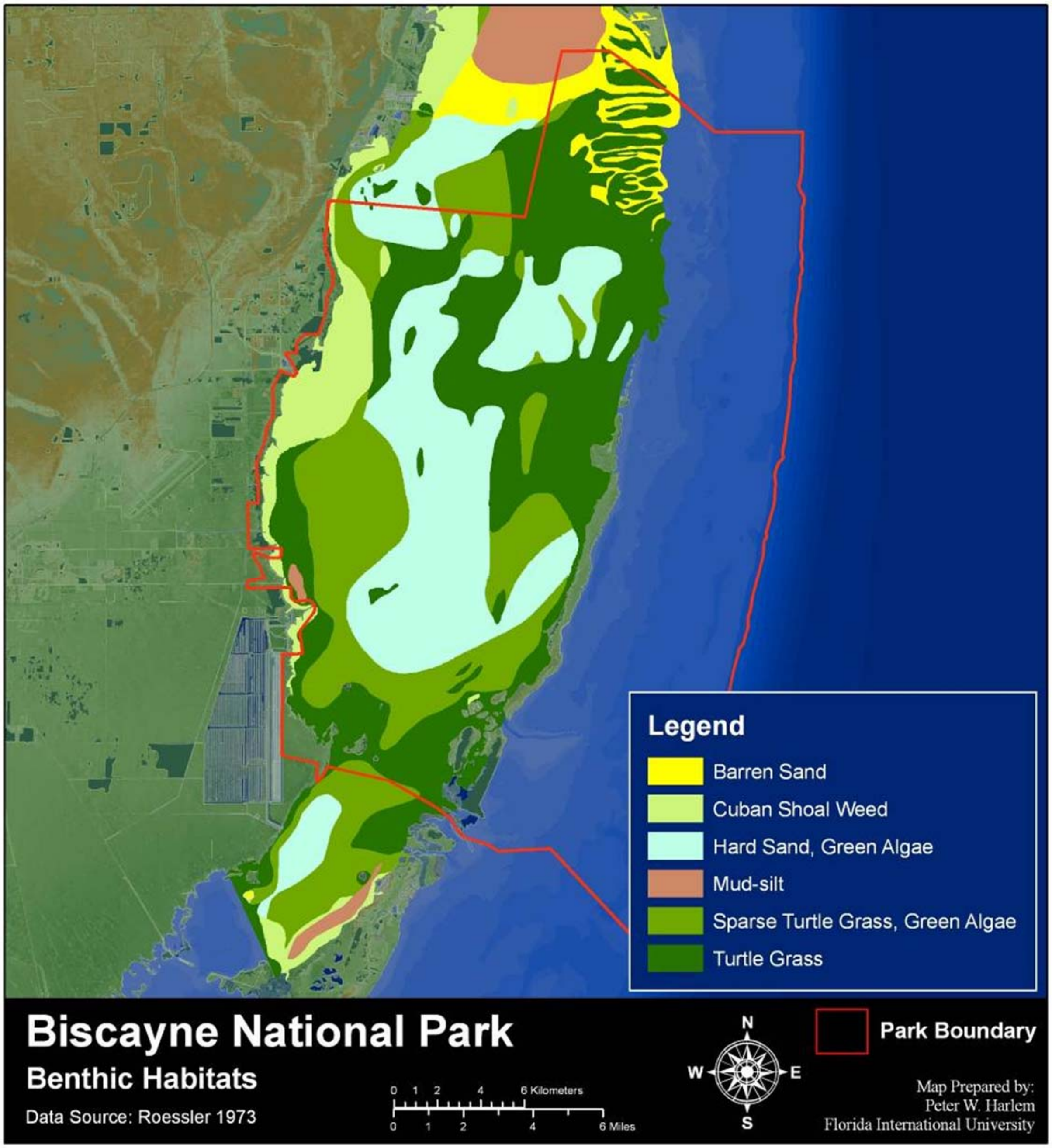


Figure 51. General benthic habitat patterns in Biscayne Bay and Card Sound derived from Roessler et al. (1973) and Thorhaug (1976). Data were collected at 29 tow transects in Biscayne Bay running roughly east-west, and five in Card Sound, resulting in the generalized patterns.

Higer et al. (1971) produced a digital simulation model and used it to forecast changes to the south Biscayne Bay benthic vegetation resulting from thermal stress. Thorhaug and Garcia-Gomez (1972) examined red algae growing in the bay near Turkey Point and in Card Sound. Salinity was suggested as the control on red algae, which was hard to find in significant quantities in shallow water near the mainland shore or near the existing Model Lands Canal., *Laurencia poitei*, the principal algae found, was more abundant along the west side of Card

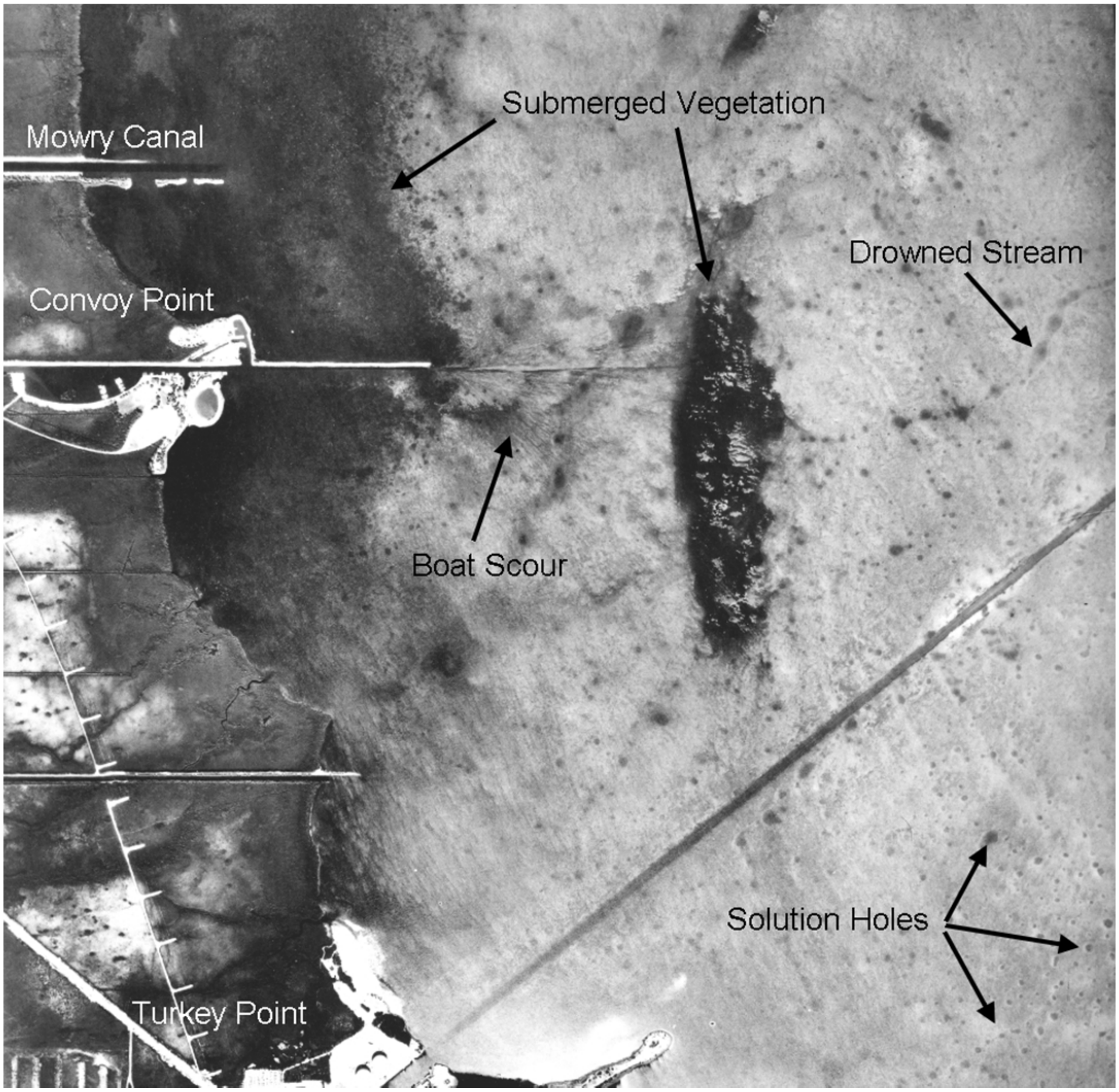


Figure 52. January 1976 vertical aerial photo showing area around the Convoy Point park headquarters. This image used Kodak water penetrating film, which shows exquisite detail of the bottom features. Although the project was reef mapping, most of Biscayne Bay was also flown, but not mapped, by Marszalek's group. The linear submerged vegetation feature north of the Turkey Point barge channel (diagonal line) has never been described and is not visible now (FLDOT image PD1638-26).

Sound. Because it is often free floating, it was not found to any degree on Card Bank but did form submarine "windrows." *Laurencia* was more sensitive to heat, siltation and low salinity than the seagrass *Thalassia*. Fell et al. (1972) continued his studies of microbial processes in mangrove litter degradation, which leads to byproduct uptake by higher trophic levels. This was conducted near Turkey Point and in Card Sound.

Thorhaug and Pepper (1972) found that thermal effluent negatively affected *Thalassia* beds adjacent to Turkey Point and concluded that water temperatures of plus 4-5°C would damage the grasses. Thorhaug (1974) compared thermally-affected seagrasses to unaffected areas in Card Sound and included some information on siltation. Roessler et al. (1975) studied the effects of

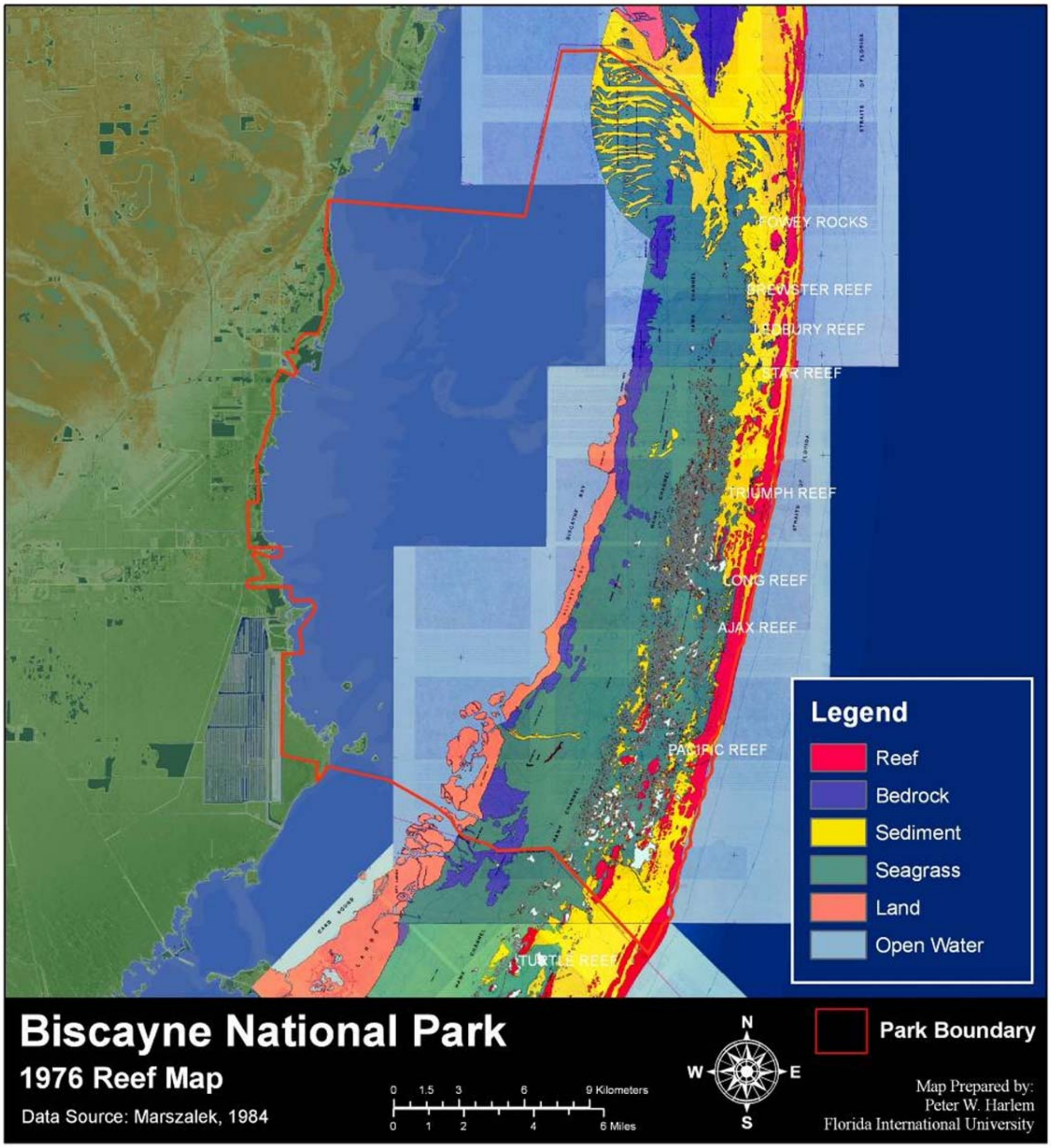


Figure 53. Compiled set of maps (# 1-3) produced by Marzalek (1984) from the 1976 water penetrating images. Originals are quite large with excellent detail. Ghosts in light blue areas are from back of scanned map originals (Georeferenced by P.W. Harlem).

thermal pollution on fish and benthic plant communities and determined that discharge water at or above 33^{o}C during hot summer months led to the most long-term damage. Sprogis (1975) examined the effect of thermal effluent on benthic diatom assemblages adjacent to the power plant. Diversity was impacted by warmer water; the affected areas were more impacted during summer and fall. Thorhaug (1975, 1976) produced progress reports of her study of the effects of thermal pollution on adjacent benthic plant communities.

Cooksey et al. (1976) studied the role of benthic diatoms on mangrove community carbon cycles in Card Sound and found that soluble organics in the pore water increased during the dry season and declined in the wet season. Humm (1976) described the algae of Biscayne Bay and listed 331 species with annotation. He stated that all known species of bluegreen algae were present in the bay. Of the species listed, 46% were reds, 30% were greens, 14% browns and 11% bluegreens. His notes give details of locations where specimens were found.

Oremland (1976) studied the chemistry of *Thalassia* beds near Soldier Key and discovered *Thalassia* beds produce the highest rate of bacterially produced methanogenesis in the sediments produced by breakdown products. Woelkerling (1976) examined the benthic marine algae in south Florida, including most important species in BNP. This included an identification key. Edwards (1977) studied oxygen uptake and macrofaunal assemblage in the *Halodule wrightii* community at Shoal Point.

Nowlin (1977) described using aerial photography of the Safety Valve at Bruce Shoals to study benthic communities. Smith and Teas (1977) used an analysis of aerial photographs from 1956 to 1973 to document a loss of benthic cover in an area known to be receiving the high temperature discharge water.

Thorhaug (1977) studied the impact of dredge and fill on seagrass communities in portions of Biscayne Bay. Thorhaug et al. (1977) produced another progress report of the effect of thermal pollution from Turkey Point into south Biscayne Bay. Holm (1978) examined the benthic community adjacent to Old Rhodes Key finding correlations between vegetation abundance and sediment stability, which also controlled the resulting macrofauna.

Thorhaug et al. (1979) produced a multidisciplinary study of Card Sound, which bracketed the opening of the thermal cooling canal from Turkey Point. The bottom closest to the canal opening was found to have the most damage. Thorhaug (1980) studied impacted seagrass beds in Biscayne Bay and offered techniques for replanting lost grass in impacted areas. Schropp et al. (1988) studied microbial communities in Biscayne Bay to analyze the effects of pollution on the phospholoid fatty acids in the microbes. Polluted samples were found to have generally higher metal concentrations.

The Florida Wildlife Research Institute (1992) published a digital map of the benthic communities of southeast Florida including all of BNP. It was based on data collected by Florida Fish and Wildlife Conservation Commission, FWRI and Miami-Dade County, and is derived from color aerial photographs taken in December 1991 and April 1992. The FWRI processed the original data and published it in 2001 with their corrections included; it is presented here as Figure 54. This map uses the seven values in the S_Class column, the “Super Class” that lumps categories from the A_Code column. For example, patch reef and platform reef types in the A_Code column are lumped as CR (Coral Reef). Additional maps using the 39 A_Code values are presented in following sections where appropriate. Table 9 presents total acreage inside the park boundary calculated from the maps.

The benthic map produced by Lewis et al. (2002) shows the distribution of seagrass communities and other related substrates. The map was produced from aerial photos of Biscayne Bay taken in November 1997 and does not include park areas east of the patch reef line (east of the upper

Figure 54. Florida Wildlife Research Institute map of bottom communities of Biscayne National Park derived from 1991-1992 aerial photos. Super Class items mapped include bare substrate, seagrass (undifferentiated), patchy seagrass, hard bottom, hard bottom with patches of seagrass, coral reef and unknown (mostly mud and silt areas). The map dataset represents conditions just prior to Hurricane Andrew (August 1992).

Keys). Total area mapped was therefore only 74 percent of the park. Categories mapped were classified by seagrass density, distributional patchiness and substrate type. Unlike similar maps, this data set also differentiates by relative water depth, giving two patterns for most map classes.

Table 9. Summary of benthic habitat areas inside Biscayne National Park in Figure 54.

Parameter	Hectares	Acres	Percent
Bare Substrate	2,499.3	6,176	3.7
Coral Reef	3,817.2	9,433	5.7
Hard Bottom	26.1	65	0.04
Hard Bottom with Seagrass	17,590.1	43,466	26.1
Continuous Seagrass	30,767.4	76,028	45.7
Patch (Discontinuous) Seagrass	8,154.2	20,149	12.1
Unknown	3,555.8	8,787	5.3
Total	**66,410.1**	**164,103**	**100.0**

These are split between areas "on bank" and otherwise, with "on bank" including true shallow banks and the intertidal areas along the shorelines. Although not used in the original paper, we have included the term "off bank" to allow for a simplified map legend (Figure 55). Off bank areas are those which are not prone to exposure at lowest tide levels and therefore never exposed (theoretically). Table 10 summarizes the acreages of the patterns mapped by Lewis et al.

An attempt was made to combine the data derived from the benthic maps to find discernable changes in important categories (Figure 56). The Roessler map used field observation methods while the other three (DERM, FWRI, and Lewis et al.) relied on aerial photos to mark patterns. Although there was some overlap, most of the parameters mapped did not have the same exact definition. For example, sparse seagrass beds were handled differently by each creator; therefore, it was only possible to use combined categories to make area comparisons. From this, it appears the seagrass cover in the park is between 55-58 percent of the bottom. Hardbottom (having some submerged aquatic vegetation (SAV) cover-definition varies) comprises 25-35 percent of the bottom, while bare areas only 1-4 percent. Corals (not including small patch reefs within Biscayne Bay) were only mapped by FWRI and cover approximately 5.5 percent of the park.

Mir-Gonzalez et al. (2003a, 2003b) and Mir-Gonzalez (2007) studied the groundwater seeping into Biscayne Bay along the shoreline and mapped the benthic macrophyte communities along the western shore of BNP from Black Point to Turkey Point in good detail. They used 210 sites with four transects, each with five sites perpendicular to shore, to determine nutrient concentrations, community and substrate characteristics and ground water flow. Figure 57 shows one of the maps produced in the thesis portion of the work.

Biber and Irlandi (2006) studied the macro-algal communities in South Biscayne Bay, Card Sound, Barnes Sound and Manatee Bay. Sample locations were chosen in shallow water in *Thalassia* communities, abutting mangroves with two locations at canal mouths (Black Creek, Fender Point), two at channels through the Keys (Sands Key and Broad Creek) and the other three inshore in the southern, small bays. Samples were collected between 1996-1999 over a variety of salinity conditions. They identified 19 species of rhizophytes representing eight genera and 22 species of drift algae (14 genera). The more abundant types of attached algae found included *Halimeda* (six) *Caulerpa* (four), *Avrainvillea*, *Penicillus* and *Udotea* (two each). The

Figure 55. Benthic map showing distribution of seagrass beds and other habitats determined from aerial photography (data from 1997). Note the similarity to the map by FWRI (Lewis et al., 2002-GIS layer provided by author).

most abundant types of drift algae found were *Chondria* (5) and the genera *Dasya*, *Jania*, *Laurencia* and *Polysiphonia*, each represented by two species. *Chondria*, *Laurencia* and *Polysiphonia*, all drift algae, were the dominant genera at the two canal sites. *Acetabularia crenulata*, *Batophora oerstedii* and *Penicillus capitatus* were the most common rhizophytic algae in areas not covered in seagrass; *Penicillus* was normally the most abundant by dry weight,

Table 10. Summary of benthic habitats inside Biscayne National Park from Figure 55.

Parameter	Hectares	Acres	Percent
Bare Substrate	441.1	1,090	0.6
Dense Seagrass Patches - Hardbottom	4,946.7	12,224	6.9
Hard Bottom on Bank	13,793.4	34,084	19.3
Land	3,136.4	7,750	4.4
Sparse Continuous Seagrass	53.1	131	0.1
Moderate-Dense Continuous Seagrass	25,446.0	62,878	35.7
Moderate-Dense Discontinuous Seagrass with Blowouts	2,934.1	7,250	4.1
Seagrass Patches in Sparse Matrix	128.0	316	0.2
Sand/Mud, Scattered Seagrass Patches	1,339.5	3,310	1.9
Unmappable	729.4	1,802	1.0
UNMAPPED	18,389.7	45,442	25.8
TOTAL MAPPED	52,947.6	130,836	74.2
Total	**71,337.3**	**176,278**	**100.0**

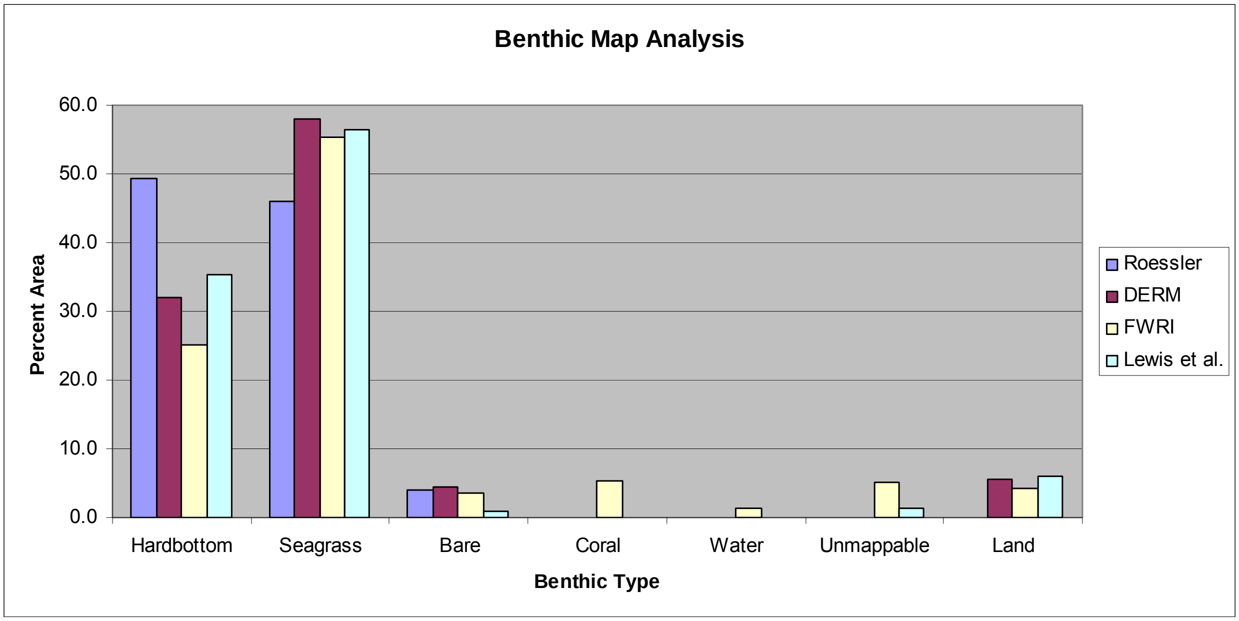


Figure 56. Comparison of bottom habitats shown on various maps of Biscayne National Park. Categories were lumped to make common categories and percent area was normalized to the entire park.

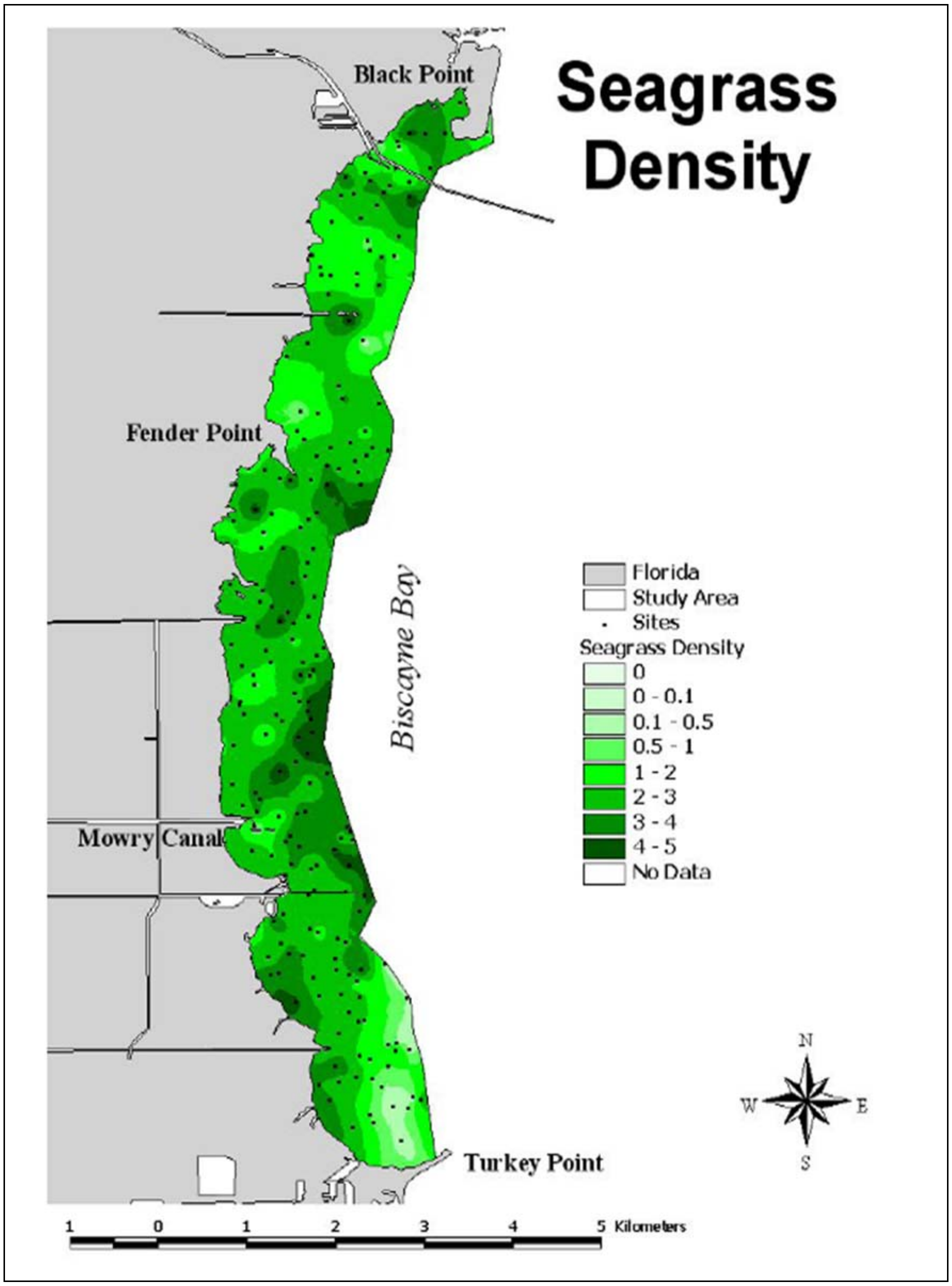


Figure 573. Seagrass density adjacent to the west mainland shore of Biscayne National Park (Mir-Gonzalez, 2007, Figure 2.4A). Density classes are the Braun Blanquet density score calculated by the author; higher numbers are higher density. This is one of several vegetation maps in this reach in the original work.

except for one month (February 1996). The sheet flow sites to the south were dominated more by drift algae and at the ocean channels, higher species counts were found but with drift algae rare in samples taken there. *Halimeda* and *Penicillus* were the two most abundant genera encountered at these sites. Salinity and temperature were the principal controls on abundance and biomass, and their data strongly suggest that episodic freshwater discharges from the drainage canal network was an important stressor on the algal communities, affecting composition and structure.

In each of the sub-communities, there are diverse and numerous microfauna and microflora that are not generally visible to the naked eye or of much concern to the typical park user. This does not imply they lack importance. Many marine species include larval stages that are extremely small and therefore easy to overlook until one realizes the micro-stage requires the right conditions for successful maturation to a macro-stage the average person might recognize. We can easily see the corals, but observing the larval polyp as the reef tries to spread is much harder. Micro-benthos also forms much of the initial step in many food chains and must not be ignored.

Lisle and Reich (2006) studied the microbial ecology of reef sediments in BNP. Nutrient data were collected and bacterial productivity measured on two reefs. Bacterial production and nutrient flux to the surrounding water are seasonal. Bacteria directly alter the sediment and water chemistry, facilitating production and cycling of nutrients; more nutrients were associated with sediments than in the overlying water column. The authors concluded that bacterial cycling of nutrients, metals, carbon and oxygen plays a major role in sediment chemistry and needs to be included in our understanding of reef ecology.

Exemplary Natural Plant Communities

Because of Everglades' drainage, which reduced freshwater flow to the coast of Biscayne Bay, BNP is now home to the longest stretch of mangrove forest on the east coast of Florida (National Park Conservation Association, 2006). This community has replaced the previous coastal marsh and white zone grass prairies and so comes at a loss in habitat diversity. However, the acreage of mangroves now rival that of the lost mangrove forests of Miami Beach, which were lost to Biscayne Bay when the strand was developed (Harlem, 1979). The upper Keys are largely undeveloped and still include many unique vegetative communities no longer thriving on the lower Keys. Combined with the large acreage of submerged aquatic vegetation, BNP is one of the best places to show visitors to South Florida a great diversity over short travel distances.

Rare Plants

Endangered plants in BNP included the beach clustervine (Beach Jacquemontia, *Jacquemontia reclinata*, Figure 58). A species of prickly pear cactus, the Florida semaphore cactus (*Console corallicola*), is endemic to the Florida Keys and a proposed candidate for listing (Figure 59). A large plant with treelike form, its range was reduced by development and is now threatened by the recently arrived exotic cactus moth (*Cactoblastis cactorum*) and disease that causes rot. Originally described as native to Key Largo in 1935, it is now known only from Little Torch Key and Key Largo. It is found in BNP in patches (about 580 plants) covering about 4 hectares (Cariaga et al., 2005), but the colony's location was not disclosed. Several attempts to establish new colonies have failed, in part because the plant does not normally spread by sexual means.

Considered to be the rarest palm native to Florida, the endangered buccaneer palm (sargent's palm, Figure 60) was found on Elliott Key and Sands Key by collectors who harvested them for them for ornamental use in the late 1800s. By 1991, only 50 palms were found on Elliott Key, of which many were damaged during Hurricane Andrew in August of 1992. Currently, slightly more than a dozen plants are known on Elliott Key and another 100 plus on Long Key where they were reintroduced by recent restoration efforts.

Figure 58. Flowering example of the endangered beach clustervine (Beach Jacquemontia, *Jacquemontia reclinata*) (D. Austin, Smithsonian).

Figure 59. The rare Florida semaphore cactus (*Consolea corallicola*) has been proposed for listing as endangered. Synonym is *Opuntia corallicola* (Meghan Fellows).

Figure 60. The endangered buccaneer palm (*Pseudophoenix sargentii*) or sargent's palm. This native to a few Keys in Biscayne National Park is maintained by stocks saved in palm preserves, like this example from Fairchild Tropical Botanical Gardens in nearby Pinecrest (FTBG).

Yeasts

Yeasts are fungi that break down sugars forming ethyl alcohol and releasing CO_2. Certain species have commercial uses (in food and drink production, as a source of vitamins, etc.) that have driven a limited examination of the yeasts found in the waters of Biscayne Bay. Fell et al. (1960) examined yeasts from sediments collected at 45 locations in Biscayne Bay, north of the southern tip of Key Biscayne. Twenty-two species were identified, most of which occurred on land. They found generally higher diversity in the Bear Cut channel and higher diversity in shallow shore areas compared to mid-bay sites. Biscayne Bay samples had less oxidative species than deepwater core samples from the Bahamas. Roth et al. (1962) studied yeasts found on marine substrates, including samples from North Biscayne Bay and various locations seaward of Elliot and Soldier Keys. No pure marine yeasts were identified; most types found have terrestrial sources. Generally, more species were found inside the bay than outside, and yeasts were more abundant in the water column than in the tissues of macroflora and fauna.

Invertebrates

Biscayne Bay is located at the border between the West Indian and Carolinian Faunal Provinces, and as a result the invertebrate fauna is rich and diverse (Voss, 1976). Unfortunately, Biscayne Bay has never been fully surveyed for invertebrates and there are no complete lists of invertebrate species. Small studies abound that provide some insight into the diversity and complexity of these groups. The area near Turkey Point is the best studied. Important groups have received attention and others are indicators of ecosystem health. Considering the importance of some groups as food for humans and others as food for higher trophic levels, a complete study of invertebrate populations in the park would be beneficial.

Weiss (1948) examined sedentary organisms which attached to plates placed and monitored at three sites (Tahiti Beach, Miami Beach [n=2]) with an eye to understanding seasonal attachment rates. Barnacles were the first organisms to foul the test plates, followed by tunicates and bryozoans, which often attached to the barnacles. Rate of growth was correlated with temperature; larger organisms produced during the summer months. More organisms settled on plates inside the bay on Miami Beach, with less productivity at the site nearest the ocean inlet. On Tahiti Beach (mainland shore), calcareous tube worms (*Hydroides* spp.) dominated during spring and fall peaks, and barnacles there were usually small with a high mortality rate. Heavy fouling was associated with poorly mixed bay waters, in locations with large fouled surfaces adjacent, where tidal currents are 2-3 knots and in moderately polluted water.

Stephenson and Stephenson (1950) produced a seminal work on the intertidal zonation in the Florida Keys, including sites in BNP (Elliot Key and Soldier Key). They defined zonation by color of each intertidal level and described the species and their relationship to the underlying rock and sedimentary structures. Rocky shorelines, including in BNP, exhibited the same patterns seen elsewhere in the tropics, but with the following differences:

- The supralittoral fringe (in connection with the wide, almost flat, upper platforms on many of the keys) is unusually well and conspicuously developed, is more or less invaded by land plants, is divided into subzones and has a varied population of snails.

- The midlittoral zone, covering the rather abrupt transition from the upper to the lower platform, is rather narrow (tidal range is small) and locally possesses a normal complement of barnacles. Its division into subzones is typical.

- The infralittoral fringe is weakly developed, though quite recognizable, and lacks substantial growth of coral. Its population differs from that of the infralittoral fringe on a coral slope exposed to deeper and more open water with less sediment, in the same way as, in any temperate region, the population of rocks in a shallow sandy inlet where wave-action is somewhat reduced differs from that at the tip of the rocky headland, sloping to a reasonable depth and exposed to strong wave-action.

- The high-level Myxophycean zone is well-marked and forms a subzone of the supralittoral fringe.

- The covering of encrusting *Lithothamnia* on open rock, commonly found at low levels, is almost suppressed.

- Organic production between tide-marks is apparently low, though the number of species present is considerable.

- Seasonal variation affects at least the more ephemeral algae, but only at one season (January to March). There must also be seasonal changes affecting animals such as *Chthamalus*.

Iversen and Roessler (1969) examined the biota and sediments of Card Sound in March to May 1969. They found the Sound to be well mixed in physical characteristics, with little substrate suitable to microscopic species. The species they did collect suggested that Card Sound had a low standing crop when compared to portions of Florida Bay and central Biscayne Bay. Within the Sound, they found the banks and nearshore areas more productive than the deeper center. In total, they found 50 species of invertebrates and 12 species of fish, and concluded the sound had low organic productivity.

Kolipinski and Higer (1970) used multiband imagery of Biscayne Bay to define spatially significant shoreline and benthic communities. Roessler et al. (1971, 1972) reported on their study of the fish and benthic animals in south Biscayne Bay near Turkey Point and Card Sound. University of Miami (1971) also looked at the effects of heated discharge from Turkey Point into south Biscayne Bay and Card Sound. They listed benthic fauna adjacent to the power station. Turkey Point's cooling canals were opened to the bay in April 1972. Berkeley, (1972) studying two species of gastropod in South Biscayne Bay near Turkey Point, concluded temperature and salinity were not limiting, but that the factor controlling abundance and distribution was the amount of benthic algae with a special affinity for *Laurencia poitei*.

Voss (1973) produced an environmental impact study of the area around Watson Island turning basin and reported severe degradation of the mostly dredged substrate. Degradation of the benthic communities resulted from high turbidity, sunken debris and garbage and eutrophied bottoms in the case of dredged substrates, and an adverse impact on both the benthic community and fishery were documented. Cole (1974) studied the Cutler Power Plant's thermal stress effect on benthic foraminifera in the adjacent dredged lagoon for a master's thesis. A high number of deformed forms were found, and a single species dominated the population. Brook (1975, 1977) conducted his dissertation research in Card Sound near Arsenicker Key, studying the relationship of *Thalassia* to higher trophic level consumer species. He found that polychaete worms and peracaridean crustaceans were the preferred food of the foraging fish species examined, and noted that the feeder abundance was low in line with the low abundance of the food species. Goldstein (1976) conducted research on the distribution of benthic foraminifera adjacent to Turkey Point, with 67 species from 37 genera identified; these showed patterns he associated with physical and chemical changes related to water depth. Rosenberg (1975) noted changes in benthic fauna from an earlier study of two sites near Key Biscayne. Changes were noted in species abundance, biomass, diversity and spatial distribution. Slow speciation with low diversity was attributed to low temperature in winter, elevated turbidity and anthropogenic stress. Voss (1976) summarized the state and health of the invertebrate communities and discussed some of the anthropogenic stressors.

Eichler's (1977) studied infaunal assemblages in *Thalassia testudinum* beds near Key Biscayne and Virginia Key and identified 109 species with polychaetes, amphipods, bivalves, gastropods, isopods and sipunculids dominating the collection. Rice (1978) used monthly samples of the benthos of the Safety Valve found seasonal variations in the infaunal assemblage and reported a correlation between species diversity and the dominant bivalve *Tivela floridan*. Tilmant (1979) documented damage to hard bottom communities in the park by shrimp roller trawls, including damage and displacement of corals, damage to sponges, uprooting of gorgonians and damage to algal colonies and *Sargassum*, with effects lasting well beyond the termination of trawling mandated by law. Brook (1981) examined several benthic communities located along the mainland shore of the park for salinity-driven affects. Dennis (1981) studied benthic harpacticoid copepods near Turkey Point and examined the role of *Syringodium filiforme* and sediment stability on this community. Sediment composition was affected by the grasses. Brook (1982) studied seagrass beds affected by the controlled freshwater discharge from the Mowry and Moody canals and found a change from amphipods to molluscs at the Moody site, with less impact at the Mowry site, which he attributed to higher diversity, adding resiliency and an overall slight decrease in abundances attributed to discharge conditions at both locations.

Montague et al. (1995a) compared the population density of the sea urchin *Lytechinus variegatus* to seagrass standing crop at Bear Cut, Crandon Park and Virginia Key. Montague et al. (1995b) and Montague et al. (1988) also studied various aspects of the urchin community in the same areas. Cox et al. (1996) studied the spiny lobster in Biscayne Bay and other locations, including the reef tract. Lobsters food types were dominated by molluscs, chitons and crabs, with bivalves less common than gastropods. Maciá and Irlandi (1996) studied salinity fluctuations on the benthic gastropod *Astraea tecta* and the echinoderm *Lytechinus variegatus* produced by episodic canal discharge, and proposed that species distributions were controlled by the severe salinity changes documented. Ishman et al. (1997) studied the benthic foraminifera of Biscayne Bay with surface samples taken from North Bay to Manatee Bay, including seven sites inside BNP. They collected 69 taxa common to this area and calculated a species diversity range of 0.080-0.493 (Simpson's index). Calcareous forms dominated, with agglutinating forms being minor. Certain forms of *Ammonia parkinsoniana* and *Elphidium galvestonense mexicanum* were found dominant in restricted regions and *Archaias angulatus* dominated open regions. They were able to identify three distinct assemblages; these were the *Ammonia-Elphidium*, *Archaias*-milliolid and *Bolivinid* assemblages. Of these, the *Archaias*-milliolid assemblage, was dominant in BNP surface sediments, the other two being from more restricted environments, with the last type found only in northernmost Biscayne Bay where there are organic-rich diatomaceous muds.

Ishman (2001) describes four benthic foraminifera assemblages from surface sediment samples taken in Biscayne Bay. He found that the assemblages were controlled by salinity, substrate and organic inputs, with two associated with open circulation, one with oligohaline to polyhaline salinity in restricted areas and one with high plankton productivity and organic inputs. Vittor (2001) studied the macro-invertebrates in South Biscayne Bay within the park and in Manatee Bay. Samples collected in December 1999 were analyzed for species and abundance, compared with some physical properties and richness values calculated. Biscayne Bay samples had 13-96 taxa, with fewer taxa found in samples closer to the mainland. Organism density ranged from 1,075-24,725 organisms/m^2. Calculated taxa diversity ranged from 1.62-3.65 and taxa evenness from 0.56-0.88. Most abundant taxa included the gastropod *Caecum pulchellum*, the malocostracan, *Hargeria rapax*, and two polychaete worms, *Exogone rolani* and *Fabricinuda trilobata*. The most widely distributed organisms were *Hargeria rapa* and the annelid family Tubificidae, found at 95 percent of the stations. The assemblage in nearshore stations was discovered to be more estuarine in character.

Ishman (2002) used sediment samples and cores to examine the historical changes in the benthic foraminifera communities in south Florida. He reported that prior to the mid-1800s, the bay was oligohaline with an increase to brackish to mesohaline during the early 1900s. Increasing salinity after 1910 (attributed to the railroad's arrival), produced a bay that was euhaline by 1940, with fluctuations related to water management practices. Salinity in the south end of Biscayne Bay and the two sounds increased further with the construction of C-111 canal, which cut off much sheet flow in that area. Schroeder (2003) conducted a benthic sampling program covering most of Biscayne Bay, including portions in BNP. Sixty stations were visited in Phase 1, followed by dredge sampling at 15 sites based on the initial survey. Data showed the benthic organisms were most stressed when there are extremes of temperature and salinity. *Syringodium filiforme* had a more diverse associated fauna than other grass types, which suggested that it would be a good candidate for further study and possibly for restoration efforts.

1989-1993: USGS maintains the dbSEABED data set compiled from numerous research projects (http://pubs.usgs.gov/ds/2005/118/index.html). Primarily a geological data source with emphasis on bottom types and grain size, the records include a number of benthic observations presented in a numerical format, which can be parsed for observations made during the original research. The principal dbSEABED sampling sites in BNP include north-central portion of the Park from Featherbed Bank to the north boundary. The CMP and PRS files comprise 182 samples in BNP; the FAC file has 74 samples taken from the Smithsonian Institution's unpublished master sediment data file attributed to a sampling program dating from October 8, 7 and 10, 1993 in the park area. The CLC file (186 samples listed) shares the sites above, but includes nine additional samples from two sites (located just offshore of Black Creek) by National Status and Trends Program Mussel Watch from 1989-1990.

Crustaceans found in BNP include crabs, shrimp and lobsters (Table 11). Food species include the giant land crab, blue crab, Caribbean spiny lobster and the stone crab. Taking the giant land crab is prohibited, which is noted by a single sign at the park entrance, but as some seasonally migrate across unpoliced roads outside the bark boundary during mating season, animals can be poached. Species that can be taken that require permits include blue crabs, for which trapping is year round, but the number of traps is limited and daily catch is restricted. A 10-day closed season for blue crab now in effect has been valuable for removing derelict crab traps. The spiny Lobster are harvested as adults in a controlled season (August 6 to March 31) on the ocean side of the islands, and legal lobster catches can be transported across park waters if specific conditions are met. Park rangers monitor this behavior during lobster season. The highly prized stone crab is also harvested in the park and harvest is controlled; take of claws is only allowed during the "Open Season" from October 15-May 15. Egg-bearing female crustaceans (of any type) are not allowed to be taken at any time. Shrimp take is limited per day as by state rules and all forms of recreational fishing require a Florida fishing license.

Table 11. Principal crustaceans found in Biscayne National Park (NPS data).

Scientific Name	Common Name	Scientific Name	Common Name
Callinectes sapidus	Blue crab	*Panulirus guttatus*	Spotted spiny lobster
Cardisoma guanhumi	Giant land crab	*Petrochirus diogenes*	Giant hermit crab
Coenobita clypeatus	Hermit crab (terrestrial)	*Scyllarides aequinoctialis*	Shovel-nose slipper lobster
Panulirus argus	Caribbean spiny lobster	*Scyllarides nodifer*	Slipper lobster

Molluscs are a major group in BNP with importance as food for humans and many other species. Appendix A Table A6 is a list of shelled molluscs in the park or vicinity. Unshelled molluscs include squid and octopus, both of which are primary predators and are consumed themselves by larger organisms. Shelled molluscs provide habitat and sediment after death and breakdown of the shell into smaller particles. Shells can be a home (e.g., hermit crabs) or a convenient place for a sessile organism to attach. Sponges, barnacles and other species are found on large shell fragments. Molluscs provide the scientist with environmental information as they often have specific ranges or salinity tolerance, and some species are sampled for polluting compounds in their tissues.

Insects are the largest group of animals in BNP. Visitors may only remember the mosquitos and fire ants or the gnats (locally known as “no-see-ems”), but there are many genera including those that are very beneficial. Butterflies, dragonflies, moths, tree hoppers and ants abound, and many are important to the overall health of the park. For example, pollinating species are essential in many plant communities. Detrimental insects are a problem for vegetation or other animals. Detrimental insects include exotic species, many of which have been introduced to South Florida by hitching a ride on ships or on imported products, especially plant materials.

Butterflies are important indicators of the health of the environment. Because many species are associated with particular plant types, the type and diversity of the butterfly population can indicate the state of the environment. Butterflies are pollinators, which makes them important to many of the park’s plant communities. Scientists have tried to improve stocks of plant varieties attractive to beneficial butterflies, and have attempted to introduce at least one form native, the Miami Blue butterfly. Appendix A Table A7 has a list of butterfly species known from South Florida, most of which are assumed to be in the park.

Arthropods include spiders, scorpions, millipedes, centipedes and horseshoe crabs. All are important members of the ecosystem with the marine dwelling horseshoe crab of particular concern, as the sedimentary environment it prefers is both scarce in much of Biscayne Bay, and threatened by anthropogenic changes in the environment.

Fishes

The fisheries in BNP includes commercial and recreational fishing including: “bonefish, snook, tarpon, permit, pink shrimp, spotted seatrout, oysters, clams, blue crabs and stone crabs, bait fishes; and, numerous coral reef fishes that include snappers, groupers, grunts, barracuda, spadefish, spiny lobster, parrotfish, surgeonfish and triggerfish” (Ault et al., 2001). The health of fishery is important economically as a principal draw for park visitors, and has impacts on the health of other biotic components, such as reefs and seagrass communities. Degradation of the fishery, by whatever means, also impacts adjacent areas as many species are migratory or are moved to adjacent waters by oceanographic processes. Fish diversity is lowest on the west side of Biscayne Bay near canal discharges and highest along the eastern reef tract. Many species occur in all marine habitats, which suggests interconnectivity between inshore areas and offshore fisheries. A representative list of fish species (298) in park waters is included in Appendix A Table A8, and Ault et al. (2001) has a more extensive list of 325 species.

Miller (1940) described the effects of a severe cold snap in January of 1940 that killed or stunned many fish species in nearshore habitats. He reported that weather at or below freezing on land produced water temperatures of 51-55ºF which severely affected the fish population. Smith (1945) examined spiny lobster fishing in South Florida and discussed suggested changes to the then current fishing restrictions. Smith (1948) described attempts to aquaculture sponges in Biscayne Bay. A University of Miami (1952) report examined fishing take throughout Florida in 1951, with details of species caught in Miami-Dade County. Cohen (1953) reported fishing take for 1952 in a similar manner. Greer (1954) followed with data on take for 1953. Siebenaler (1953) described the commercial fisheries of Biscayne Bay and compared results by fishing technique. He reported that during the two years studied (1951-52) mullet represented about 98 percent of the fish taken. Eldred (1960) described the two principal species of shrimp from Biscayne Bay and first reported the presence of *Penaeus brasiliensis*.

Idyll (1968) examined the commercially valuable fisheries in Biscayne Bay. Table 12 shows some of the species taken for the aquarium industry. Figure 61 shows the principal fishing areas defined in this report. Eldred et al. (1972) studied juvenile spiny lobsters (*Panulirus argus*) in Biscayne Bay. Roessler et al. (1972, 2002) conducted extensive biological surveys for a thermal pollution study done around Turkey Point, which includes considerable fishery data from 1968-1973. Berkeley (1983) conducted a fisheries assessment of Biscayne Bay covering the 1982-1983 periods, which included areas in the park. Sutherland and Harper (1983) examined the wire fish-trap fishery of South Florida for the years 1979-1980 with catch data including mortality statistics for a number of caught reef fish species in the area near Key Biscayne.

McKinley (1995) examined penaeid shrimp abundance in Biscayne Bay in areas close to significant anthropogenic alterations of the western coastline habitats (water quality near canals and bulkheads), and found little effect due to water quality or elevated salinity and was unable to confirm that undeveloped areas produce more shrimp, as has been reported elsewhere. Bello (1997) examined penaeid shrimp species passing through Bear Cut and discovered additional species. Serafy et al. (1997) found increased abundances of some fish species near or in canal mouths in the bay, which suggested that salinity was a controlling factor. Bohnsack et al. (1999) compiled some baseline fish data for the Florida Keys National Marine Sanctuary and the offshore reef areas of BNP. Serafy et al. (1999) reported negative results of juvenile red drum (*Sciaenops ocellatus)* releases into Biscayne Bay, which were apparently eaten by barracuda and needlefish. Ault et al. (1999) developed a multi-stock model of the fishery in Biscayne Bay. Humston et al. (2004) studied movement and growth of fish stocks in Biscayne Bay using models. Humston et al. (2005) used acoustic techniques to track bonefish (*Albula vulpes*) in the area south of Old Rhodes Key and Ault et al. (2007) tagged bonefish and tracked them with an acoustic array located east of Elliott Key to determine the viability of this method for studying fish stocks and behavior. Johnson et al. (2007) reported on the commercial fishery landings in Southeast Florida, including portions of BNP.

Table 12. Important aquarium fish species in Biscayne Bay (Idyll, 1968).

Common Name	Scientific Name
Blue striped grunt	*Haemulon sciurur*
Parrotfish	*Pseudoscarus coelestinus*
Rainbow parrotfish	*Pseudoscarus guacamania*
Green parrotfish	*Sparisoma virlde*
Blue parrotfish	*Scarus caeruleus*
Striped goby	*Garmania macrodon*
Fat goby	*Gobiosoma robustum*
Whitehurst's jewfish	*Opisthognathus whithursti*
Pike blenny	*Chaenopsis ocellata*
Hairy blenny	*Labrisomus nuchipinnis*
Marbled clinid	*Paraclinus marmoratus*
Banded clinid	*Paraclinus rasciatus*
Sea robin	*Prinotus scitulus*
Clingfish	*Gobiesox strumosus*
Cowfish	*Lactophrys tricornis*
Smooth trunkfish	*Lactophrys trigonus*
Brown demoiselle	*Pomacentrus fuscus*
Mapo	*Bathygobius soporator*
Blue tang	*Acanthurus caeruleus*
Ocean surgeon	*Acanthurus bahianus*
Doctor fish	Acanthurus chiturgus
Fringed filefish	*Monacanthus hispidus*
Hairy filefish	*Monacanthus ciliatus*
Spiny boxfish	*Chilomycterus schoepfi*
Queen angelfish	*Holacanthus ciliatus*
Blue angelfish	*Holacanthus isabellita*
Black angelfish	*Holacanthus aureus*
French angelfish	*Holacanthus paru*
Foureyed butterflyfish	*Chaetodon ocellatus*
Butterflyfish	*Chaetodon capistratus*
Butterflyfish	*Chaetodon stratus*
Two lined cardinalfish	*Apogon binotatus*
Spotted cardinalfish	*Apogon maculatus*
False spotted cardinalfish	*Apogon pseudomaculatus*
Conchfish	*Apogonichthys stellatus*
Variegated wrasse	*Halichoeres garnoti*
Pudding wife	*Halichoeres radiata*
Blue head	*Thalassoma bifasciatum*

Table 12. Important aquarium fish species from Biscayne Bay (Idyll, 1968) (continued).

Common Name	Scientific Name
Dwarf wrasse	*Doratonotus megalepis*
Dusky squirrelfish	*Holocentrus vexillarius*
Sergeant major	*Abudefduf saxatilis*
Rock sergeant	*Abudefduf taurus*
Spotted moray	*Gymnothorax moringa*
Green moray	*Gymnothorax funebris*
Round stingray	*Urolophus jamaicensis*
Spotted moray	*Gymnothorax nigromarginatus*
Dwarf seahorse	*Hippocampus zosterae*
Smooth puffer	*Spheroides spengleri*

Biscayne National Park waters and watershed are included in several NOAA designated Essential Fish Habitat (EFH) that have been designated along the southeast coast. EFH has been designated for penaeid shrimp, spiny lobster, snapper and grouper, migratory pelagic fish with shallow water life stages and coral reefs/hardbottom. Under EFH, regions with special importance for the health of a particular fishery can be designated as Habitat Areas of Particular Concern (HAPC). All of BNP is within the footprint of one or more EFHs and HAPCs (Figures 62-65).

Commercial fishing for live bait shrimp dates from the early 1950s. Two principal species are fished, *Penaeus duorarum* and *Penaeus brasiliensis* (Eldred, 1960), comprising about 95 percent of the shrimp species taken in samples. Campos and Berkeley (1986) determined that *Penaeus* bait shrimp spent approximately 21 weeks inside Biscayne Bay. January was the month of greatest abundance and lowest was in May; western Bay areas produced higher shrimp abundances than those found in the eastern Bay. They calculated mortality rates by sex and concluded that more shrimp left the bay (emigration) than were taken by the bait industry at that time. Commercial fishing was calculated to take less than 10 percent of the shrimp stock during peak months (Campos and Berkeley, 1986). Juvenile shrimp are less abundant in the area south of Turkey Point; this is thought to be caused by extensive hard-bottom and fluctuating releases of freshwater from nearby canals (RECOVER, 2007).

The snapper/grouper complex comprises 73 species of fish dominated by the groups that give the complex its name. The complex includes hogfish, grunts, porgies and jacks and has been overfished historically. Certain species are more sensitive to overfishing and many play important ecological roles on the reefs. Harvest of too many fish in this category can affect reef health and may alter or undermine other ecosystems inhabited by the fish (Ault et al., 2005). Figure 66 shows the life cycle-ontogeny relationship of the snapper/grouper complex.

The rainwater killifish, an estuarine species, is the most abundant fish along the west shoreline of Biscayne Bay, and three other fish species (gray snapper, spotted seatrout and pink shrimp) are economically valuable and important to the ecosystem. All show changes in abundance and distribution with changes in salinity and are used in monitoring programs, although the relationships are not always clear (CERP, 2007).

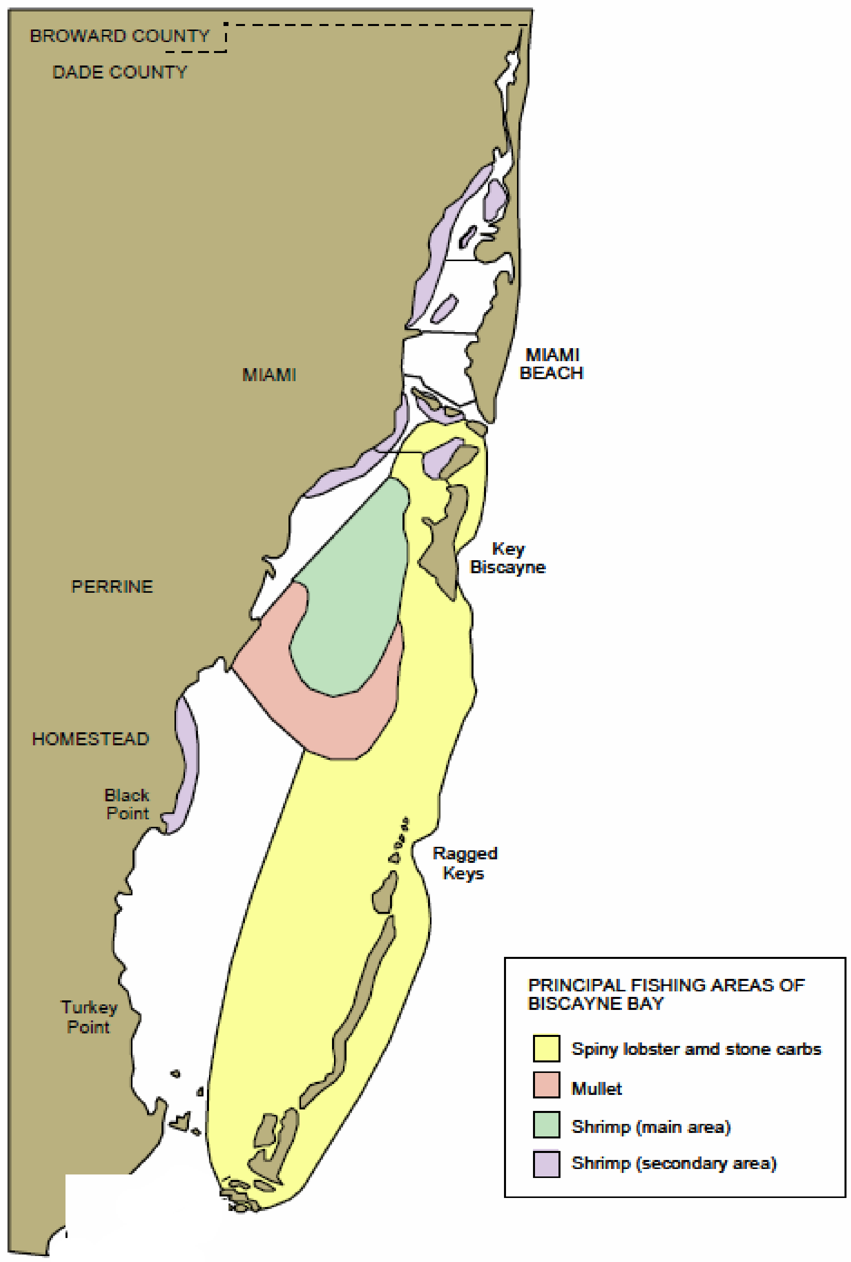


Figure 614. Historical fishing areas in Biscayne Bay (Idyll, 1968). Map is outdated because lobster fishing is now limited to the Biscayne Bay lobster sanctuary and offshore areas only.

Continuing coastal development and the associated stressors which affect water quality also impact important fish groups. This can occur in the nursery areas inshore, such as the mangrove fringe where juveniles mature or offshore where turbidity, sediment pollution or nutrient loading can occur. The management of freshwater delivery to the coast was shown to affect these populations as timing, quality and quantity of water delivered impact the success of fish that spend some part of their life in inshore areas. Future water management decisions have the potential to either improve or degrade fish stocks (Ault et al., 2005).

Figure 62. Essential Fish Habitat (EFH) and Habitat Areas of Particular Concern (HAPC) for Penaeid shrimp in Biscayne National Park. Note that coastal marshland is included in EFH, but HAPC is confined to the waters of Biscayne Bay (Data from NOAA National Marine Fishery Service).

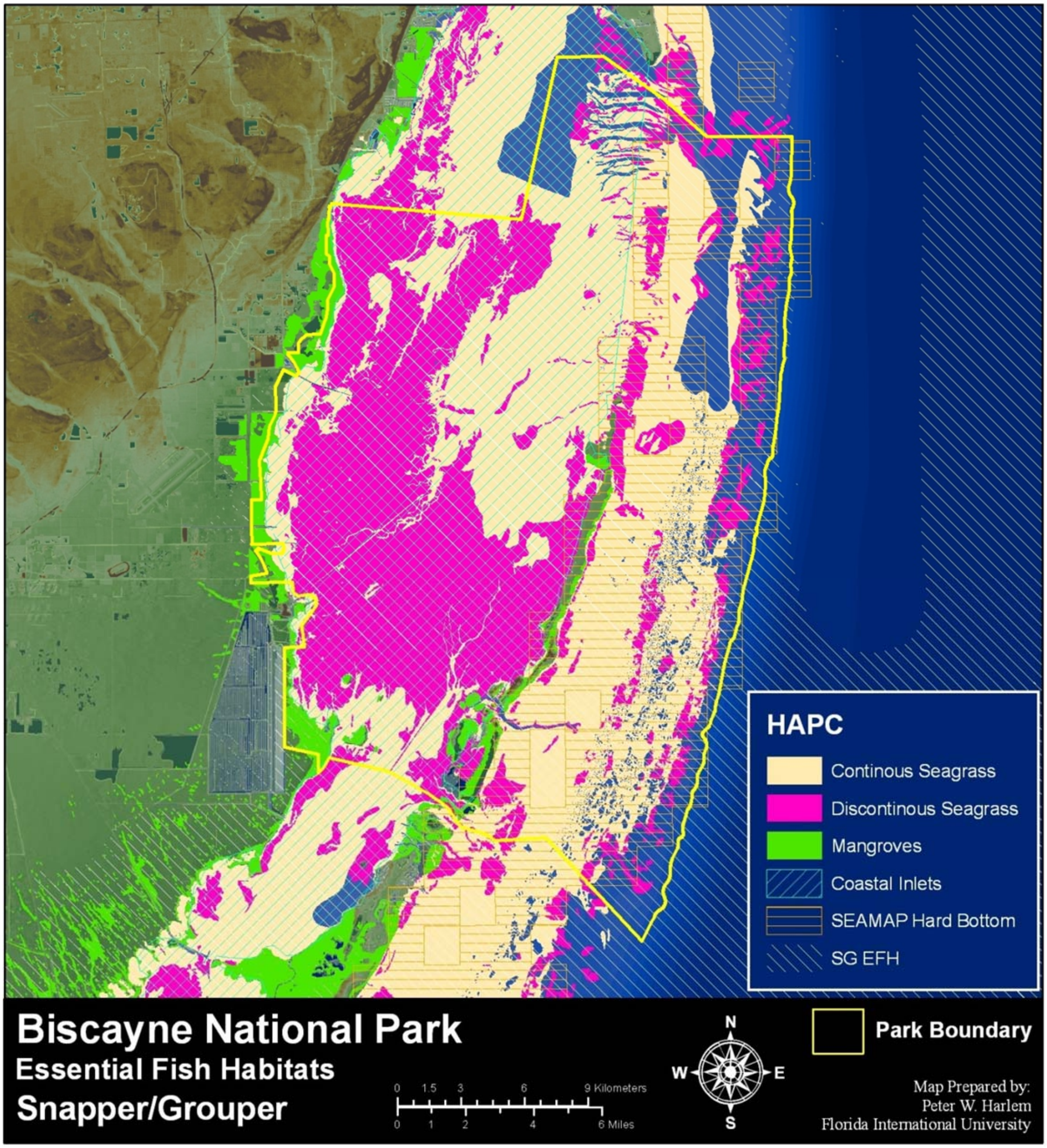


Figure 63. Essential Fish Habitat (EFH) for the Snapper/Grouper complex. Two types of seagrass covered bottom, coastal mangrove swamps, coastal inlets through the keys and islands and the hard bottom areas offshore are defined as HAPC for this group. The EFH includes coastal marsh areas and deeper waters offshore of the park (Data from NOAA National Marine Fishery Service).

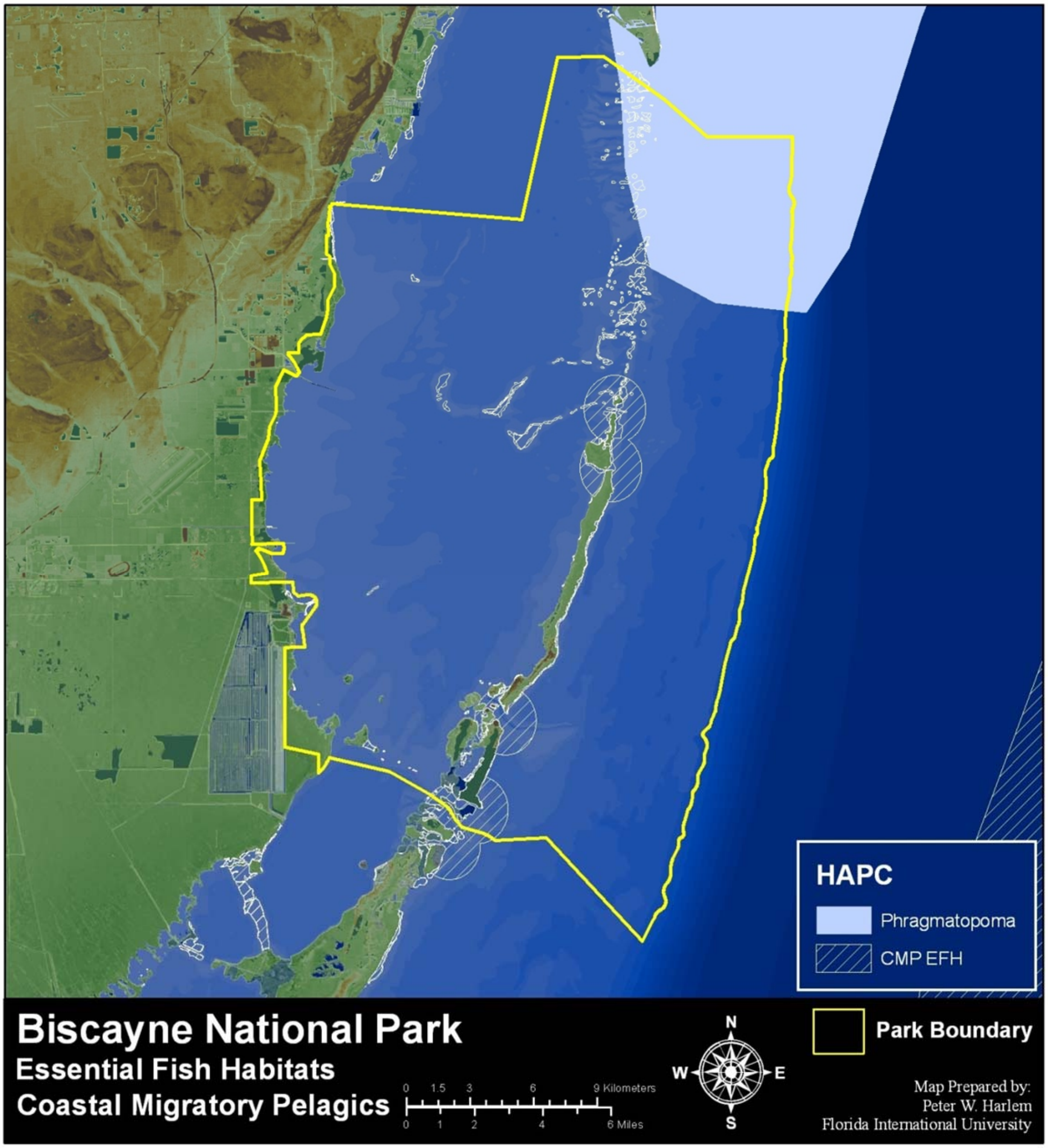


Figure 64. Essential Fish Habitat (EFH) for migratory pelagic fish, which includes shoal areas within Biscayne National Park (BNP) and the inlets between the islands. The Habitat Areas of Particular Concern (HAPC) for this group is for the area where *Phragmatopoma* worm reefs may be found, a species important to the migratory group and which includes the NE corner of BNP (Data from NOAA National Marine Fishery Service).

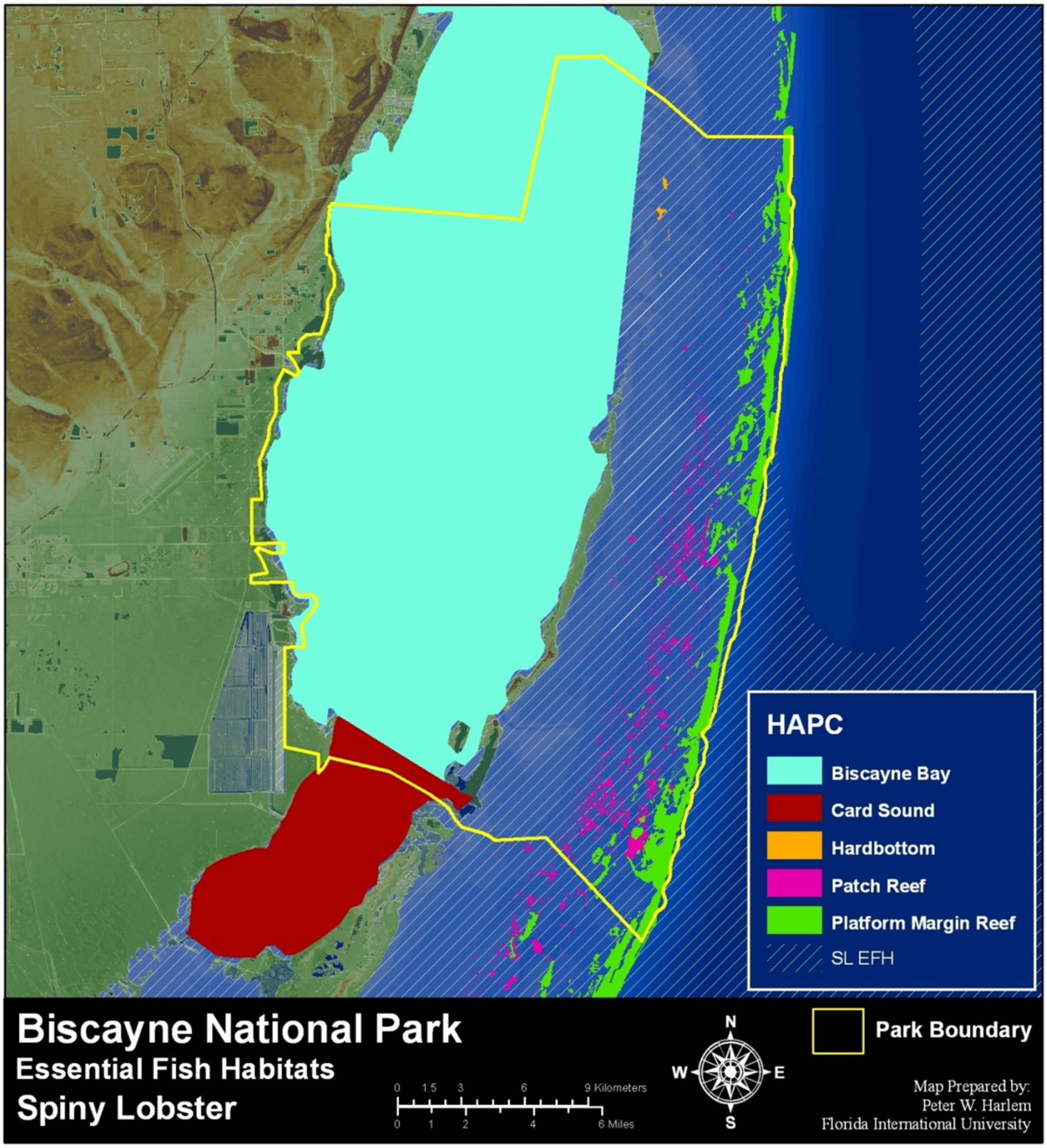


Figure 65. Essential Fish Habitat (EFH) and Habitat Areas of Particular Concern (HAPC) for spiny lobster. The EFH covers the entire park area, while the HAPC are divided between Biscayne Bay and Card Sound and the offshore reef and patch reef areas. The hardbottom HAPC is found only in a small area at the NE portion of the park (Data from NOAA National Marine Fishery Service).

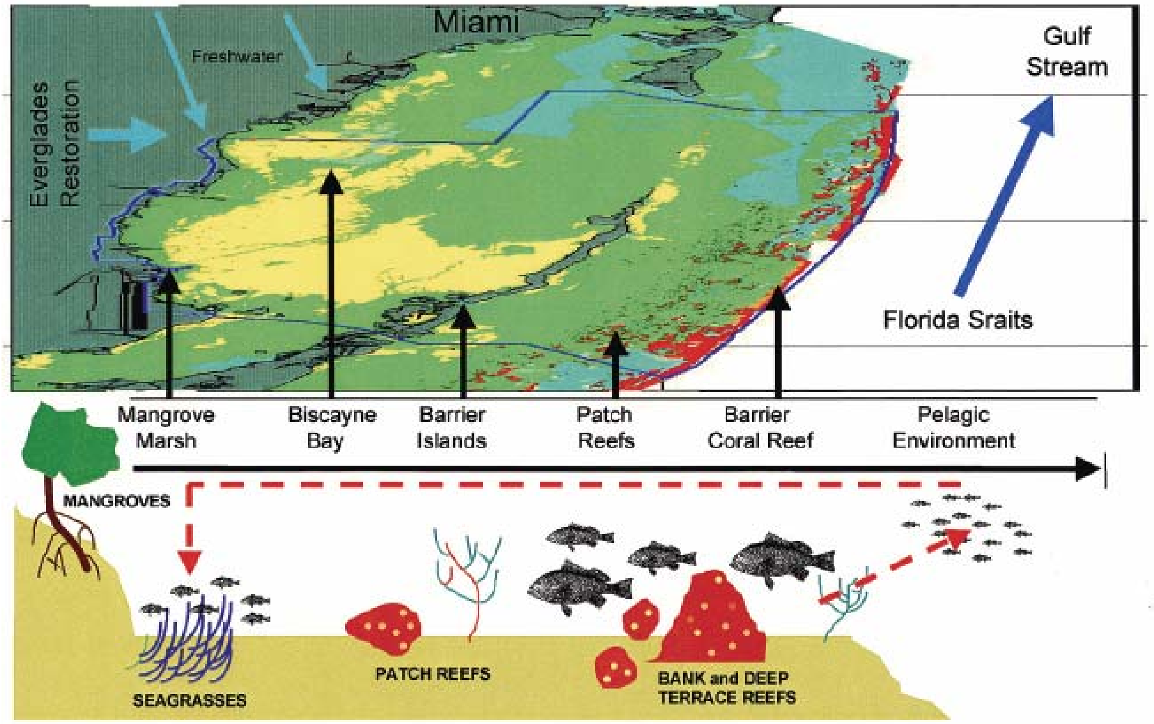


Figure 56. Snapper/grouper complex life cycle relationships. This diagram shows how the group moves through Biscayne National Park via many of its marine environments (Figure 5 from Ault et al., 2005).

Fish are impacted by food availability and by predation by larger species, both of which can affect the stocks of important fish types. The extensive harvest of pink shrimp at different life stages (juveniles in the bay or adults offshore), as well as smaller bait fish, removes prey, while harvest of predator fishes removes controls on fish populations, which can become unbalanced.

Many valuable fishery species are in general decline compared to historical data; those that inhabit the former estuarine zone along the coastline have to deal with wide fluctuations in salinity (CERP, 2007) resulting from diversion of natural flows into controlled canals (Meeder et al., 1999, 2001). Adult oysters, which were found at the mouths of tidal creeks with freshwater outflow, are largely absent from the system. Estuarine fish (e.g., redfish), and shellfish dependent on intermediate ranges of salinity, have declined substantially; attempts to restock red drum have failed because of unstable estuarine conditions inshore (Serafy et al., 1996, 2003). Figure 67 shows the diversity patterns for fish in the park as determined from TRAWL and RVC sampling methods.

Ault et al. (2001) made the following observations on long-term trends:

- Many exploited species of fish are the same size as those taken in the past.
- Black grouper average size is now 40% smaller than in 1940; spawning stocks are less than 5% of historical values.
- Of 35 species capable of being analyzed, 77% are overfished as determined by spawning potential ratios.

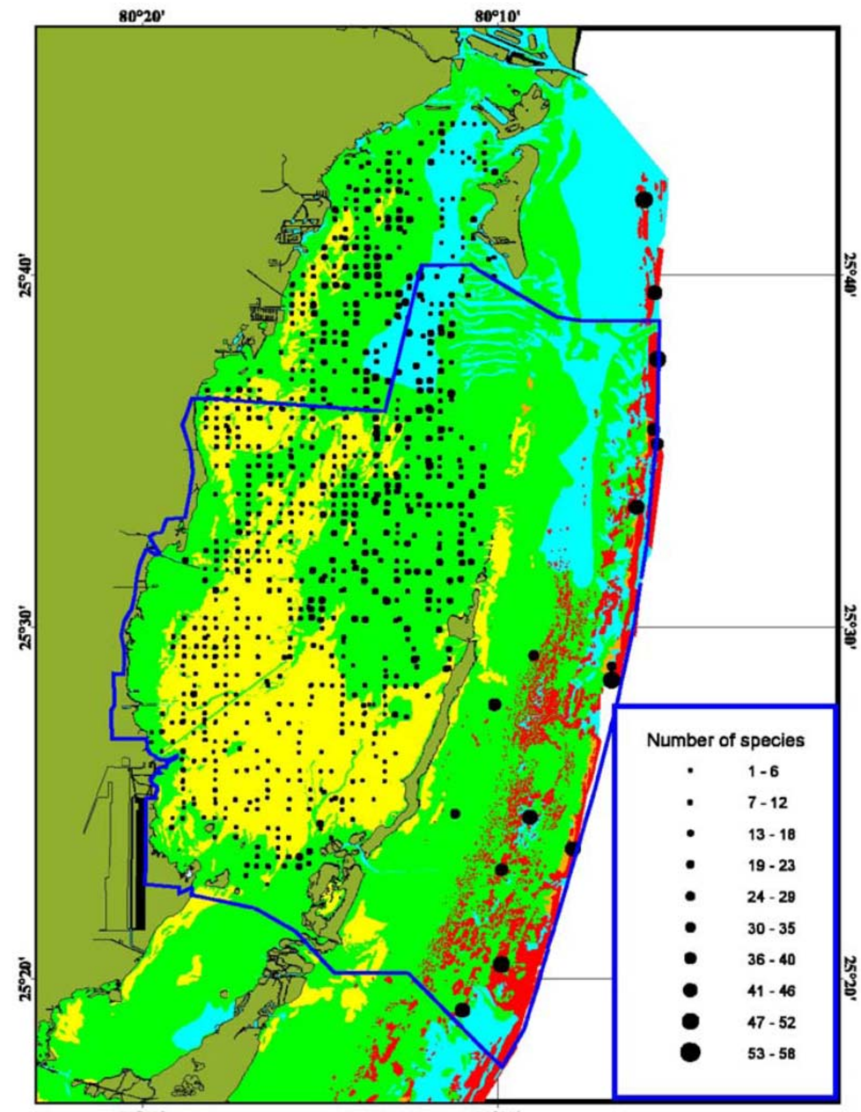


Figure 67. Number of species by sampling site for benthic habitats in Biscayne National Park. Data from TRAWL and RVC sampling methods. Red is coral reefs, green is seagrass and yellow is hardbottom (Figure 5 from Ault et al., 2001).

- Some stocks have been chronically overfished since the late 1970s, producing critically low stock biomass. Grouper are cited as an example.

- "Serial overfishing" of key fishery resources has emphasized smaller, less desirable species, which have become more common as larger fish have been eliminated.

- Numbers of recreational fishing boats and increases in technological tools to catch fish have increased the fishing pressure on the resource dramatically.

- Undersized fish takes, and poaching of protected species and sizes, can be as high as 70% of the fish caught. Ignorance of fishing laws contributes to this problem.

- Enforcement of fishing regulations is insufficient to discourage poaching.

- BNP reef fish resources are extremely poor relative to other reef areas in South Florida and may be close to eminent resource collapse.

- Thirteen of 35 species analyzed have minimum size standards at or below the size required to spawn.

- Many important frequently-taken species' catches are not well documented, while others are not monitored at all. Included are tarpon, bonefish and permit, as well as commercially taken, juvenile pink shrimp and spiny lobster, blue crab and stone crab.

- Fisheries are not sustainable in BNP under present levels of exploitation, which impacts stock status and habitat quality.

Controls placed on fishing behaviors, such as size, equipment or number limits, have not improved the situation; direct controls combined with no-fishing zones are likely the best way to maximize remaining stocks. Ault et al. (2001, 2005) suggested this, also suggesting that management practices that reduce fishing-related fish mortality are a priority for a sustainable fishery. They suggest that if the fishing-related losses were reduced to zero, it would take 10-20 years for the snapper/grouper complex to recover. Increasing human population increases fishing for target species, prey and bait fish, which will only make recovery times longer as the population of Miami-Dade County continues to grow. Table 13) is a preliminary list assembled by NPS of marine and estuarine fish stocks that are at risk and/or endangered.

The impact of sea level rise on fish stocks is unknown. The physical changes associated with a rising ocean will affect benthic communities and the fish which rely on them, as well as cause human reactions in coastal zones, which are both likely to be negative and generally unpredictable. Sea level rise will push the estuarine zones landward or eliminate them entirely, which is likely to aggravate the already distressed conditions.

The National Park Service has developed a Fisheries Management Plan with cooperation from Florida Fish and Wildlife Conservation Commission, the agency tasked with regulatory control over the fisheries. The plan has been through a 60-day comment period and meetings with the public and stakeholders in September 2009. The goal of the plan is to protect existing fisheries and extend fishing experiences well into the future. Plans to improve the timing and delivery of freshwater by diverting canal water into coastal marshes and creeks in the near future are based on the idea that recreating nearshore estuarine salinity patterns will improve the populations of estuarine fish, crustaceans and shellfish (RECOVER, 2007).

Coral Reefs

The reefs inside Biscayne Bay and along the offshore reef tract are critical for biological productivity and are an economical engine for the region by drawing thousands of users to the area. They are currently under threat from sea level rise, climate change induced heat threat, contamination from aerosols and overuse or damage by visitors. In total, BNP has 291 km^2 of coral reefs (Andrews et al., 2005).

Table 13. Vulnerable, threatened and endangered Fishes in Biscayne National Park (Ault et al., 2001). Species in blue are threatened; species in red are endangered, species in bold are Protected under U.S. and Florida Law.

Family	Common Name	Scientific Name
Acanthuridae	Gulf surgeonfish	*Acanthurus randalli*
Balistidae	Queen triggerfish	*Balistes vetula*
Carcharhinidae	Blacktip shark	*Carcharhinus limbatus*
Carcharhinidae	Dusky shark	*Carcharhinus obscurus*
Centropomidae	Swordspine snook	*Centropomus ensiferus*
Centropomidae	Fat snook	*Centropomus parallelus*
Centropomidae	Tarpon snook	*Centropomus pectinatus*
Gobiidae	Spot-tail goby	*Gobionellus stigmaturus*
Gobiidae	Orangespotted goby	*Nes longus*
Labridae	Hogfish	*Lachnolaimus maximus*
Lutjanidae	Mutton snapper	*Lutjanus analis*
Lutjanidae	Cubera snapper	*Lutjanus cyanopterus*
Myliobatidae	**Spotted eagle ray**	***Aetobatus narinari***
Pristidae	Smalltooth sawfish	*Pristis pectinata*
Scaridae	Scarus guacamia	*Rainbow parrotfish*
Sciaenidae	Blue croaker	*Bairdella batabana*
Scombridae	Bluefin tuna	*Thunnus thynnus*
Serranidae	Speckled hind	*Epinephelus drummondhayi*
Serranidae	Yellowedge grouper	*Epinephelus flavolimbatus*
Serranidae	Goliath grouper	*Epinephelus itajara*
Serranidae	Marbled grouper	*Epinephelus inermis*
Serranidae	Warsaw grouper	*Epinephelus nigritus*
Serranidae	Snowy grouper	*Epinephelus niveatus*
Serranidae	Nassau grouper	*Epinephelus striatus*
Serranidae	Blue hamlet	*Hypoplectus gemma*
Serranidae	Black grouper	*Mycteroperca bonaci*
Serranidae	Yellowmouth grouper	*Mycteroperca interstitialis*
Serranidae	Gag grouper	*Mycteroperca microlepis*
Serranidae	Scamp	*Mycteroperca phenax*
Syngnathidae	Fringed pipefish	*Anarchopterus cringer*
Syngnathidae	Lined seahorse	*Hippocampus erectus*
Syngnathidae	Longsnout seahorse	*Hippocampus reidi*
Syngnathidae	Dwarf seahorse	*Hippocampus zosterae*
Syngnathidae	Opossum pipefish	*Microphis brachyurus*

Marzelek et al. (1977, 1984) conducted the first spatial survey of the Florida Reef tract. They mapped the distribution of reefs in Southeast Florida from Key Biscayne to the Dry Tortugas (Figure 53). Their report provides general information about the location and dimensions of reefs in the region. They found little patch reef formation north of Elliott Key and attributed that to tidal and wind driven exchange with Biscayne Bay waters. They found good reef development at the northern end of the reef tract and attributed that to the Florida Current flowing near, and occasionally over, the outer reef area, unlike reefs to the south. Poor outer reef development north of Biscayne Bay was attributed to colder waters. Voss (1983) summarized results of reef surveys done throughout the FKNMS. He noted that the offshore reefs were generally healthy but with signs of stress; inshore patch reefs did not show signs of stress. He noted a general decline in water clarity and suggested that continued coastal development would reduce future viability.

Porter (1987) provides a good summary of the biology and environmental conditions of corals and Porter and Meier (1992) discussed two stations in BNP that were covered photographically in 1984-1991. During that period, they documented a 13-29% decline in coral species richness, with actual coral colony losses at 7.3-43.9% and concluded the reef tracts were losing corals at a rate which prevents a return to historical reef abundances.

Toscano and Lundberg (1998) used seismic and core data to examine the post-late Pleistocene sea level rise with cross sections of Carysfort Outlier and Sand Key Outlier reefs. These show how the Holocene reefs are growing over previously drowned, older, elevated reef structures. Lidz (2006) explained this relationship in greater detail and speculated that seasonally inconsistent temperatures, salinity fluctuations, high turbidity and nutrient loading have impeded recent coral growth. Porter et al. (1999) tested two possible stressors on reef systems to better understand how corals withstand assault by more than one stressor. They found that salinity or temperature extremes would affect corals negatively, and that prolonged exposure to both reduced survivability drastically. They postulate that if that relationship happens with two stressors then consideration of the many stressors which affect reef organisms is in order. They suggest sediment loading and light penetration to be critically important stressors which must be investigated more thoroughly.

Miller et al. (2000) discussed coral recruitment and juvenile mortality within the park. They found that the offshore bank-barrier reefs were depauperate in corals and with low relief; however, inshore patch reefs had greater coral cover and species richness. Their data suggested that juvenile colonies were present on offshore reefs but that large adults were not. This means that sufficient new corals are present but that few are reaching maturity in the offshore reef areas. Suggested causes were predation (by fish primarily), physical stress (abrasion, sedimentation) or temperature extremes (cold snaps). Clayton et al. (2002) reported on initial design of the Experimental Advanced Airborne Research LiDAR (EAARL) mapping pilot program, which showed promise as a management tool, however, no data was presented

Miller et al. (2002) reported general results of the Quick Look survey program of coral reefs in the Florida Keys reef tract. This included 13 survey sites along the eastern edge of BNP and others north and south of the park perimeter. They observed that coral cover was lowest in the region of the park with the patch reefs having higher mean percent cover than the offshore terrace, and spur and groove habitats. The greatest number of reef-building coral species (21) was found in the patch reefs offshore and the fewest (13-14) inshore of Triumph Reef and Fowey Rocks. Juvenile corals' densities were lower in the BNP area than along the reef tract to the south. Sponges varied from 25-43 species and gorgonians from 12-21 species, both groups were lowest near Fowey Rocks. Urchin densities were low, particularly for the formerly abundant black spine variety, *Diadema antillarum*, which suffered a die-off in the early 1980s.

Lirman et al. (2003) examined coral communities in Biscayne Bay and adjacent offshore areas. They found that temperature, sedimentation and salinity affect the abundance, diversity and distribution of corals in Biscayne Bay. Two species that were found in dense populations, *Siderastrea radians* and *Porites furcata*, and others found at lower densities, indicated that some species are adapted to extremes in the controlling conditions. *Siderastrea* was impacted by high sedimentation experimentally, and low salinity affected its growth rate negatively. Low coral density along the western shoreline was attributed to fluctuations in salinity related to periodic canal discharges. Seventeen coral species were identified, two from the western shore area, nine in central Bay areas, eight from east Bay areas, and 15 from offshore sites (keys shoreline to Hawk Channel). Coral density decreased with sediment depth; above 10-15 cm, seagrasses dominated the benthos. Boats were correlated with higher sedimentation rates and "no wakes zones" were suggested as a possible solution.

Florida Fish and Wildlife Conservation Commission (2004) has a brief on the Coral Reef Evaluation and Monitoring Project (CREMP) at FFWCC-FWRI, which includes sampling sites in the upper FKNMS. This states that from 1996-2004 there has been an overall decline in number of stony coral species at most sites. Sanctuary-wide decline is from 11.9 % cover to only 6.6%, with the first half of the time covered not significantly different from the latter half (since 1999). "In 2004, the most common stony coral species were *Montastraea annularis* (2.6%), *M. cavernosa* (1.0%), *Siderastrea siderea* (0.8%), *Porites astreoides* (0.5%), *Colpophyllia natans* (0.4%) and *Millepora complanata* (0.3%).The significant declines in mean percent stony coral cover between 1997 and 1999 were largely due to losses in *M. annularis*, *A. palmata*, and *M. complanata*. "

Brock and Wright (2004) used NASA's EAARL mapping project to measure rugosity (relief) of 15 patch and bank coral reef areas in the park in 2002. This method could show the relationship between habitat complexity and topographic complexity, which would allow rapid assessment of shallow coral reefs through time over wide areas. The area studied was along the east margin of the park due east of Caesars Creek bank. Reed (2004) examined deep reefs offshore of the Miami area. None are within BNP, but are to the east in over 200 m water on the Miami terrace. Wilkinson et al. (2004) provided a general assessment of coral reefs in Florida and reported that 1997 and 1998 were years with higher than normal bleaching. Miller et al. (2005), from the Quick Look series, documented damage from four hurricanes crossing the Florida reef tract. Hurricane damage included: scouring, sediment movement, toppling of gorgonians, sponge detachment and removal of algal communities down to bare substrate. Sediment was transported upslope covering reef areas and exposing previously buried structure.

Andrews et al. (2005) also described the state of coral reef ecosystems in Florida and noted that staghorn coral (*Acropora cervicornis*) underwent a substantial decline in 1998-1999. BNP has 291 km^2 of coral reefs. They divide coral reef habitats into three descriptive types: hardbottom, patch reefs and bank reefs. Hardbottom habitats are the most extensive, are found at a wide range of water depth and are colonized by some stony corals, octocorals, sponges and calcareous algae; colonization is controlled by local environmental conditions. Patch reefs are built of massive stony corals dominated by the star coral (*Montastraea annularis*), *Colpophyllia natans* and *Siderastrea siderea*. Patch reefs are well developed in the park from Hawk Channel to the outer reef tract with relatively high species diversity and richness. The outer bank reefs feature spur and groove (ridge and channel) morphology, formerly dominated by Elkhorn coral (*Acropora palmata*), with water depths from 10 m to a few centimeters with some areas descending down to 30 m. At about 40 m, depth sediment accumulations prevent significant reef growth to seaward.

Lapointe et al. (2005) examined macroalgae on coral reefs in Broward and Palm Beach counties and attributed most to widespread assimilation of sewage nitrogen associated with ocean outfalls. Their study area was north of BNP, but the ocean outfall associated with Miami is much closer to the park and presents a similar threat although the State of Florida has required Miami-Dade County to stop use of the outfalls in the near future. Miller et al. (2006) reported on a baseline population survey of *A. cervicornis* and *A. palmata* corals in the Florida Keys reef tract, including sites just south of BNP. The overall decline in the two species dates from the late 1970s and was caused by bleaching, white-band disease, storm damage and predation by damselfish and corallivorous snails. Both corals were listed as threatened in 2005. Numbers of coral colonies reported were low, as were the populations of urchins, which are generally prevalent on healthy reefs; low populations suggest reduced health.

Fisher et al. (2007) used induced coral lesions at four six-meter deep patch reefs within BNP, and others in FKNMS to the south, to study reef recovery from damage. They concluded the sites in BNP were in poor physiological condition or subjected to less than optimal environmental conditions. Those displayed: 1) highly variable and low regeneration rates, 2) low percent of full healing and 3) high occurrence of either breakage or lesions, which increased in size by merging with adjacent denuded tissues of the coral colony. Collier et al. (2008) focused on areas from BNP north and draws similar conclusions about reef health, as does Donahue et al. (2008).

Coral bleaching is one of the conditions receiving much attention in research locally, as the problem is widely accepted as a response to environmental stress commonly seen in corals and easy to spot in the field. Douglas (2003) examined the existing literature on coral bleaching, which he defined as the loss of color in symbioses between the coral and its associated dinoflagellate, *Symbiodinium*. Douglas examined three elements: 1) the triggering external factors, 2) the symptoms, including loss of zooxanthellae and/or pigment and 3) the mechanisms causing the symptoms. This phenomenon is believed to be increasing in recent years and has caused alarm among coral researchers because it is associated with mass coral mortality. Temperature extremes, elevated irradiance, long periods of darkness, pathogenic micro-organisms and certain heavy metals (copper, cadmium) have been implicated as triggers of bleaching. The symptoms normally include a high rate of expulsion of the *Symbiodinium* from the coral animals, which produces the white tissue that gives rise to its name. Expulsion of the zooxanthellae results in a loss of photosynthetic beneficial nutrients to the corals and can lead to detachment of the animals from their exoskeleton. Synergistic relationships may be required to produce bleaching, such as the combination of pollution and/or microbial activity with elevated temperatures.

Baker (2003) discusses the biology of coral symbionts in the genus *Symbiodinium* and the symbionts' ability to withstand certain stressors. He describes the ability of some species of *Symbiodinium* to withstand heat stress, and suggested managers of reef systems need to fully understand the details of this community in order to understand reef outcomes. The rate at which coral communities can rebound from bleaching events may depend on the ability of the corals to replace one type with a more resistant type assuming, the latter is available for the corals to utilize. Baker et al. (2004) reported that observations of coral reefs showed that after bleaching episodes, the heat resistant strains of *Symbiodinium* were more abundant after the event, and surviving coral communities had symbiont assemblages more like those of reefs in high-temperature environments; this suggests that some adaptation to warmer conditions is possible. It was speculated that this symbiont shift is more likely to occur after longer heat-stress events. They suggested that affected reefs may revert to the previous symbiont patterns if enough time without further stress passes. They propose that adaptive shifts are common in cases of severe bleaching and that this might be a mechanism that will increase resistance to future bleaching.

Miller et al. (2005) identified moderate bleaching in BNP with photos of some examples. The highest mid-channel scleractinian coral density was recorded at Margot Fish Shoal in the park and attributed to an abundance of branching *Porites* colonies. Highest density of gorgonians was recorded from a mid-channel patch reef inshore of Pacific Reef, BNP. They show park corals had from 1.6% (fore reef) to 14.6% (mid-channel patch reef) of their area bleached during the 2005 season. Santavy et al. (2005) discussed the meaning of coral bleaching studies and suggested a more broadly-based approach for determining reef health. They suggest a community-wide estimate of various bleaching observations is more useful than raw numbers of affected animals. Drohan et al. (2005) used experimental data to show that elevated UV-B wavelengths can increase the stress on gorgonian symbionts caused by elevated temperature, leading to additional bleaching. McClanahan et al. (2005) argues that local conditions are more important than regional trends in understanding bleaching events and the adaption of affected coral communities, and leads to patchy reorganization of reefs after the stress events. Wilkinson and Souter (2008) examined recent bleaching and hurricane damage to Caribbean reefs, including those in Florida. They provide a chronological history of bleaching in the Keys back to 1979. They described the spate of hurricanes and discuss the widespread bleaching in 2005, which is attributed to elevated water temperatures that produced plus 2-3˚C hotspots in August.

Corals also suffer disease-related declines that have been studied, although less-so than bleaching events. Coral diseases are grouped into three categories: 1) black band, 2) white diseases (white plague, white band and white pox), and 3) other (dark spot, yellow band, idiopathic). Woodley et al. (2003) describes the activities of the Coral Disease and Health Consortium, which was formed to better understand this issue. They list eleven objectives for the group to improve the coral disease knowledge base. Florida Fish and Wildlife Conservation Commission (2004) stated that corals showing diseases increased in the 1996-1999, but a decline in diseased corals was recorded between 2003-2004 for white disease, black band disease, "other" disease and coral bleaching, and indicated that these were not impacting stony coral percent cover numbers. They conclude that multiple stressors at all levels were the cause of negative impacts on the coral reefs in the FKNMS. Andrews et al. (2005) suggested white pox disease can be attributed to the human fecal bacterium (*Serratia marcescens*). Coral diseases remain an area needing further study.

Physical damage to reef structures (and seagrass beds) can occur when vessels "run aground" on reefs or patch reefs. Large ships have historically been a problem along the seaward margin of the park. Recently, statutory authority (e.g., Park System Resource Protection Act, 16USC19jj) has improved, making it possible to remove the offending vessel quickly and to see that the owners are required to repair the damage area, where possible. However, small boat damage is probably a bigger problem for park reefs, as the number of boating visitors to these excellent diving and fishing spots continues to increase. Small boats can hit the reefs, can cut it with propellers, drop anchors and anchor lines that drag across the corals and increase wave energy that can increase erosion and sediment movement. The park maintains data on groundings and one study of small boat damage at Bache Shoal patch reef (offshore of Sands Key Cut inside the park) showed more than 40% damage at this popular dive site (Lutz, 1998).

Recently, the new focus on climate change has determined that the acidification (souring) of ocean water by increased levels of atmospheric CO_2 will affect the depth at which aragonite is supersaturated. Guinotte et al. (2006) studied the aragonite saturation horizon (ASH) and showed how it will move upward as a result of climate change (increasing pCO_2). The ability of many calcareous species, including corals, to make their shells (tests) is dependent on the ASH; many believe this will severely hinder reef health around the world. However, this report shows that the ASH change has less of an impact in Florida waters, where the ASH is considerably deeper because of present circulation patterns, than in other oceans, and will take much longer to affect the organisms living near the surface. Deep-water coral reefs seaward of BNP will be affected first and much later in the century than reef areas in the Pacific. Monitoring the deep reefs offshore of the park might provide insight to the progression of this problem long before surface studies show it. Hoegh-Guldberg et al. (2007) suggest that managers of reef systems should concentrate on lowering known stressors locally, so that elevated temperatures and changes in pCO_2 in the future will have less impact on reef communities when they do begin to be affected.

Heat stress from elevated water temperature is expected in the near future, and sea level rise expectations are also significant in most projections of future climate conditions (e.g., Bates et al., 2007). Both stressors are problematic for the park's reefs. Heat increases can lead to more bleaching and ultimately, loss of corals, and higher sea levels will physically affect reefs with higher energies (Wilkinson and Souter, 2008). Sedimentation rates should increase as this energy picks up bottom sediment and moves it around and will cause shoreline erosion and entry to the water column of both turbidity-producing material and nutrients which will further impact offshore areas. Mielbrecht et al. (2008) used GIS-based mapping for a regional analysis of the Florida Keys reef tract which indicates current water temperature ranges. It showed the offshore upper keys reefs were in the 28.48-28.72˚C range (slightly below average) and 29.04-29.25˚C inshore, with variance of 1.95˚C (deep offshore), 1.95-2.2˚C (shallow offshore) and 2.96-3.59˚C (inshore). To offset the loss of symbionts caused by heat stress, Andrew Baker at the University of Miami is attempting to introduce heat resistant zooxanthellae to corals in a laboratory setting with the idea of making them more tolerant to climate change-induced warming (Eilperin, 2008). Wilkinson and Souter (2008) suggest the following scenarios for Florida reefs: 1) more frequent warming and more intense warming in the near future which will lead to more bleaching and coral mortality, 2) severe coral bleaching events become common by 2030, 3) annual bleaching events become common by 2100 and 4) increased potential of more severe hurricanes that will also threaten reefs in the region.

It would appear that the reefs are already declining as a result of anthropogenic, as well as natural, stressors, with climate change dominating in the future. While reef communities might find ways to adapt to the changing world (sea level rise is not new) most of the expected changes are not susceptible to local management solutions. As one of the only areas they can affect, reef managers must expend greater effort to protect reefs from anthropogenic stressors, if only by increasing reef resiliency through reef restoration, protection of water quality, reduction of vessel groundings and anchor damage.

Amphibians and Reptiles

Table 14 lists the known amphibians in BNP.

Table 14. Amphibians found in Biscayne National Park (NPS).

Scientific Name	Common Name
Osteopilus septentrionalis	Cuban tree frog
Gastrophryne caarolinensis	Eastern narrowmouth toad
Eleutherodactylus planirostris	Greenhouse frog
Bufo marinus	Cane toad
Hyla cinerea	Green tree frog
Bufo terrestris	Southern toad
Hyla squirella	Squirrel tree frog

Biscayne National Park has a wide variety of reptiles that inhabit it (Table 15). Included are rare and endangered turtles, crocodilians and snakes. Sea turtles are commonly seen in the park including loggerhead, green, and hawksbill types, as well as the rarely seen leatherback; all are listed as either “threatened” or “endangered” because of loss of viable nesting grounds outside the park. The shoreline of several Keys provides at least five nesting beaches within the park, where female sea turtles can return to lay their eggs. Park staff monitors nesting from May to August to locate new nests and install screens over them, preventing raccoons from digging up the eggs. Debris is a problem for turtles; it is removed from nesting beaches when possible.

Birds

Appendix A Table A9 shows the bird species identified in BNP.

Mammals

Table 16 shows the mammal list for BNP.

Table 15. Reptiles known to inhabit Biscayne National Park.

Scientific Name	Common Name
Alligator mississippiensis	American alligator
Anolis carolinensis	Green anole
Basiliscus vittatus	Brown basilisk
Caretta caretta	Atlantic loggerhead turtle
Caretta caretta	Loggerhead sea turtle
Chelonia mydas	Green sea turtle
Coluber constrictor paludicola	Everglades racer
Crocodylus acutus	American crocodile
Crotalus adamanteus	Eastern diamondback rattlesnake
Dermochelys coriacea	Leatherback sea turtle
Dermochelys coriacea	Atlantic leatherback turtle
Diadophis punctatus	Ring-necked snake
Diadophis punctatus punctatus	Southern ring-necked Snake
Drymarchon corais couperi	Eastern indigo snake
Elaphe guttata	Corn snake
Elaphe obsoleta quadrivittata	Yellow rat snake
Elaphe obsoleta rossalleni	Everglades rat snake
Elutherodactylus ricordi planirostris	Greenhouse frog
Eretmochelys imbricata	Hawksbill turtle
Eumeces egregius	Mole skink
Eumeces inexpectatus	Southeastern five-lined skink
Hemidactylus turcicus	Mediterranean gekko
Iguana iguana	Green iguana
Kinosternon baurii	Striped mud turtle
Lepidochlys kempii	Kemp’s ridley turtle
Malaclemys terrapin rhizophorarum	Mangrove diamondback
Micrurus fulvius	Northern coral snake
Nerodia fasciata pictiventris	Florida water snake
Opheodrys aestivus	Rough green snake
Python molurus bivittatus	Burmese python
Scincella lateralis	Ground skink
Seminatrix pygaea	Black swamp snake
Sistrurus miliarius barbouri	Dusky pigmy rattlesnake
Sphaerodactylus notatus	Reef gecko
Tantilla coronata wagneri	Florida crowned snake
Terrapene carolina bauri	Florida box turtle

Table 16. Mammals found in Biscayne National Park (NPS).

Scientific Name	Common Name
Tursiops truncates	Atlantic bottlenose dolphin
Rattus rattus	Black rat/roof rat
Lynx rufus	Bobcat
Tadarida brasiliensis	Brazilian free-tailed bat
Peromyscus gossypinus	Cotton mouse
Balaenoptera physalus	Finback whale
Vulpes vulpes	Gray fox
Sciurus carolinensis	Gray squirrel
Sigmodon hispidus	Hispid cotton rat
Megaptera novaengliae	Humpback whale
Peromyscus gossypinus allpaticola	Key Largo cotton mouse
Neotoma floridana smalli	Key Largo woodrat
Cryptotis parva	Least shrew
Sylvilagus palustris	Marsh rabbit
Sciurus aureogaster	Mexican red-bellied squirrel
Dideophis virginiana	Oppossum
Procyan lotor	Raccoon
Balaena glacialis	Right whale
Lutra canadensis	River otter
Balaenoptera borealis	Sei whale
Lasiurus seminolus	Seminole bat
Glaucomys volans	Southern flying squirrel
Physeter macrocephalus	Sperm whale
Mephitis mephitis	Striped skunk
Didelphis virginiana	Virginia opossom
Eumops glaucinus	Wagner's mastiff-bat
Trichechus manatus	West Indian manatee
Odocoileus virginianus	White-tailed deer

Assessment of Threats

Introduction

There are many threats to the resources of Biscayne National Park and many gaps in our knowledge of the functioning of the Biscayne Bay ecosystem. The principal threats are presented with a brief description of the problem(s) and a description of how the threats were rated. Tables at the end of each section summarize the threats and rate the extent of the problem and the quality of the available information.

Each table presents threat/stressor information for different abiotic and biotic resource components classified as terrestrial, canals, and wetlands, the bay proper, marine/reef and groundwater. Table cells coded **red** highlight acknowledged current problems; cells coded **orange** highlight potential problems and those coded **yellow** highlight areas of uncertainty about the extent of resource management problems. Cells in **green** suggest either no problems or issues that are under control; cells in **blue** represent historical problems. Given unlimited monetary, personnel and technical resources, all of the yellow, orange and red issues require research into the drivers of the resource issues. In practical terms, priorities must be set to wisely spend the available resources.

To further guide the expenditure of resources, the state of knowledge for understanding the color-coded problems is summarized using letters to indicate whether the knowledge base is **good (G), fair (F), poor (P) or only inferred (I)**. Issues with scores of **I** or **P** should be higher research priorities than issues for which there is a fair or good level of understanding. Existing problems with a good knowledge base are candidates for management actions, while problems with less certain understanding are candidates for research. Given our understanding of the natural resources of BNP, current problems that deserve research priority are highlighted.

Atmospheric Deposition

Acidification occurs when atmospheric chemistry produces decreased pH of rainwater. Rainwater in Florida is normally slightly acidic and has the capability to dissolve the limestone surface (epikarst) and produce subterranean drainage systems (karst). Pollution of certain types can decrease the pH beyond background levels and produce additional acid compounds of concern (e.g., hydrogen sulfide converted to sulfuric acid). Additionally, the rapidly increasing levels of CO_2 in the atmosphere can directly affect the pCO_2 levels in both surface water and groundwater, which may produce further lowering of the pH. This can affect the life processes of many organisms, particularly those that depend on making or using calcium carbonate in their life cycles.

Airborne sources of pollution include general combustion products (Long et al., 2002), industrial and agricultural emissions as well as elements comprising or attached to dust events deposited locally. Prospero and Nees (1977), Prospero et al. (1987), Prospero (1999a, 1999b, 1999c) and Chiapello et al. (2005) discussed the long term patterns of dust transport, correlating it to African climate changes and droughts. The USGS National Atmospheric Deposition Program/National Trends Network maps (USGS 1994-2006) show the values for 22 chemical species measured from atmospheric deposition for the continental U.S. With only a few points measured in Florida, these are not usable for detail but do provide a general guide to the deposited chemistry in south Florida.

Acidification

Natural acidification of rain is the principal source of mildly acidic surface and groundwater, which produces the karst terrains of the region. Acidification related to emissions, re-deposited on terrestrial systems, is known from many other locations in the U.S. Sulfur dioxide (SO_2) and nitrogen oxide (NOx) react with other atmospheric components to produce a mild solution of sulfuric acid or nitric acid, respectively. These are transmitted to the earth's surface in wet form (acid rain) or as dry particles or gasses. This acidic deposition can harm anthropogenic structures and etch limestone and can reach groundwater, as some surfaces shed the particulate compounds during subsequent rainfalls. This can be a problem for sensitive species, such as varieties of vegetation and certain fish, and it can impact soil chemistry by stripping nutrients from the soil which deprives plants of much needed chemicals.

Because atmospheric pollutants can be deposited into park waters, and local powerplants may produce harmful emissions, especially during peak demand periods, acidification from atmospheric deposition is considered an existing problem in BNP's surface environments and a potential problem in its groundwater. However, South Florida ranks in the lower end of values for the United States in acid-forming compounds according to data maintained by the National Atmospheric Deposition Program.

Chemical and Particulate Deposition

Seba (1969) reported pesticides associated with the surface microlayer in Biscayne Bay and suggested these to be atmospheric transport and deposition. Shinn et al. (2000) has suggested that dust from Africa may be a significant contributor to reef declines in Florida. They state that the "near synchronous" loss of many acroporid corals, the echinoderm Diadema in 1983 and the coral "bleaching" (zooxanthellae expulsion) increases in 1987, correlate with deposition maxima. They hypothesize that this results from either the mineralogy of the dust (iron, silica and aluminum clays) or with dust riding harmful biota such as *Aspergillus* spores, which survive long distances.

Holmes and Miller (2004) discussed the mercury and arsenic components in African dust and estimated that about 25% of the arsenic deposited in Florida comes from this source. Hayes et al. (2001) suggested that "the iron component of dust alters the macronutrient balance in such a way as to aid the growth of opportunistic organisms and pathogens in coastal systems, particularly in macronutrient-rich coastal systems" such as BNP. Lenes et al. (2001) suggested that nutrient iron from African dust events may feed algal blooms in Florida coastal waters. Kellogg and Griffin (2003) suggest other environmental and health issues related to aerosol dust from Africa. Savoi et al. (2002) discusses non-sea-salt sulfate from aerosol sources in the North Atlantic Ocean.

In addition to African dust, there are many local sources of aerosols, mainly derived from combustion sources, biomass burning and incinerators. Lang and coworkers (Lang et al., 2002) reported the abundance and fluxes of a variety of organic contaminants, including polycyclic aromatic hydrocarbons (PAHs), in the Miami metropolitan area. Such wet and dry deposition to Biscayne Bay and adjacent areas represents an additional, non-point source of pollutants to the bay. Caccia and Boyer (2007) showed that atmospheric deposition was the second largest source of nitrogen. Areas closest to the park had double the load of phosphorus from atmospheric deposition when compared to that derived from canals.

Chemical and particulate deposition in BNP is considered to be a potential problem for both abiotic and biotic components of all ecosystems. Declines in coral reefs, patch reefs and sea fan communities, including important species of echinoderm, have been attributed to African dust events and may be caused by the chemistry of the dust due to chemical contamination (e.g., pesticides) and by fungal spores which attach to the aerosol particles for the transport to the Caribbean (Shinn et al., 2000; Shinn, 2001; Garrison et al., 2003). Lenes et al. (2001) suggested that nutrient iron from African dust events may feed algal blooms in Florida coastal waters. Declines in echinoderms and corals have been attributed to this cause and should suggest that other organisms are also affected. The National Park Service has measures air quality at Everglades National Park and data show that the sulfate deposition trend is getting worse (degradation) and that nitrate deposition is improving significantly (NPS, 2002). Data on this threat is considered to be fair to poor in quality.

Pathogen Deposition

Shinn et al. (2000) suggested that the "near synchronous" loss of many acroporid corals and the echinoderm Diadema in 1983 and with coral "bleaching" (zooxanthellae expulsion) increases in 1987 correlate with dust maxima and may have been caused by dust riding harmful biota, such as Aspergillus spores. Although Kellogg et al. (2004) discussed the types of bacteria and fungi found on African dust samples, the impact of pathogens or other problematic organisms on dust particles on the biotic components of BNP is largely unknown. No effects are anticipated on the physical environment and data on this subject are fair for the reefs, but poor for other environments.

Table 17. Atmospheric deposition. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

KEY ISSUE	RESOURCE COMPONENT										
	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
Acidification	F	I	F	I	F	I	F	I	F	I	I
Chemical and Particulate Deposition	F	P	F	P	F	P	F	P	F	P	P
Pathogen Deposition		P		P		P		P		F	

Ultraviolet Radiation

Ultraviolet radiation from the sun is known to cause problems for both plants and animals, particularly the UV-B radiation component (280-320 nm) of sunlight which can damage DNA and proteins in tissues. Therefore, changes in the protective ozone layer or other long term variations in UVR can be expected to cause problems with the environment. For example, UV sensitive plants will reduce foliage to compensate which can reduce yields of fruit and allow less sensitive plants to out compete them. This is also true of insects, including pest varieties which might gain advantage in higher UVR conditions. Phytoplankton, which normally inhabits the upper layers of the ocean, is affected by UVR which limits both growth and reproduction. Changes in UVR levels that impact phytoplankton would therefore also affect all the higher organisms in a plankton-based food web. In higher order animals, such as mammals, UVR exposure damages tissues and can lead to the formation of certain cancers.

The impact of solar radiation may not be intuitive. For example, shallow water diatoms are negatively affected by UVR, with fewer produced when levels increase, but more diatoms are produced in the UVR affected environments than in adjacent UVR protected ones. Predatory species on the diatoms are also affected by UVR with some varieties repressed during certain growth stages which may allow more diatoms to survive than would be expected under the elevated UVR conditions. Therefore, one cannot predict precisely the ecosystem response unless one studies more than one trophic level (Bothwell et al., 1994).

Because of worldwide concerns of ozone depletion in the upper atmosphere (ozone holes) there is considerable literature on this subject but none specifically related to South Florida. However, negative impacts produced by UVR on the environments of BNP are inferred for all biotic components and are considered a potential threat to marine biotic systems as future climate changes alter the UVR.

Table 18. UV radiation. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**	
	Abiotic	*Biotic*	*Abiotic*	*Biotic*	*Abiotic*	*Biotic*	*Abiotic*	*Biotic*	*Abiotic*	*Biotic*	*Abiotic*	
UV Impacts		**I**		**I**		**I**		**I**		**I**		

Visibility

Visibility affects visitor experience and the environment. Air quality has an impact on park visitors, while water turbidity affects visitors (divers and boaters) and benthic organisms, which either require light for life functions or are sensitive to high sedimentation rates.

Air Quality

As urbanization is brought to the coastal plain, and former wetlands adjacent to the park are developed, the future air quality is expected to deteriorate. This impacts the experience of visitors to the park. Currently the National Park Service monitors the air quality at Everglades National Park but not at Biscayne. Everglades, unlike BNP, is a Category I Airshed; this prevents BNP from commenting on many aspects related to this issue. Most air pollution issues the Park Service is concerned with are in northern parks in the system as both South Florida units are considered to have adequate air quality, to the point that Biscayne is not mentioned and Everglades briefly mentioned in the Service's air quality report for the entire system (NPS, 2002). South Florida has an average visual range of 39 km and is slightly better than the area around the Great Smokey Mountains, which is the region with the lowest visibility in the continental U.S. (IMPROVE program website at http://vista.cira.colostate.edu/improve/).

The only air quality trends discussed in the NPS Air Quality Report (NPS, 2002) are no change in either sulfate or nitrate values but an increasing trend in ammonium in precipitation. However, BNP is affected by local air pollution and smog on days when the prevailing winds are incapable of removing it and also by smoke from brush fires in the winter/spring fire season. As the county continues to urbanize, the general trend of air quality may decline, but at this time the park is considered to have good, natural visibility on most days. Air quality data is available and currently adequate to evaluate future trends.

Water Turbidity

Suspended particulates in the bay and marine waters of the park have detrimental environmental effects discussed elsewhere, but also impact the water visibility for the park's many snorkel and scuba divers. Experienced reef divers are aware that there are days when good, quality diving is limited, such as periods of high onshore wind. Turbidity is increased when bottom sediments are resuspended by high energy, which can also be caused by boat scouring, boat wakes, planktonic blooms, animal browsing and extreme weather events; it can also come from water circulation in areas with high turbidity, principally the urbanized bay north of the park.

Many studies in Biscayne Bay collected turbidity data during routine water sampling, and report instantaneous values based on NTU values or other means; none bring this data to a comprehensive analysis of turbidity. The only comprehensive study of turbidity in the bay is Wanless et al. (1984), which studied both sources and the circulation patterns of turbid water over the entire bay for several years. Cores were collected to characterize the sediment components and water samples were collected and analyzed for suspended particulates and planktonic components. Coley (2006) examined long term trends for all of Biscayne Bay and found turbidity decreased with time. Turbidity was higher north of the park than within.

From the Wanless et al. (1984) study it is possible to make the following observations about turbidity in BNP:

- Turbidity-producing sediment is largely produced in Biscayne Bay or its surroundings by biological processes. This includes almost all carbonate material, some siliceous material and considerable organic material (plankton and resuspended flocculants). A small component is derived from Pleistocene sediment resuspension where those are available.

- Primary planktonic productivity is a form of turbidity.

- Resuspension of bottom sediments results from currents, both natural and anthropogenically produced. Natural agents of resuspension are water currents (tidal driven), wind-produced waves (climate related) and extreme events (storms and hurricanes). Anthropogenic resuspension occurs when boats are grounded or their propellers are allowed to chew up shallow bottoms, and from boat wakes (see also Harlem, 1979).

- Because hurricanes have the capability to erode shallow bottom areas, they produce turbidity during the storm and may cause elevated levels for years after as seagrass cover is reestablishing over the eroded areas.

- The area north of the park adjacent to Key Biscayne is affected by turbidity leaving the Miami River, from resuspended flocculants from the deep axis of the bay (14 ft plus deep zone west of Cape Florida) and diatom production along the western bayshore. Incoming tides passing north of Virginia Key or Key Biscayne move large amounts of resuspended sediment during winter storms, which ultimately move toward or across the northern boundary of the park.

- Tidal resuspension of carbonate sediments from the deep axis of south Biscayne Bay, which is sparsely covered with aquatic grass, is the principal natural source for turbidity in the bay portion of the park. Organic production is significant at the north end (west of the Safety Valve) and near outlet canals entering the bay along the west shoreline. Turbidity produced north of Featherbed Bank drifts south into the southern portion of Biscayne Bay. The flanks of the bay produce resuspended materials during wave-producing storms and from frequent boat wakes.

- The southernmost portion of Biscayne Bay receives turbidity from north of Featherbed Bank and from materials resuspended from the rocky bottom areas common there. Bottom feeding fish and the oil barge servicing Turkey Point produced whitings and turbid plumes respectively. Net transport of suspended sediment from Biscayne Bay at Caesars Creek both produces the shoal there (Caesars Creek Bank), and exports turbidity to the reef areas offshore.

Turbidity in BNP is both a natural process, to which many organisms are well adapted, and an unnatural process, when induced by human activities. Turbidity produced by boats is the principal physical source of resuspended particulates, but plankton biomass increases (blooms) that occur as a result of the release of nutrients to the bay via the drainage canal network are significant at certain times. Storm-induced turbidity is temporal with seasonal components as well as random, rare, extreme events and is the principal mechanism for resuspension along the reef tract. Figures 68-71 shows examples of turbidity in the park.

Turbidity problems in BNP are reasonably well understood with good data on the sources and sinks as well as the effects on organisms. As long as dredging projects are prohibited and boat use is controlled to some degree, no problems are likely in the foreseeable future. Turbidity from the north of the park has been a long term problem, and it is likely to get worse as the downtown Miami area continues to grow and the seaport is expanded. Increases in boats using the park can be a problem, and turbidity in canals along the west side is a potential problem and not well studied. Natural turbidity is part of the park's ecosystem, which may change as sea level rises but otherwise is a normal function to which most organisms are well adapted. Regular park users, particularly divers visiting the offshore reef areas, are generally experienced enough to know that.

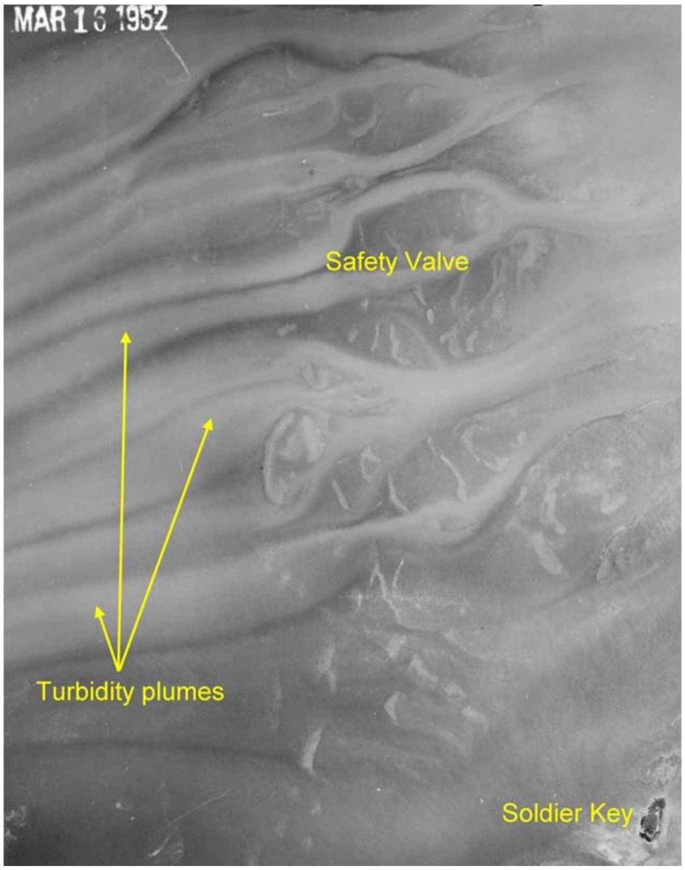


Figure 68. Turbid plumes entering Biscayne Bay via Safety Valve channels on incoming tide March 16, 1952 (USDA image BUP-4h-058).

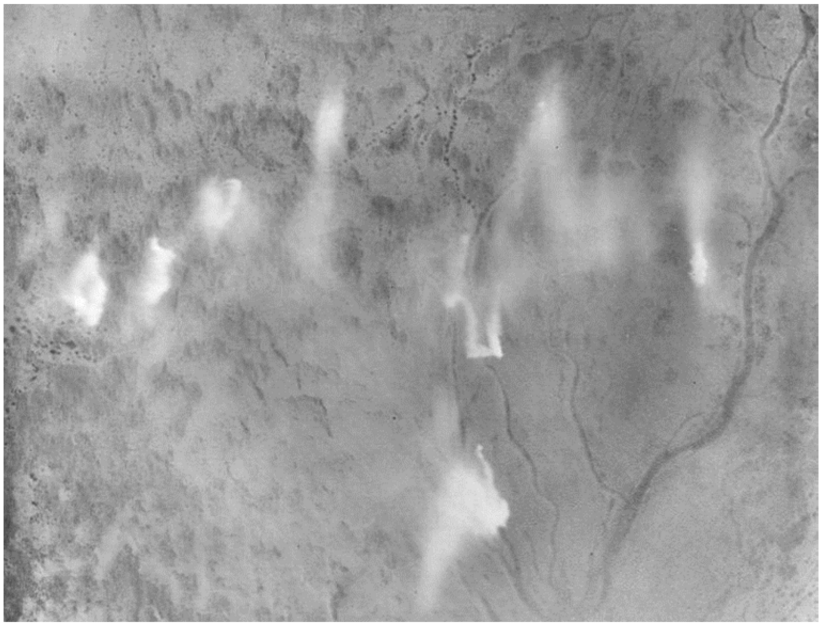


Figure 69. Whitings in south Biscayne Bay opposite Elliot Key. These cloudy water areas are believed to be caused by fish stirring up muddy bottom sediment during feeding. Note also the extinct drainage system etched into the bottom bedrock (1976 Florida DOT image PD1638-22-07).

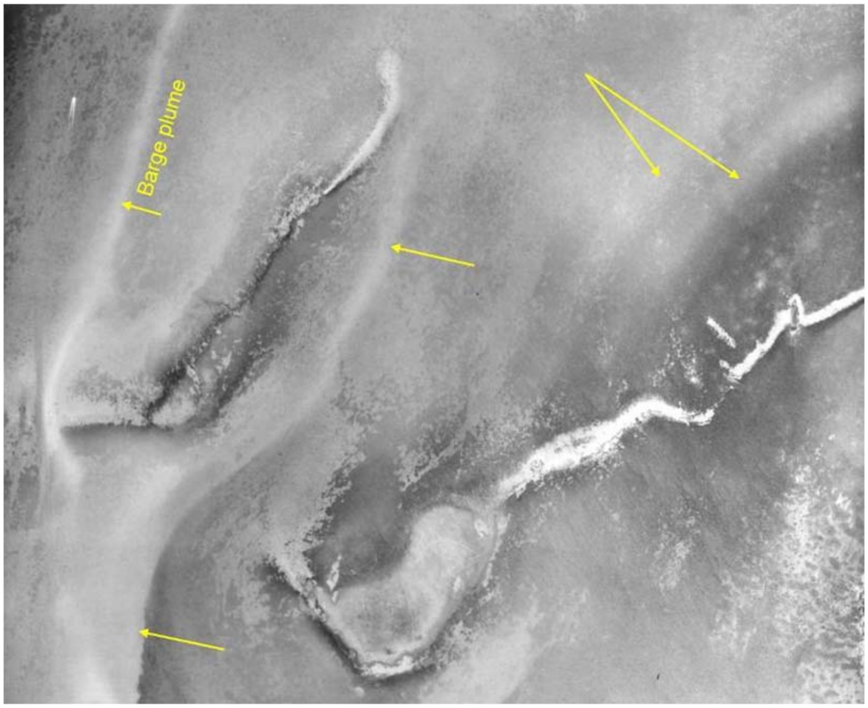


Figure 70. Turbidity plumes moving slowly near Featherbed Bank(s) include a long, thin variety made by the recent passing of the oil barge for Turkey Point. Most of the turbidity in this area ultimately moves to the south (1976 Florida DOT image PD1638-21-12).

Figure 71. Recent color orbital image of most of the park showing turbidity patterns. Two boat induced plumes are visible as are plumes at Featherbed (top), on both sides of Old Rhodes Key and in Hawk Channel. Wind likely from NW at time of photo (USGS download).

Table 19. Visibility. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Air Quality	G	I			G	I	G	G	G	G		
Water Turbidity			F	F	G	G	G	G	G	G	G	

Ozone

Ozone in the ground-level air is considered to be a phytotoxic air pollutant which can also affect humans and animals, but it is especially toxic to many plant species. It is the principal component in urban smog and is produced by sunlight modifying nitrogen oxide or volatile organic compounds emitted by vehicles, boats and smokestacks. Ozone can injure leaves or cause leaf loss in sensitive plant species and results in less growth. Synergistic effects by other stressors can magnify the effect of ozone on plant tissues.

Ozone Concentrations

Everglades National Park data show that this region has a maximum 3-month Ozone SUM06 (see NPS 2002 for explanation) value of 13 ppm-hr for 1995-1999, which is high enough to cause plant damage. The fourth highest daily maximum 8-hr concentration at Everglades National Park for 1999 was 67 ppb. The ozone trend for Everglades National Park is classified as “degradation” by the National Park Service (NPS, 2002).

There is a potential threat to terrestrial and wetland biota from the ozone levels in, and adjacent to, BNP which will probably become worse as the adjacent land is urbanized and population growth continues. Other resource components are not significantly impacted, and data on this subject is considered to be good or inferred.

Table 20. Ozone. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Ozone Concentration	I	I	I	I	I	I	I	I	I	I		
Impacts on Air Quality	I		I		I		I		I		I	

Impacts on Air Quality

Ozone is an important component in photochemical smog and, as the region around BNP is further urbanized, air quality is expected to further deteriorate. However, smog is not currently a problem for the park’s biotic resources as the climate prevents long term, more damaging smog events. The threat to the park is considered minimal at this time, although the lack of detailed trend data in Biscayne makes this interpretation inferential.

Nutrient Enrichment

McNulty (1957) studied central Biscayne Bay (north of BNP) for sediments pollution. The focus was on fecal coliforms and biological oxygen demand (BOD). This was one of a series of articles by McNulty that focused on the sewage problem around the seaport and Miami River outlet; it was followed by analysis of improvements occurring after most sewage outfalls in the river area were shut off (McNulty, 1970). Fogarty (1969) took single samples around Biscayne Bay to look for fecal coliform to identify contaminated areas for possible future study. This data showed Black Creek and Snapper Creek canal areas to have high coliform values (Figure 72).

Matteson et al. (1974) made a single transect down the axis of Biscayne Bay, Card Sound and into Florida Bay. They looked at carbon values and found they could see a distinct change below Featherbed Bank and another between lower Biscayne Bay and Card Sound. Pitt et al. (1975) examined five sites along the coastal ridge which were adjacent to septic tanks and determined that septic tank output was entering the groundwater. Waller (1981) examined water quality in the East Everglades, dominated by agricultural runoff. McKensie and Irwin (1983) studied the runoff from a highway system north of the Miami River to understand the chemicals entering the environment. They measured solids, TOC, COD, total nitrogen (TN), total lead (TPb) and total zinc (TZn) and found that about 10-15% of the solids were derived from rainfall.

Scheidt and Flora (1983) studied the water quality and discharge from Mowry Canal (C-103) into the west side of Biscayne Bay. They calculated an annual discharge of 162,234 ac-ft, one of the largest in south Biscayne Bay. High nitrogen loading in the C-103N canal coincides with the highest nitrite plus nitrate nitrogen readings in Miami-Dade County canals. Shinn and Corcoran (1987) documented pollution emanating from the south Dade landfill adjacent to the park and stated, “There can be little doubt that during and after heavy rainfall, significant amounts of ground water flow out under and into Biscayne Bay.” The South Florida Water Management District (1988, 1989) produced the first surface water improvement (SWIM) plan for the bay.

McKensie and Irwin (1988) examined the effect of stormwater runoff at two locations near the Miami Airport, noting differences in groundwater quality due to amount of stormwater dilution of the upper layers of the aquifer, which caused high, poorly drained, organic soils to have anaerobic water. Cheesman (1989) sampled the Mowry Canal and connected North Canal and found this canal to have higher levels of nutrients and agricultural compounds (chlorides and sulfates) than in other surveyed canals in the county. Florida Department of Natural Resources (1991) published a management plan for Card Sound. It identified stormwater runoff and septic leachate as pollution sources, pointed to the developments on Key Largo as sources of concern and suggested that boating and other user activities were impacting the waters of the Sound. Howie (1991) studied the effects of dumping sludge on farmland in South Miami-Dade County and how it affected the water quality of the groundwater near the test sites; little difference in quality values caused by the sludge application was found. Britt and Cheesman (1992) examined the water quality of the Princeton Canal (C-102) and found that agricultural practices in well-drained areas adjacent to the canal produced enough excess nitrogen to degrade surface waters; they implied it would degrade groundwater as well. Shinn et al. (1994) studied groundwater from wells installed in transects from shore to reef tract, including one offshore of Key Largo.

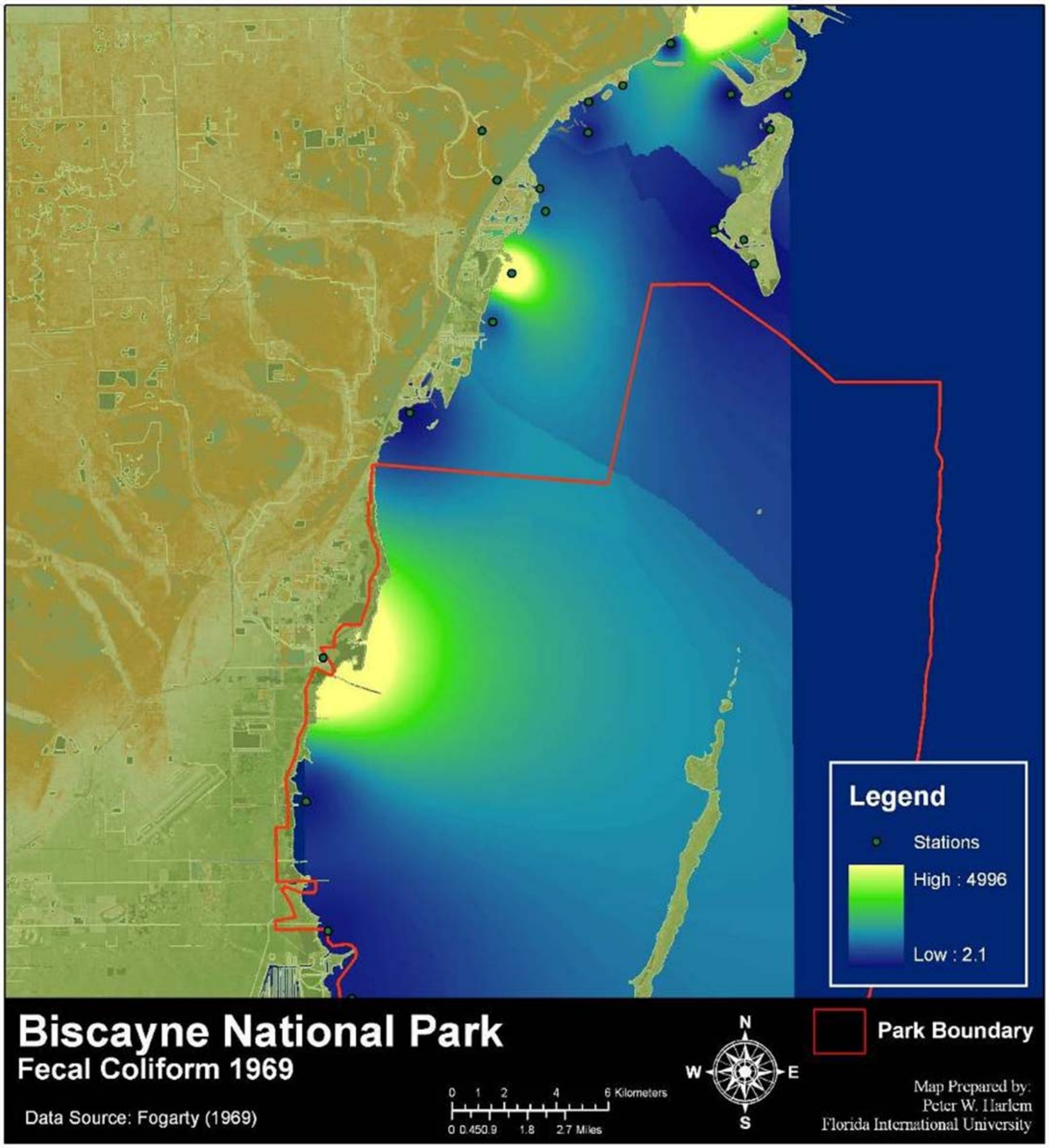


Figure 72. Inverse distance weighting interpolated fecal coliform levels from Fogarty (1969) data. Note hotspots at Black Point, Coral Gables Waterway and the outlet of the Miami River.

They provided background data on nutrients, salinity and pollution moving through the rock floor, and they discuss its possible effect on the reefs, the influence of tidal pumping into the rock and exchange with the water column. They suggested that coral reef declines may be results of nutrient seepage from below.

South Florida Water Management District (1995) produced a follow-up SWIM plan for Biscayne Bay. Leitz (1996) discussed the USGS method for determining nutrient loading by the coastal canals along the bayshore. Lietz (1999) examined nutrient loads in the canals along the bayshore, providing data and an analysis of both sampling techniques and model fit. He examined land use categories in the Biscayne Bay watershed and found that:

> "…median concentrations of total nitrite plus nitrate tended to be higher in agricultural areas than in urban or wetland areas. Median concentrations of ammonia, total phosphorus, and orthophosphate tended to be higher in urban areas than in wetland or agricultural areas, and median total organic nitrogen concentrations generally were higher in wetland and urban areas than in agricultural areas."

Haag et al. (1999) summarized available information on water quality in South Florida, including Biscayne Bay, and noted that the Biscayne Aquifer, near vegetable growing areas of Miami-Dade County, exceeded drinking water standards for nitrate (NO_3^-). Leitz (2000) examined water quality at the Miami Canal (C-6) outlet up to 1994 and found improvement in suspended sediment, turbidity, total ammonia (NH_4^+), total phosphorus (TP), iron and fecal coliform. Deteriorating trends were found in specific conductance, dissolved solids, chloride, potassium, magnesium, sodium, sulfate, silica, suspended sediment, total organic carbon (TOC), fecal streptococcus and pH. McNeill (2000) studied the causes of effluent rising prematurely from injection wells adjacent to the South District treatment plant and reported that the cause was improperly drilled injection holes. Seven of fifteen wells were found to not have been sealed at the intended aquaclude layer. As a result, ammonia-loaded effluent was detected in upper layers after only 11.5 months, instead of the project-intended 343 years.

Meeder and Boyer (2001) studied areas within, and adjacent to, BNP (Figures 73-75) and documented a strong correlation between elevated NH_4^+concentrations, with a decrease in *Thalassia*, an increase in *Halodule* and fast growing algae and an increase in filamentous algae cover near Black Creek. The mangrove fringe was a source of TP and possibly some NH_4^+ to the bay, but was lower than expected, while the bay contributed $NO_3^-$to the mangrove fringe.

Miami River Commission (2002a, 2002b) found improvements in some water quality indicators in Wagener Creek but fecal coliform was a continuing problem in this Miami River tributary. Florida Department of Environmental Protection (2002) described a plan for adopting quantitative water quality standards for Florida waters, including the areas adjacent to BNP. U.S. National Park Service (2003) examined the previous research of the water quality of the park and adjacent waters, which relies heavily on data retrieved from the EPA STORET system. Sheng and Davis (2003) presented a CH3D model to simulate water quality and circulation in Biscayne Bay and Florida Bay. Alleman (2005) showed time series plots for canal discharges of NH_4^+, nitrate/nitrite nitrogen (NO_x^-) and TP for all major canals entering Biscayne Bay.

Boyer (2005), using collected monthly water quality data, partitioned Biscayne Bay into six statistical cluster zones (Figure 76): North Bay (north of Rickenbacker Causeway), Main Bay (most of the main bay south of the causeway), Inshore (western shoreline to mid-bay), Alongshore (along the western shoreline closest to Military, Mowry, and Goulds canals, Turkey Point (one site) and South Card Sound (below Card Bank). Box plots of the chemical species considered were provided as was statistical summary tables. Boyer (2006) was a continuation, which also examined briefly the TP plume in the two bays south of the park that caused a major algal bloom in this area beginning in 2005.

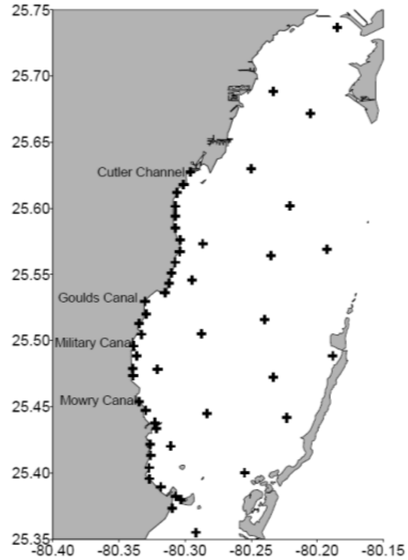


Figure 73. Reproduction of Figure 2 from Meeder and Boyer (2001) showing sample locations for their ammonia study.

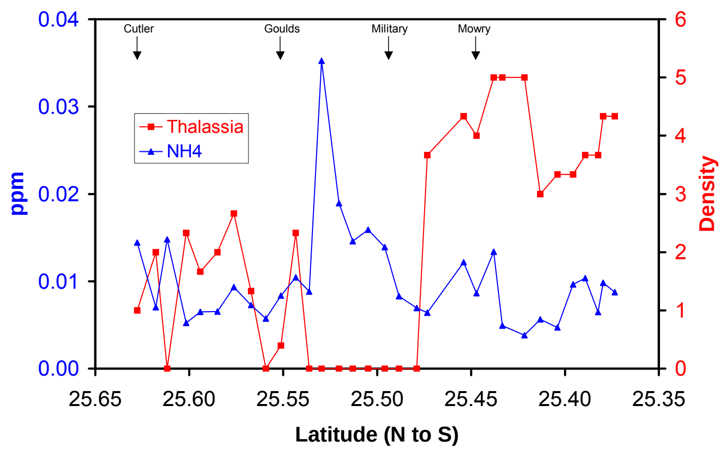


Figure 74. Reproduction of Figure 32 from Meeder and Boyer (2001) showing plot of *Thalassia* vs. NH_4^+ along Shoreline Benthic Survey sites.

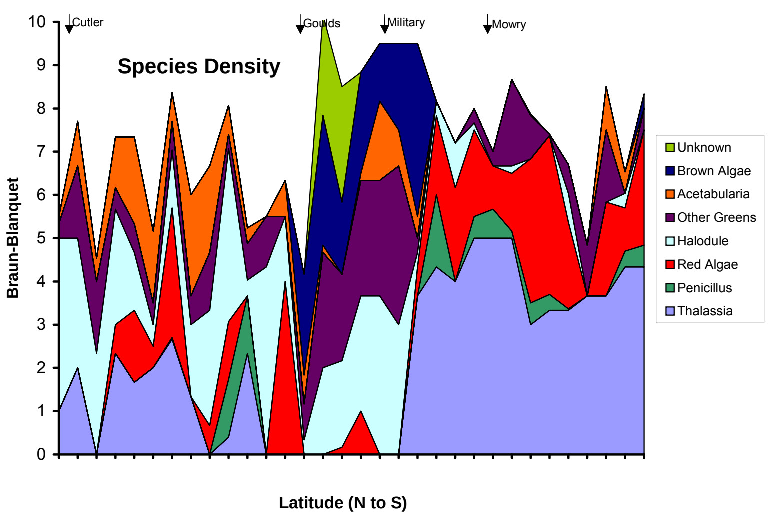


Figure 75. Reproduction of Figure 30 from Meeder and Boyer (2001) showing plot of plant species distribution along Shoreline Benthic Survey sites.

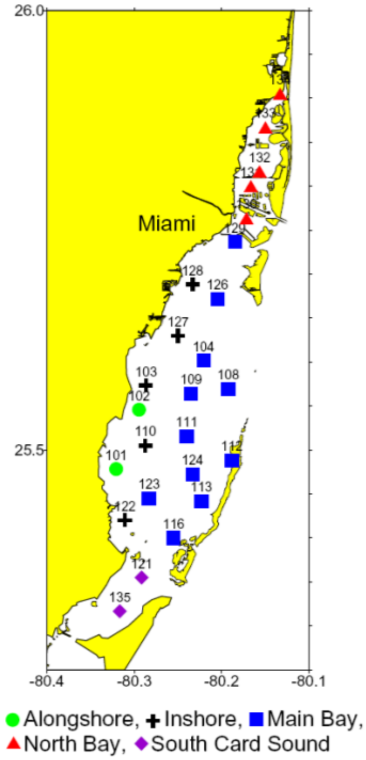


Figure 76. Reproduction of map from Boyer (2005, 2006; Figure 4) showing cluster grouping of water quality samples**.**

Boyer and Briceño (2005) found that Biscayne Bay salinity was strongly affected by its large tidal exchange with the ocean, except along the shoreline where canal inputs impact salinity as freshwater is released into the bay. They suggested that even with elevated nutrient inputs from the canal network, the excellent flushing of the bay prevented algal blooms. The hurricane season covered in their study showed increases in chlorophyll *a* after Katrina passed, but the increase was modest. Caccia and Boyer (2005) reported spatial clustering driven by DIN, which produced a strong gradient from alongshore to offshore. They attributed the impacted nearshore zones (Alongshore and Inshore) to freshwater input from the canals draining the agricultural areas to the west, the South Dade landfill and South District sewage treatment plant. Their South Bay zone (formerly South Card Sound) was high in dissolved organic constituents but low in inorganic nutrients. Because the main bay was diluted by good water exchange with the ocean, only the coastal portion water quality was dependent on land use and watershed issues.

Lietz and Meyer (2006) studied the wastewater at the South District Wastewater Treatment Plant, which may be used for rehydrating the Biscayne Bay coastal wetlands in the future. This provides baseline data on various pollutants and nutrient loads. Coley (2006) examined long term trends for all of Biscayne Bay and found that mean NH_4^+ concentrations showed no trends over time, mean NO_x, TP and turbidity decreased with time; TP mimicked canal flows to the bay with higher values to the north and south of mid-bay. Caccia and Boyer (2007) showed that canals contributed the bulk of nitrogen loading (88%), with atmospheric deposition the second largest source. NO_x^- exceeded NH_4^+ by about four times in canal waters, with the highest values in southern bay canals indicating the main source as agricultural runoff there (Figures 77-78). Areas closest to the park had double the load of phosphorus from atmospheric deposition compared to that derived from the canals. Groundwater input was examined for south Biscayne Bay and provides as much nitrogen as the atmospheric loading, while the phosphorous load was almost equal to the canal loading.

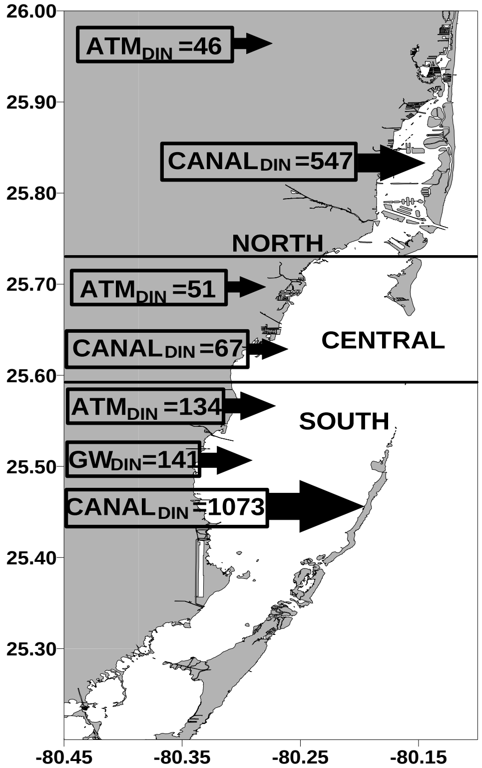


Figure 77. Reproduction of Figure 6 from Caccia and Boyer (2007) of annual average DIN loading budget. Breakdown shows canal, atmospheric (ATM) and groundwater (GW) loads by region of Biscayne Bay (tons/yr).

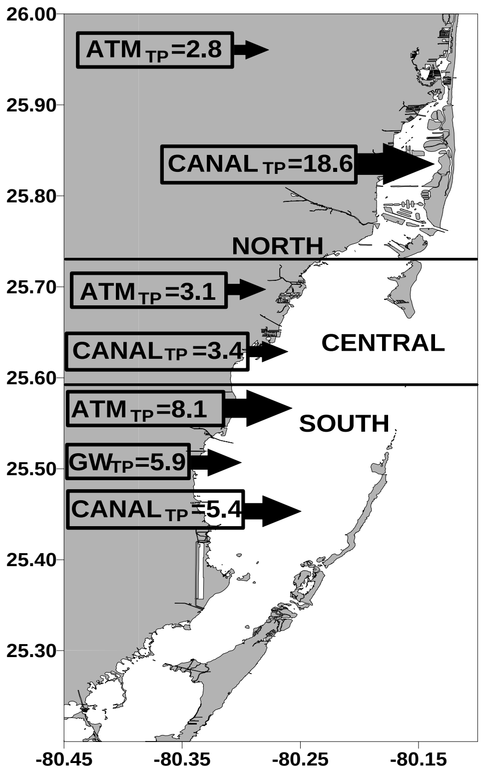


Figure 78. Reproduction of Figure 7 from Caccia and Boyer (2007) of annual average TP loading budget. Canal, atmospheric, and groundwater loads by region of Biscayne Bay (tons/yr) are given.

Koopman et al. (2006) examined the effect on the environment of the ocean outfalls located along the SE coast of Florida. The data showed impacts to be located close to the outfall location, with the Florida Current diluting and removing most of the effluent quickly. They discussed the impact on water quality briefly for the outfalls located north (seaward of Virginia Key) and south (opposite Key Largo) of the park.

Mir-Gonzalez and Boyer (2003a, 2003b) studied the western nearshore stretch of bottom from Black Point south to Turkey Point for nutrient loading by groundwater seepage into BNP. They reported average seepage flux rates from 116-13 L/m^2/d in August, October and December 2002, with highest rates found 150 m offshore of the Mowry Canal. The second highest rate was 300 m offshore of Black Point. Seepage water was higher in phosphorus, TN, TOC and NH_4^+ than bay water. Mir-Gonzalez (2007, Figure 79) reported that the old and new landfills located near Black Creek have created high nutrient loading of the groundwater seeping into the park. She concluded the nearshore benthic macrophyte communities were significantly affected by nutrient loading from canal discharge and/or groundwater seepage upward into the benthos.

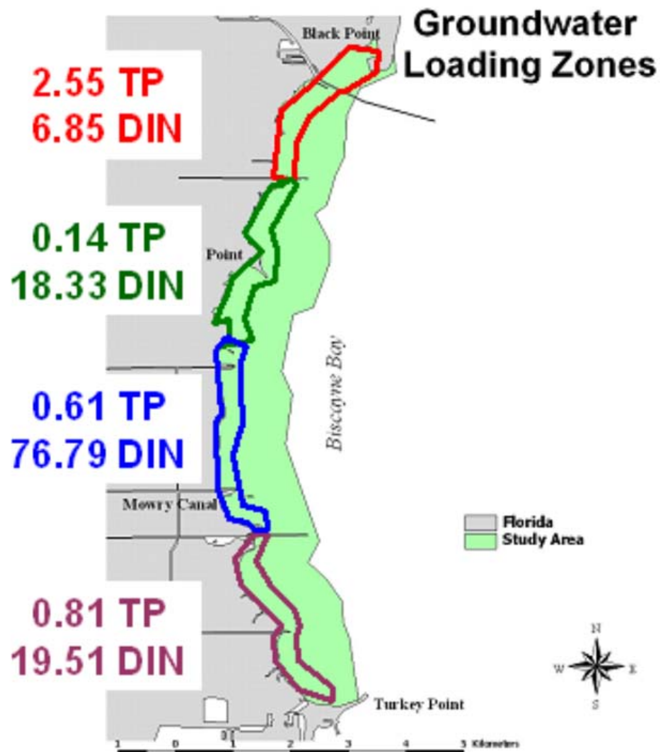


Figure 79. Reproduction of Figure 3.17 from Mir-Gonzalez (2007) showing groundwater loads (tons/yr) for each region along the shore of Biscayne National Park.

Nutrients from agriculture and urban sources are a significant problem for BNP. Everything from atmospheric deposition, surface runoff, canal discharge and groundwater contribute additional nutrients to the park. Of these, canal discharge and surface runoff are the only delivery systems which could be affected by management. However, canal discharge is largely controlled to both maintain agriculture where it still exists and to control flooding in wet periods, both of which have historically taken priority over the health of BNP. Whether this can be changed in any appreciably way in the future is not certain. Years of trying to alter the flow of nutrient rich water from point sources (canals) to surface discharge through the fringing marshes have not come to fruition. As this is being written, several small projects are on hold due to lack of money; therefore, nutrient enrichment is either an existing threat or a potential problem for all areas of the park, with the exception of the terrestrial environment. Data is good to fair, with the best information focused on the canal loading.

Table 21. Nutrient enrichment. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Nutrient Enrichment	I	I	G	G	G	G	G	F	F	F	G	

Microbial Contamination

Most ecosystems support natural communities of microbes, which provide many services to the environment. However, allochthonous microbes, which are harmful to both the environment and its inhabitants, can be introduced. Sewage leaks are but one well-known example. Typical groups of concern include: fecal coliforms, enterococci, *Clostridium perfringens*, coliphage and known pathogens such as *Escherichia coli*, *Serratia marcescens* and human enterovirus. Miami-Dade County tests human-frequented beaches for microbial contamination regularly, as well as certain other areas when a spill or sewer brake occurs. Data is largely confined to areas north of BNP and may not relate to conditions within the park.

In urban areas, discharges of treated or untreated sewage, and leakage from septic tanks, can be important sources of pollution to nearby coastal areas. Wakefield (1939) discussed the problems with sewage contamination in the Miami River and shoreline sewers and concluded Biscayne Bay was polluted by these sources. He also reported the contamination is higher closer to the source and that it does not escape out of Biscayne Bay seaward before it is "purified." Moore et al. (1955) conducted pollution studies of Biscayne Bay and concluded that virtually all freshwater entering the bay contained sewage. McNulty (1956), as part of a long running study of sewage pollution associated with the downtown Miami coastline and Miami River area, documented reduced abundance of benthic organisms in formerly polluted areas.

Lee and Bada (1977) studied amino acids from seawater, including surface samples from Biscayne Bay. They postulated a bacterial source for the acids studied. Pitt et al. (1975) studied the contamination of groundwater by septic tanks and reported that effects were diminished at depth and that agricultural activity and storm-water infiltration probably had a more important effect on groundwater quality. Shinn et al. (1994) examined the possibility of contaminated groundwater entering the bay or offshore reef areas from injection-well effluent. They found the limestone extremely porous, permeable and able to transmit fluids both vertically and horizontally. Fecal bacteria were found in groundwater offshore, which strongly indicates movement from onshore sources to the groundwater under the bay. Corrales et al. (2000) suggested abnormal scale growth in pinfish was attributable to those portions of Biscayne Bay with high sediment contamination; this would imply that this problem is associated with areas north of the park (e.g., Miami River) or in the distal ends of the canals entering Biscayne Bay. Kellogg et al. (2004) discusses the types of bacteria and fungi found on African dust samples, and this is a potential source of microbes. Renken et al. (2005) provides a good overview of the porosity issues related to the Miami Limestone formation and its ability to pass pathogens quickly via its high porosity.

So called "white" diseases in corals may be caused by microbes, such as *Serratia marcescens*, *Aurantimonas coralicida* or members of the vibrios family. The cause of such infections is unknown, but work in the U.S. Virgin Islands on corals there suggests that "white" diseases in BNP might be caused by similar activity. The USGS has proposed several projects to better understand the natural and harmful microbial activity in BNP, which may improve the data on this subject (Wolfert-Lohmann et al., 2008).

Studies of pathogens attached to atmospheric particulates suggest that deposition of fungi and bacteria to the park from outside, by aerosol means, is quite likely to occur. Some concerns have been raised for this to be a driving force for the coral declines seen in recent years, but proof is inconclusive. Microbial contamination from terrestrial sources does occur and is a potential problem for BNP. Data is sparse so the threat is inferential.

Table 22. Microbial contamination. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Microbial Contamination		I	F	P	I	P	I	F	I	F	I	

Pollutants

The reality of a large metropolitan city complex located on the shores of Biscayne Bay means the waters are subject to many sources of pollution. BNP has pollution problems similar to many other coastal areas and a few unique to this location. For Biscayne Bay, there are a variety of potential and well identified sources of pollution. As for any large metropolitan area, pollutant transport through runoff from urban structures and agricultural lands can reach the bay, either through direct runoff from adjacent areas or through drainage canals and streams. Contaminated surface water runoff is a major source of pollutants such as nutrients, pathogens and various toxicants to the Dade County canal system (Long et al., 2005). Other means of transport are through contaminated groundwater exposed to leachates from agricultural fields, landfills and municipal dumps, atmospheric deposition of pollutants derived from combustion sources, agricultural applications, industrial discharges and vehicle emissions and, finally, from direct disposal and point sources.

Surface runoff has been a historically significant source of pollution to Biscayne Bay for a long time, with environmental awareness and cleanups starting in the late 1960s and making considerable improvement more recently. Urban runoff is more problematic as one travels north of the park, but recent extensive residential development just west of the park will provide challenges in the future as this development was conducted on low-elevation land that is prone to flooding. Normal rainfall runoff along the west shore and the Keys continues, but channelization, ditching and the construction of berms and levees for various purposes affects the patterns of this runoff. Much of the surface runoff of south Miami-Dade County runs into the canal network and moves contaminants there to await a period when the canal structures are opened and the polluted water and associated sediment load are allowed into the bay. Any pollutants that end up in the canal network are likely to end up in the bay by this pathway, or they may contaminate groundwater seeping around control structures. Two power plants, Cutler Plant and Turkey Point (nuclear), are located on the shoreline of the bay adjacent to the park, and both have been sources of discharge elements of concern in the past. Expansion of the Turkey Point facility, which is undergoing consideration now, is a future unknown in this regard, as its source of cooling water is still not resolved. However, current proposals include using approximately 120 million gallons/day (mgd) from submerged radial collecting wells located under Biscayne Bay in park waters.

The degradation of the environmental quality of Biscayne Bay due to the introduction of trace metal and organic pollutants has been a topic of great concern locally. Concerns and recommendations have been addressed through the Biscayne Bay SWIM Plan (South Florida Water Management District, 1995) and, more recently, through the Biscayne Bay Partnership Initiative (Biscayne Bay Partnership Initiative, 2001; Hefty et al., 2001). SWIM addressed the need to further investigate the sources of abnormalities in fish, monitor the pollutant content in tissues of bivalve and marine organisms, establish a sediment monitoring program and establish sediment quality targets. Municipal waste dumps and landfills adjacent to the bay, and suspected of being significant pollutant point sources, needed to be properly monitored. In agreement, BBPI recommended that the effects of exposure to contaminants in surface waters and sediments needed to be determined for both local plant and animal populations, and that there was an urgency to pursue the goal of identifying and eliminating all sources of pollutants and toxicity to the bay. The need to develop water quality targets and performance indicators was stressed. As presented in this report, some aspects of these recommendations have been initiated, but the full implementation has still not been accomplished.

Biscayne Bay is surrounded almost entirely by large metropolitan areas. As a result, it is common to see studies assessing the quality of Biscayne Bay resources to make a clear distinction between the more urbanized northern portion of the bay (north of Coconut Grove-Key Biscayne) and the less urbanized southern portion of the bay where BNP is located. Regardless of this distinction, sources of pollution to the bay are usually restricted to freshwater inputs from the inland canals that receive urban runoff, industrial discharges, treated and untreated wastewaters or waters impacted by agricultural activities. Besides these inputs, activities on the bay itself, such as boat traffic and the presence of large marinas and boating facilities, are the main source of anthropogenic chemicals from near coastal environments. Because of this divide and the limited transport of sediment between the north and south portions of the bay, the following discussion will be centered on BNP.

Three groups of contaminants have been consistently targeted when environmental assessments of Biscayne Bay were or are conducted. Trace metals, chlorinated pesticides, polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs).

Early studies of pollution were focused on the impact of raw sewage from open sewers and septic tanks (Wakefield, 1939; Moore et al., 1955; McNulty, 1956). Cheesman (1989) sampled the Mowry Canal and connected North Canal and found had phenol levels higher than standard, but typical for Dade County canals.

More recently, Long et al. (1999) examined chemical contamination and toxicity of sediments in Biscayne Bay. They concluded that chemical concentrations were relatively low overall except in peripheral tributaries and canals along the bay shore, and they found the bay north of Rickenbacker Causeway to be more affected than to the south of the causeway. Cantillo and Lauenstein (2004) analyzed samples from South Biscayne Bay and Manatee Bay for contaminated marine sediment. Organophosphates were detected at three sites, including Military and North Canals. They also found that contaminant plumes do not extend seaward of the canal mouths to any appreciable extent so the sediments in open areas of the park have generally low toxicity. Lidz (2002) reported initial results of surface sediment samples analyzed for heavy metals and concluded that deformed benthic forams were common near the landfill (Black Point area), and that nearshore sites showed more signs of environmental stressors. The stressors suggested were anthropogenic pollution and sea level rise.

Runoff-related pollution is one of the oldest recognized problems in Miami-Dade County and has the most research associated with it. There are many agencies in place that deal with aspects of the problem and numerous lines of continuing research. The most heavily polluted areas are generally accepted as being the Miami River and vicinity, marinas and the mouth of canals discharging into the bay. The park needs to be vigilant in monitoring the canal-related pollution and in working toward cleaner means of accessing park waters, other than the current boating technologies. The transfer of flocculated sediment southward from the seaport occurring at mid-bay in deep water, and the ultimate fate of chemicals escaping the urban coastline along the NW park boundary, should be of concern. With sea level rise in the future, wave and current energy levels will rise and the ability to erode and move polluted sediment will increase with time.

Groundwater discharge to the bay occurs along the shoreline where former springs and seeps are located, as diffuse flow from the underlying limestone up through sediment packages along the nearshore and as percolating seeps into the bottom of the bay, or perhaps even the reef tract from, deep aquifer sources via fault structures (Cunningham, 2008).

Waller et al. (1984) studied the effect of depth on stormwater contamination as groundwater percolates downward in the Miami Limestone, contamination decreasing as a result. Shinn and Corcoran (1987) installed wells adjacent to the landfill in South Miami-Dade and detected Lindane, Aldrin, o,p'-DDD, endosulfan and dimethyl phthalate (plasticizer) in the shallowest samples and Aldrin, endosulfan and dimethyl phthalate in deeper samples, but at half the surface concentrations. Aliphatic and aromatic hydrocarbons were also found with lower values below an unconformity. Shinn et al. (1994) examined the possibility of contaminated groundwater entering the bay or offshore reef areas from injection-well effluent. They found the Pleistocene limestones extremely porous and permeable, with the ability to transmit fluids both vertically and horizontally. Nutrient levels in offshore groundwater were elevated compared to those found in the overlying seawater. Reefs and bare bottom areas, as well as those with porous sediment cover, were capable of leaking nutrients into the overlying water. Presence of fecal bacteria found in groundwater offshore strongly indicated movement from onshore sources to the groundwater under Biscayne Bay. Renken et al. (2005) examined porosity issues in the Miami limestone and reported that values used in the past are too low, and groundwater movement is much faster than previously realized. Meeder et al. (1997) and Meeder and Boyer (2000) compared nutrient levels in surface and groundwater environments along the shoreline of BNP and found elevated levels of ammonia in areas adjacent to the South Dade landfill and other inactive landfills nearby. An association with reduced benthic grass cover was made. McNeill (2000) examined the leakage of effluent around poorly installed injection wells adjacent to the south Miami-Dade landfill and found seven of 15 wells to be leaking upwards because the confining unit was not properly sealed.

Groundwater inputs to the park are the least understood and perhaps the most needing attention in the future. Clearly, there are polluted waters entering the bay, even with reduced groundwater heads. More effort should be placed on finding underwater springs or seeps, and a better understanding of the seepage through the rocks and surface sediments is needed.

Direct discharge of polluting chemicals to Biscayne Bay and adjacent areas can occur in a number of ways. The most obvious is illegal dumping, which is difficult to control. More commonly are boating activities which can introduce toxic chemicals including antifouling paints, petroleum hydrocarbons and trace metals to the environment, including those related to chemical toilets through illegal flushing within park waters. Marinas and marine facilities located along portions of the shoreline are sources of many contaminants; bottom sediments can become polluted and periodically flushed into the bay when re-suspended due to tidal action, increased water discharge, turbulence created by boat traffic or weather-related events. Toxic materials located on shore can be introduced into the bay systems by erosion during storms, as polluted sediments or deposits are picked up and redeposited seaward. This process is not well documented or understood and can be considered minor—until one examines the potential problems of sea level rise on remobilization of landfill materials and polluted canal/river sediments. There are many small landfills adjacent to the park and two large ones located nearby. The landfill on Virginia Key is the most exposed to the ocean and, with a rising sea level, will become threatened with erosion first. It already has an effect on groundwater leaving the Key, as does the large South Dade landfill, but both landfills will require intervention in order to keep the large amount of contaminants in them from entering bay waters in the future.

Many point source discharges of pollutants are thus related to marinas and areas where boat maintenance and repairs are performed. Most of these pollutants are expected to be derived from engine lubricants, fuels, paints and body-work related materials, including such antifouling agents as Cu(II) and butyl-tins, and organics such as Irgarol 1051 (an anti-fouling paint additive); runoff from highly urbanized portions of the county are second in importance. Corcoran et al. (1983) examined the hydrocarbons found in sediments throughout Biscayne Bay. They found that hydrocarbons in surface sediments ranged from below detection to ca. 3,000 µg/g, surface waters from 0.8-64.5 µg/L and biota from 0.3-601µg/g, with highest values associated with the Miami River and its plume. Gardinali et al. (2002, 2004) detected Irgarol 1051 in surface waters from Biscayne Bay. High values were found in the Miami River and poorly circulated marinas, with lesser values associated with navigation channels and open water areas. Irgarol's impact on coral reefs was thought to be minor because of rapid degradation away from the point source. Gardinali and Fernandez (2008) looked at uptake of Ingarol by submerged vegetation and found *Halodule wrightii* (shoal grass) had the highest capacity to accumulate it in the tissues. Gardinali et al. (2008b) analyzed sediments at 11 stations in BNP for pesticides, herbicides, PAHs and pharmaceutical byproducts with the canals leading to the bay having significant values, as did the marinas studied.

While much of the point-source discharges cannot be controlled at the park level, some forms can be reduced with due diligence in working with visitors and users. The park already works on this aspect, and more resources may be required in the future as increasing water depth will encourage usage of more and larger vessels, since the Miami area continues to expand.

Ultimately, toxic chemicals introduced into the bay will become associated with bottom sediments and find their way up the food chain to bioaccumulate in organisms of higher trophic levels (e.g., bottlenose dolphins). Corcoran et al. (1984a,b) examined the trace metals, pesticides, PCBs, and phtalic acid esters in Biscayne Bay sediments. Phthalic acid esters (PAE) were found most frequently followed by herbicides, PCBs, and then insecticides. High concentrations of synthetic organic compounds and metals were found in north Biscayne Bay and in the canals entering the bay, where PAEs were ubiquitous. Similarly, Gardinali et al. (2008a) examined trace metals in sediments from BNP and found elevated levels of Cu, Zn and Pb in two samples taken from shoreline marinas, as well as enriched values of Cu and Zn in several other stations in the park. High values of PAHs in these areas indicated that they were predominantly coming from vehicle and vessel exhausts. Such accumulation of toxic pollutants can affect the environmental health of aquatic ecosystems. Long (2000) compared estuaries nationally and found toxicity in 30-45% of sediment samples from Biscayne Bay and categorized overall Bay toxicity as intermediate to least pervasive. Long et al. (2002) conducted another toxicity study of Biscayne Bay and found the highest levels of chemical contamination in the lower Miami River and concluded the highest pollution-induced degradation was associated with river and canal locations.

Pharmaceutical Chemicals

A group of new contaminants of particular concern is the pharmaceuticals and personal care products. Usually introduced through the discharge of treated and untreated human derived wastewater, these set of diverse chemicals have the potential to cause numerous effects, including endocrine disruption. Few data are available and only isolated reports of their presence in canal waters (Cantillo and Lauestein, 2004; Singh, 2006) are available to date. Reports of nonylphenol etoxylates, caffeine, several hormones and fecal steroids at low part per trillion levels are common at the C-1 canal and in several of the canals leading to BNP (Princeton and Florida City canals). Although the environmental risk associated with the presence of such chemicals is not fully understood, close monitoring of the present trends is important to assess future changes in water deliveries, which will be implemented as part of CERP and the pressing need for Miami-Dade County to rehydrate coastal wetlands with reclaimed water.

Pait et al. (2006) found cotinine, acetaminophen and anthelmintic thiabendazole mostly in samples taken near the canals along the western shoreline of south Biscayne Bay. Lietz and Meyer (2006) have analyzed the wastewater at the South District Wastewater Treatment Plant adjacent to the landfill to obtain baseline data in preparation for using the wastewater for coastal restoration projects planned for the coastline of BNP. These authors detected a series of pharmaceuticals and other pollutants of concern, suggesting that the discharge of such treated wastewaters may still pose a threat to organisms in Biscayne Bay.

Pesticides and Herbicides

Key et al. (2003) examined pesticides attributed to contaminated canal discharge levels in grass shrimp and found correlation between reduced levels of acetylcholinesterase enzyme and canal chemicals at Military and North Canals. Cantillo and Lauenstein (2004) analyzed samples from South Biscayne Bay and Manatee Bay for contaminated marine sediment. Eight types of pesticide were found in seawater samples including atrazine, metolachor, CEAT, CIAT (metabolized herbicides), chlorpyrifos, diazinon, malathion and 4,4'DDE (DDT metabolite). The majority was found at highest levels at the upstream sites associated with the canal network; at the mouths of the canals, metolachlor was present at all sites sampled. Two sites, Princeton Canal mouth and Florida City Canal mouth, had high levels of ethoxylates which can be an endocrine disruptor. Carriger and Rand (2008) attempted to assess the aquatic risk caused by atrazine, metolachlor, Malathion, chlorpyrifos and endosulfan in south Biscayne Bay and found that atrazine was the most frequently detected pesticide, but only at low levels. Harman-Fetcho et al. (2005) studied pesticides associated with agricultural runoff to the canal network and found that there were seasonal variations and that harvest season when endosulfan is commonly used had a higher hazard potential. Seba (1969) reported pesticides associated with surface microlayers in Biscayne Bay related to atmospheric transport and deposition.

Past and present-use pesticides and herbicides have been consistently detected in canals and near-shore locations along the southern portions of the bay. For example, Atrazine and some of its metabolites are present in almost all water samples collected in the freshwater environments at concentrations up to approximately 100 ng/L and also in coastal areas at lower levels 5-10 ng/L; a similar trend is also evident for the herbicide Metolachlor. However, the water quality guidelines for these herbicides are several orders of magnitude above the environmental concentrations, thus they are unlikely to produce detrimental effects. Past use pesticides, mainly p,p'-DDE (the environmental metabolite of DDT), are often found in canal sediments and in occasions in the areas immediately adjacent to canal discharge points (Princeton, Military, Mowry, North and Florida City Canal and Black Point Marina). Gardinali et al. (2008c) examined the levels of endosulfan in fish tissues from Biscayne and Everglades national parks, and reported that endosulfan sulfate is generally present in areas of Everglades National Park near the Homestead Agricultural Area (HAA), but seldom detected in coastal areas of Biscayne Bay. Lauenstein et al. (1997) shows the location of Mussel Watch Project sites used in the NSTP, where bivalves are studied for bioaccumulation of organic compounds. These are located at the north end of Biscayne Bay at Maule Lake and at both the Goulds and Princeton Canals on the shore of BNP. Oysters are the species they examine in Biscayne Bay but this effort is hampered by small size and scarcity, resulting from the collapse of the freshwater system alongshore the two southern sites.

Metals

Judge and Curtiss (1977) examined sediment samples from the middle of Biscayne Bay (just north of the park) for heavy metal contamination and found little difference between most areas sampled, except for lower values near Fisher Island and a sink for metals in sediments near the mouth of the Miami River. They expressed the concern that south Biscayne Bay may have been polluted by waters from North Biscayne Bay. Schroeder and Thorhaug (1980) examined uptake of trace metals into seagrass blades, finding higher levels in tissues than in the surrounding water. Miller (1984) analyzed the runoff from several different basins types in South Florida and found the highest lead runoff was from a commercial (shopping center) basin. Further, he found that rainfall of less than 2 inches tended to draw contaminants only from the contributing basin, with more rain required to have overflow from adjacent basins present. Cantillo and Lauenstein (2004) analyzed samples from South Biscayne Bay and Manatee Bay for contaminated marine sediment. The total trace metals (Cu, Zn, Ni, Pb, Cd, Hg, Ag) found in sediments at the mouths of five canals studied indicated toxic conditions were likely. Lidz (2002) reported initial results of surface sediment samples analyzed for heavy metals and concluded that Cu, Pb and Zn were highest near marines in the upper parts of the bay and that metal contamination decreased toward the south (away from older urban areas) and seaward.

Among the trace metals, copper, arsenic, and lead have been reported in sediments of the bay at concentrations that are above the national median for the NOAA NS&T Mussel watch program and in some cases above the 85th Percentile “high” (copper at the North Canal – Bayfront Marina; Table 23). However, all the values reported for south Biscayne Bay, away from the influences of marinas, are below the “probable effects level” (PEL), or the sediment quality assessment guidelines (SQAGs), for coastal sediments used in Florida to assess sediment contamination (Table 24). With regards to mercury levels in biota, Evans et al. (2008) reported mercury levels in fish samples from Florida Bay and Biscayne Bay, with highest values in crevalle jacks found in south Florida and in other species associated with areas of restricted circulation.

Anti-fouling Agents

In the past decade, some non-traditional contaminants have been reported near BNP. Organotin tin (TBTs) antifouling compounds were reported in sediments at the North Canal at Homestead Bayfront Marina, and Irgarol 1051, an antifouling booster biocide, was reported in many marinas in the bay. All these pollutants are related to boating activity, so transport beyond their localized usage area is not expected. Since TBTs have been banned, Irgarol 1051and copper are contaminants that need to be monitored for marinas and boatyards.

PCBs and PAHs

Lang and coworkers (Lang et al., 2002) reported the abundance and atmospheric deposition of a variety of organic contaminants, including polycyclic aromatic hydrocarbons (PAHs), in the Miami metropolitan area. PAHs are commonly present in many sediment samples, but their concentrations are relatively low and consistent, with background levels in urbanized areas. Marinas, however, represent a deviation of this observation; it is common to see sediments in canals and access areas to major marinas with elevated concentrations of total PAHs.

Thermal Pollution

Water temperature often determines the range of species found in marine waters. Freezing water is not an expected problem in South Florida, as cold events are rare and of short duration; however, cold water can cause some mobile species to move to warmer water. The best known example is the manatee, which will move into warmer canals or other warm areas during colder periods; fish and other aquatic animals do likewise. The problem of hot water can be natural; summer heating makes water temperatures quite high with shallow, low circulation areas along the coastline becoming “bathtub” hot. Certain important benthic species are temperature-limited (e.g., *Thalassia*); this controls where they can thrive.

	Al (%)	Si (%)	Cr	Mn	Fe (%)
n	223	178	222	199	223
Median	2.4	3.0	54	370	2.1
85th percentile	4.8	36	120	740	3.7
	Ni	Cu	Zn	As	Se
n	223	223	223	223	207
Median	17	14	67	6.9	0.38
85th percentile	36	47	130	12	0.74
	Ag	Cd	Sn	Sb	Hg
n	223	223	223	178	223
Median	0.11	0.19	1.3	0.47	0.057
85th percentile	0.59	0.56	3.1	1.8	0.22
	Tl	Pb	TOC (%)	ΣDDTs	ΣPCBs
n	145	223	220	224	224
Median	0.073	18	1.0	2.9	15
85th percentile	0.56	40	2.4	18	80
	ΣPAHs	ΣCdane	ΣDieldrin	Mirex	
n	224	224	224	224	
Median	380	0.51	0.30	0.002	
85th percentile	2300	3.1	1.9	0.36	
	Hexachloro-benzene	Lindane			
n	223	224			
Median	0.14	0.04			
85th percentile	0.92	0.47			

ΣDDTs: The sum of concentrations of DDTs and its metabolites, DDEs and DDDs.
ΣPCBs: The sum of the concentrations of homologs, which is approximately twice the sum of the 18 congeners.
ΣPAHs: The sum of concentrations of the 18 PAH compounds determined on a long term basis as part of the NS&T Program.
ΣCdane: The sum of *cis*-chlordane, *trans*-nonachlor, heptachlor and heptachlorepoxide.
ΣDieldrin: The sum of dieldrin and aldrin.
ΣBTs: The sum of the concentrations of tributyltin and its breakdown products dibutyltin and monobutyltin (as ng Sn/g dry wt.).
n: Number of data points (roughly equivalent to the number of sampling sites).

Table 23. National Status and Trends (NS&T) Mussel Watch sediment data medians and 85th percentile values (1986-1993). (Medians and percentiles were determined using the average at each site across all sampled years. Element data in µg/g dry wt., unless noted, and organic data in ng/g dry wt.). From Cantillo and Lauenstein, 2004.

The principal source of anthropogenic heating is the outfall waters from power plants. Considerable study of this effect has been conducted in the past at Turkey Point, where the nuclear reactors use water for cooling (Figure 80). The original petroleum-fired generators (Units 1 and 2) burned fuel transported to the location by a barge through a long canal dredged in the bottom of Biscayne Bay (Turkey Point Barge Canal). Cooling waters run through the plant and were discharged directly into what was then Biscayne National Monument. In 1970, the U.S. Department of Justice sued Florida Power and Light Co. for discharging water that was 10-20 degrees hotter, which was damaging marine life (Science, 1970). The solution was to construct 168 mi of cooling canal, located on former wetlands southwest of the power plant, which ended up covering an area two miles wide by five miles long (U.S. Nuclear Regulatory Commission, 2002). Hot discharge water enters one end and is reused after travelling sufficient distance to cool off. Outlets from the canal system exist, but are closed off to contain the cooling waters. Seepage below the earthen levees is possible, but has not been documented.

Thermal pollution is a potential threat to the canal network and perhaps groundwater near the park, but is under control in south Biscayne Bay and Card Sound and not a problem in the more marine areas of the park.

Table 24. State of Florida sediment quality assessment guidelines (SQAGs) applicable to coastal waters (TEL = threshold effects level and PEL= probable effects level).

Substance	Total Number of Records	Number of Entries in the EDS	Number of Entries in the NEDS	Sediment Quality Assessment Guidelines TEL	PEL
Polycyclic Aromatic Hydrocarbons (PAHs; SQAGs in µg/kg)					
Benz(a)anthracene	249	63	186	74.8	693
Benzo(a)pyrene	259	68	191	88.8	763
Chrysene	258	68	190	108	846
Dibenzo(a,h)anthracene	246	54	192	6.22	135
Fluoranthene	279	85	194	113	1494
Pyrene	263	70	193	153	1398
Sum HMW-PAHs	274	64	210	655	6676
Total PAHs	250	58	192	1684	16770
Pesticides (SQAGs in µg/kg)					
Aldrin	180	15	165	ID	ID
Azinphos-methyl (Guthion)	0	0	0	ID	ID
Chlordane	203	25	178	2.26	4.79
Chlorthalonil	0	0	0	ID	ID
Chlorpyrifos	1	1	0	ID	ID
p,p'-DDD	173	22	151	1.22	7.81
p,p'-DDE	211	37	174	2.07	374
p,p'-DDT	175	26	149	1.19	4.77
Total DDT	89	37	52	3.89	51.7
Dieldrin	181	25	156	0.715	4.3
Disulfoton	0	0	0	ID	ID
Endosulfan	6	4	2	ID	ID
Endrin	146	14	132	ID	ID

Substance	Total Number of Records	Number of Entries in the EDS	Number of Entries in the NEDS	Sediment Quality Assessment Guidelines TEL	PEL
Pesticides (SQAGs in µg/kg)					
Heptachlor	168	14	154	ID	ID
Heptachlor epoxide	137	9	128	ID	ID
Lindane (gamma-BHC)	181	21	160	0.32	0.99
Mirex	120	3	117	ID	ID
Phorate	0	0	0	ID	ID
Quintozene (PCNB)	0	0	0	ID	ID
Toxaphene (alpha-BHC)	133	4	129	ID	ID
Trifluralin	0	0	0	ID	ID
Chlorinated Organic Substances (SQAGs in µg/kg)					
2,3,7,8-Tetrachlorodibenzo-p-dioxin	18	2	16	ID	ID
2,3,7,8-Tetrachlorodibenzofuran	17	1	16	ID	ID
Pentachlorophenol	82	7	75	ID	ID
Phthalates (SQAGs in µg/kg)					
Bis(2-ethylhexyl)phthalate	131	31	100	182	2647
Dimethyl phthalate	86	10	76	ID	ID
Di-n-butyl phthalate	79	7	72	ID	ID

Total Number of Records = Number of data records in the expanded biological effects database for sediments.
All of the sediment quality assessment guidelines are expressed on a dry weight basis, as potential normalizers (e.g., Al, TOC, AVS) were rarely reported.
EDS = Effects data set: NEDS = No effects data set; TEL = Toxic effect level; PEL = Probable effect level.
ID = insufficient data to derive sediment quality assessment guidelines.
SQAG = Sediment quality assessment guidelines

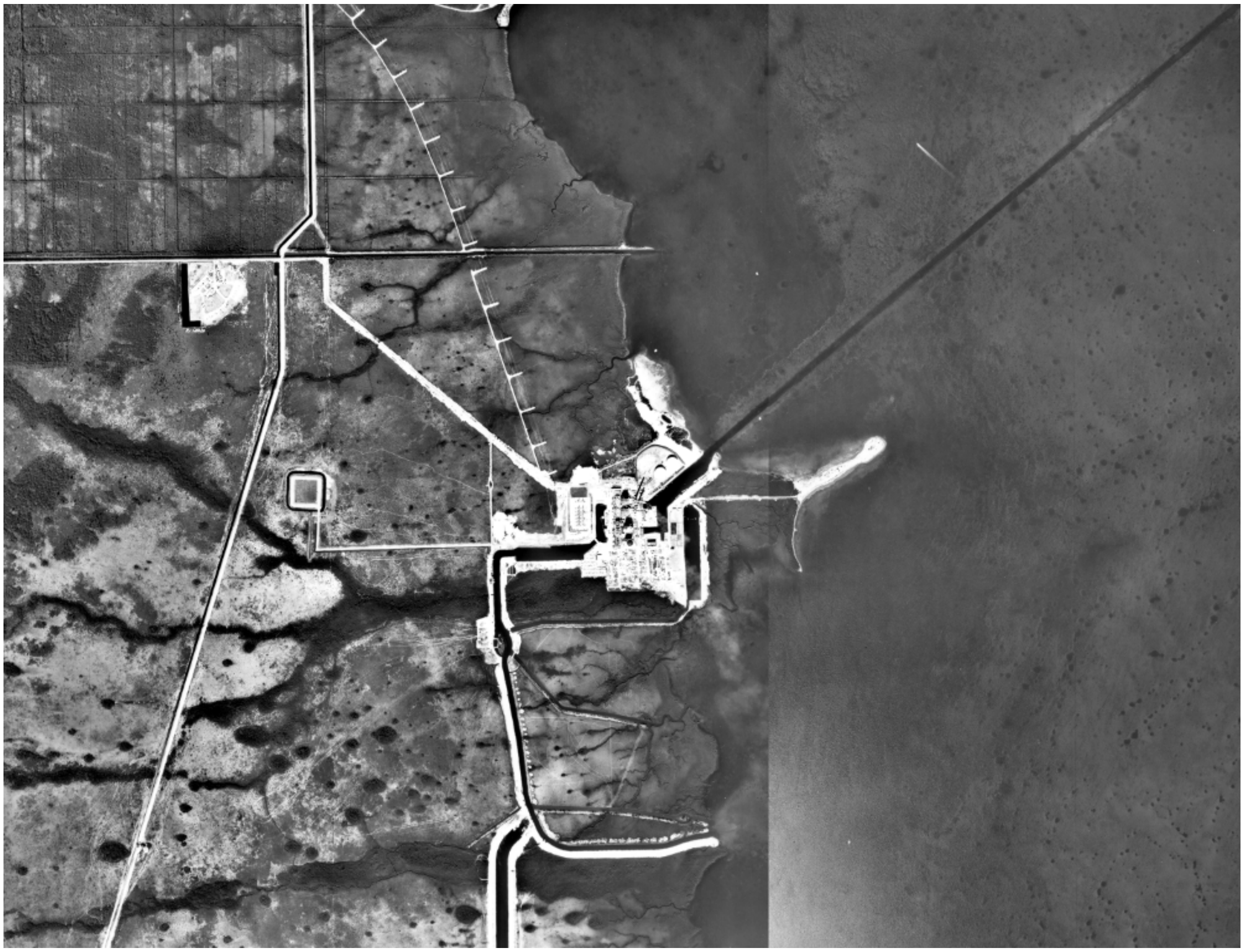


Figure 80. Turkey Point nuclear plant site in 1971 during construction. The first of the cooling canals can be seen at bottom center. The area between the north/south canals is now covered with additional cooling canals. Note the former freshwater stream/tidal creek system the FPL plant was built upon (Florida DOT, 1971, composite). Compare with Figure 47.

Radiological Contamination

The presence of a nuclear reactor complex on the SW shoreline of BNP represents a threat of radiological contamination. Turkey Point Nuclear Plant, Units 3 and 4, are currently licensed by the Nuclear Regulatory Commission; renewed in 2002 for 20 years beyond the current license, they have expiration dates of July 19, 2012, and April 10, 2013, respectively. Turkey Point Units 3 and 4 are Westinghouse pressurized-water reactor nuclear steam supply systems designed to produce a core thermal power of 2,300 megawatts or approximately 693 net megawatts of electric power (U.S. Nuclear Regulatory Commission, 2002).

The FPL-operated plant is governed by federal, state and county rules and an elaborate warning system to warn inhabitants in case of an accident (Miami-Dade County, 2009). The release of small amounts of radioactive material in discharge waters, or as a gas, is monitored and within limits set by the NRC. Small amounts of tritium are released with the cooling water and some small portion has leaked by groundwater to the perimeter of the property, but levels are considered low. Sampling has shown tritium at levels above 4,000 pCi/L in the bottom of the canal surrounding the cooling structure (Florida Power and Light, 2007). However, the inferred threat of a catastrophic release during a future accident is a potential problem requiring vigilance. The primary, long-term health concern of a spill is an increased risk of cancer in humans. Studies exist on the effect of nuclear weapon testing in the South Pacific (e.g., Bikini Atoll); the effects on BNP resources from a spill at Turkey Point are unknown, but assumed to be negative. The likelihood of expanding the plant to include two additional reactors, as FPL is requesting, increases the likelihood of a radiological release into park space (most of the park is within 10 mi of the facility). Park headquarters are within the 5-mile boundary. A significant radiological accident would likely require the park to be closed to visitors and users of park resources for a considerable time, and could have severe, long-term consequences for its natural resources.

Table 25. Pollutants. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Pharmaceuticals	I	I	F	F	F	F	F	F	F	F	F	
Pesticides and Herbicides	F	F	F	F	F	F	F	F	F	F	F	
Metals	F	F	F	F	F	F	F	F	F	F	F	
Antifouling Agents							P	P	P	P		
PCBs and PAHs	F	F	F	F	F	F	F	F	F	F	I	
Thermal Pollution			I	I	I	I	G	G	I	I	I	
Radiological Contamination	I	I	I	I	I	I	I	I	I	I	I	
Marine Debris	P	I	I	I	P	I	I	I	I	I		

Marine Debris

When a vessel sinks or is abandoned, it can become an environmental hazard and pollution source. Vessel sinkings are relatively rare except during hurricanes, when vessels may be brought into park waters for refuge during the onset of the storm, or drift there for various reasons. Both the U.S. Coast Guard and National Park Service have response teams or plans, which have been used in the past and should be effective in most cases in the future. However, one category of marine debris not under control is “marine trash,” which enters the park by floating on or in the water and ends up on the bottom or, more likely, the shoreline. Examination of the trash indicates that much of it is not locally derived but comes from the Caribbean, Europe and other locales. Debris of this type can damage coral colonies, prevent female sea turtles from nesting, prevent newly hatched turtles from reaching the ocean, strangulate or kill by ingestion many species which inadvertently eat it and negatively impact habitats used by migratory shorebirds.

All windward coastline areas of the park suffer this problem, which can only be mitigated by cleanups. Events, such as the yearly Baynanza sponsored by Miami-Dade County DERM, include clean-up patrols that pull trash off of shorelines (38 tons in 2008), and the park participates in "Alternative Spring Break" in March. Park staff is assisted by volunteer high school and college students who clean up trash along the coastlines in BNP. As long as people on boats throw trash overboard, the problem will continue, and increases in the boating population will only exacerbate the problem. Figure 81 shows one example of the magnitude of the problem. Marine debris is an existing problem in BNP in all resource categories except groundwater. Detailed data for the park is poor or must be inferred from direct observation.

Figure 81. Aerial view of the east coast of Elliott Key. The brownish algal covered intertidal surface back from the beach berm is covered in trash (white dots) and larger debris (wood pallets). Storm tides move this material inland, and debris can be found even in the center of the island (2008, P. W. Harlem).

Fire

Egler (1952) made extensive notes on the effects of fire on vegetation patterns in the Southeastern Saline Everglades (SESE). He described the way that the type and nature of shrub and tree species communities were driven by fire, and he discussed the different kinds of fire that occurred naturally and anthropogenically. He believed that Native Americans started fires (intentionally and accidentally) and suggested that their arrival in Florida produced detectable changes in hammocks and shrubs. He described a change from many "light" fires in historic times, to a regime where fire occurs naturally, but less frequently, with more destructive fires because more fuel is built up between them. He suggested the spread of mangroves is partly a result of the change in fire patterns. This is especially important in the sawgrass-dominated zone west of the mangrove fringe ("white zone") where fire was an important mechanism to prevent invasion by woody plants into the grass marsh. He discussed the ability of exotics like *Casuarina* (Australian pine) to spread because of the change in fire regime, and many areas that used to be sawgrass are now dominated by exotics.

Historic fire data is virtually absent, as fire is not documented for the islands except for an account of early settlers setting fires to burn out hammocks in order to produce land for farming

(Munroe and Gilpin, 1930). The 2004 NPS fire management plan (NPS, 2004) describes eight wildfires within park boundaries on the mainland, affecting two acres total, and all suppressed. The fire locations are not shown but are described as being located in previously disturbed areas dominated, apparently, by exotic vegetation.

Managers in other regions have used fire to control habitat development and to produce positive effects from nutrient recycling. Wildfires in or adjacent to the park are routinely extinguished because of the potential loss to human development and negative impact on transportation lines (e.g., smoke on highways). This behavior is driven by the park's fire management plan, which is designed for upland parks, and whose main priority is the suppression of wildfire. This has further reduced the role fire in determining the pattern and successional patterns of coastal vegetation. There has been no attempt to use fire to control vegetation patterns resulting in an increase in spread of exotics and mangroves into former grasslands, aided by the lowered water table and intrusion of salt into former wetlands by storm surge and sea level rise.

The park's fire management plan dictates suppression of all wildfires. In order to facilitate this, the property has been divided into three Fire Management Units. Unit 1 is the mainland property, Unit 2 is Elliot and Boca Chita Keys, and Unit 3 is divided between the Old Rhodes Key/Totten Key complex and the Ragged Keys (Figure 82).

Table 26. Fire. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Curtailment of historic fire patterns	P	P										

Hydrology/Water Management

Freshwater input from the mainland is largely controlled by anthropogenic structures, which were built in the last 100+ years to provide drainage of the naturally wet landscape. The original, much larger Everglades supported numerous streams and transverse glades across the Miami limestone ridge that has been radically altered since the 1890s. Canal construction eliminated rock barriers to overland flow, which drained lands and channelized flows to the east. Mosquito ditching along the coastline broke up natural pathways into small ineffective pieces, and storm levee construction in the 1960s eliminated overland surface runoff for the majority of the park coastline. The resulting system is heavily impacted; this affects water quality in numerous ways.

Wingard (2004) used invertebrate assemblages to assess changes in salinity patterns from cores taken from several sediment bodies in Biscayne Bay, Card and Barnes Sounds and Manatee Bay. They were dated using isotopes and calibrated with the first occurrence of Australia pine pollen. The data showed an increase in salinity in all the bays. Gaiser et al. (2006) used diatom species distribution and community structure to examine water quality in Biscayne Bay. They concluded that diatoms could predict salinity values within 2.5 ppt, with high accuracy in predicting water

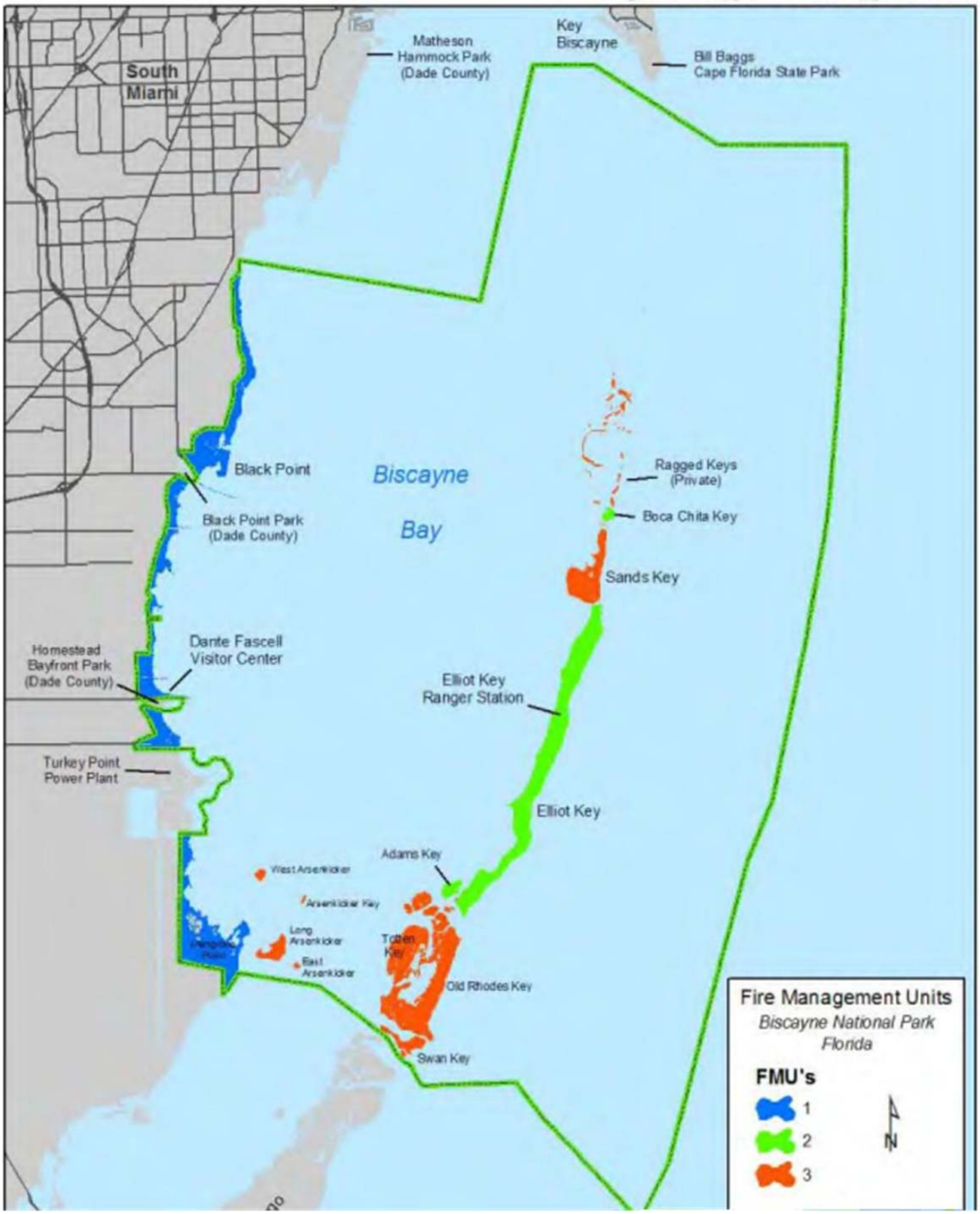


Figure 82. Fire management units in National Park Service Fire Management Plan (NPS, 2004).

column and soil phosphorus concentrations. A high degree of habitat specificity was found, which could be used for both a water quality indicator and analog for interpretation of paleo-record in sediment cores. Diatoms were both good predictors of salinity as communities changed with seasonal trends, and species composition reflected macro-nutrient availability.

Regional Stage/Level

Drainage of the Everglades Basin has been ongoing since the late 1800s when early visitors first suggested that the local lands would be farmable or developable if the water was removed. Canal construction began in earnest around the turn of the century when the Miami Canal was dug by floating dredge from the Miami River to Lake Okeechobee. Other canals soon followed, ultimately resulting in a drop in Everglades water stage levels from 4-6 ft by the late 1940s (Parker et al., 1955) and further lowering thereafter (McVoy, 2011). Since the 1960s, development pressure and flood control mandated to the South Florida Water Management District has produced lake levels as low as 10 ft. This indicates a loss of about half the former water supply. The CERP plan for the Everglades (South Florida Water Management District, 2004) envisions raising the levels in the main basin with a retaining structure along the east side; this will control flooding of urban build out in former wetlands. The Biscayne Bay Coastal Wetlands project is pending, as is a plan to use diverted canal water to rehydrate the coastal wetlands seaward of the coastal control structure (L-31E levee).

The result of drainage modification of stage levels has been:

- The loss both sheet flow through the coastal marshes and loss of surface streams.
- The control of remaining surface flow by many levee structures associated with canals, ditches, and roads.
- Alteration of the timing of water delivery to the coast to controlled releases and emergency releases associated with wet hurricanes.
- Drying of wetlands allowing rezoning as farmland and/or urban use categories. The development of all privately-held coastal land remains a possibility.
- Spread of mangroves inland at the expense of the former coastal gramminoid marshes.
- Increased salt water intrusion landward.
- Connection of surface water to the upper aquifer by unlined structures dug through the coastal marl aquaclude.

Discharge

<u>Stream Discharge</u>

Natural streams used to flow into Biscayne Bay along the coast of what is now BNP. Several rivers emptied into north Biscayne Bay (Miami, Little, Arch Creek, Oleta and Snake Creek). Snapper Creek, just south of Matheson Hammock Park, Cutler Creek under the Deering hardwood hammock, Black Creek (North R. on the oldest maps) to the west of Black Point and a series of small coastal streams (unnamed) emptied directly into the bay at, or adjacent to, the park's current coastline. The largest of these were channelized to produce the current coastal canal network. Many lesser streams were cut off from their water source, which allowed them to convert to tidal creeks and were easily invaded with red mangroves along their former trace. Mangrove peat built up along the channels, infilled the lows and raised the levees to the point where restoration would require modification to restore the original morphology (Meeder et al., 2002, 2003). Surface stream discharge into the park is effectively nonexistent.

Springs entering directly into Biscayne Bay still exist near the Deering Estate (National Oceanographic and Atmospheric Administration, 2006) and may exist in the park (Belmund et al., 2008) although numbers and flow values are few; this aspect of discharge is not possible to estimate. However, the widespread karst throughout the Miami Limestone (Harlem and Meeder, 2008; Meeder and Harlem, in progress) argues that this mechanism was important in the past.

Canal Discharge

The major canals emptying into Biscayne Bay (Figure 7) north of BNP include (from south to north): Cutler Drain (C-100), Snapper Creek (C-2), Coral Gables Waterway (C-3), Miami River, Little River (C-7), Biscayne Canal (C-8), Arch Creek and Snake Creek (C-9). All drain heavily urbanized terrains. Canals emptying into the western edge of the park include Mowry Canal (C-103), Military Canal, Princeton Canal (C-102) and Black Creek (C-1). Black Creek is a collector canal with input from several others draining the land west of Cutler Ridge. These extend across former farmlands which, in recent years, have been converted into residential or urban terrain. To the south are several main canals which can impact the adjacent waters, namely Card Sound Canal and the Aerojet Canal (C-111). North Canal and Florida City Canal are located just south of Mowry Canal; both are now plugged and the latter's outlet path has recently been restored for a mitigation project. A planned project to restore Cutler Creek through the Deering Estate with water from the inland C-100A canal would be located northwest of the park perimeter.

Table 27 gives the average yearly flows from the five canals closest to BNP calculated from South Florida Water Management District data (DbHydro online). Water releases since 1989 total 4.12×10^{12} ft^3 and the average yearly release rate is almost 200,000 ft^3/s. These numbers are a fraction of what was received by overland flow and surface streams historically (Meeder et al., 2003, 2002; SFWMD, 2008) when the water level in the Everglades was higher. The release of large volumes of fresh water to the nearshore affects the marine benthic community negatively; therefore, canal discharge is an existing problem for the park.

Timing

Discharge timing is controlled seasonally to allow inland groundwater levels to be manipulated for farming requirements and to adjust to wetter periods, when surface flooding can cause problems in the urban environments. During extreme weather events with high rainfall, some of the canal gates are opened to reduce upland flooding; this becomes the largest volume of water released to Biscayne Bay. This timing is loosely tied to the natural rainfall patterns, but otherwise does not simulate the historical release patterns well. This affects species downstream which are adapted to natural event timing, as the freshwater releases come either too soon, or too late, for their life cycles.

Table 27. Yearly average flow rates from principal canals discharging water into Biscayne Bay adjacent to Biscayne National Park. Data prepared by Frank Marshall (with permission).

Year	C-1 Rate (cfs)	C-1 Volume (cf)	C-102 Rate (cfs)	C-102 Volume (cf)	Military Rate (cfs)	Military Volume(cf)
1989	11,388	3.59E+11				
1990	21,822	6.88E+11				
1991	52,573	1.66E+12	30,951	9.76E+11		
1992	55,418	1.75E+12	45,476	1.43E+12		
1993	50,646	1.60E+12	36,665	1.16E+12		
1994	92,427	2.91E+12	46,959	1.48E+12		
1995	126,583	3.99E+12	59,543	1.88E+12		
1996	60,042	1.89E+12	32,979	1.04E+12		
1997	67,434	2.13E+12	37,908	1.20E+12		
1998	82,545	2.60E+12	34,679	1.09E+12	5,363	1.69E+11
1999	77,243	2.44E+12	50,008	1.58E+12	6,990	2.20E+11
2000	46,216	1.46E+12	47,155	1.49E+12	6,265	1.98E+11
2001	65,692	2.07E+12	48,793	1.54E+12	12,462	3.93E+11
2002	95,774	3.02E+12	53,568	1.69E+12	12,789	4.03E+11
2003	111,221	3.51E+12	50,140	1.58E+12	4,782	1.51E+11
2004	74,981	2.36E+12	39,431	1.24E+12	2,564	8.09E+10
2005	92,414	2.91E+12	61,125	1.93E+12	15,500	4.89E+11
2006	62,861	1.98E+12	34,986	1.10E+12	3,226	1.02E+11
Average	**69,293**	**2.18E+12**	**44,398**	**1.40E+12**	**7,771**	**2.45E+11**

Year	C-103	C-103 Volume (cf)	C-2 Rate (cfs)	C-2 Volume (cf)
1989				
1990				
1991			45.240	1.43E+12
1992	9,936	3.13E+11	42,178	1.33E+12
1993	7,128	2.25E+11	69,557	2.19E+12
1994	22,978	7.25E+11	83,489	2.63E+12
1995	40,021	1.26E+12	126,625	3.99E+12
1996	20,332	6.38E+11	49,747	1.57E+12
1997	22,068	6.96E+11	60,726	1.92E+12
1998	13,220	4.17E+11	62,557	1.97E+12
1999	26,037	8.21E+11	86,108	2.72E+12
2000	15,073	4.85E+11	32,988	1.04E+12
2001	19,111	6.03E+11	51,433	1.62E+12
2002	15,263	4.75E+11	59,844	1.89E+12
2003	14,552	4.59E+11	69,596	2.19E+12
2004	6,241	1.97E+11	28,922	9.12E+12
2005	36,367	1.15E+12	72,037	2.27E+12
2006	5,050	1.59E+11	20,902	6.59E+12
Average	**18,218**	**5.75E+11**	**60,122**	**1.90E+12**

Table 28. Hydrology and water management. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Regional Level/Stage			F	F	F	F	F	F	I	I	F	
Discharge			F	F	F	F	F	F	I	I	F	
Timing			F	F	F	F	F	F	I	I	F	

Habitat Loss

The NPSIMP subdivide indicators of biological integrity into vital signs associated with invasive species and those that measure attributes of focal species or communities. All four main benthic community types in BNP–seagrasses, coral reefs, sand/mudflats and intertidal regions–are focal marine communities under the NPSIMP Vital Signs indicator rubric.

Status of the communities is determined by the geology, climatology, hydrology, water quality and disturbance regimes. Species composition and temporal trends in seagrass communities of south Florida are determined by salinity regime (Irlandi et al., 2002; Lirman and Cropper 2003; Lirman et al., 2008), water quality (Fourqurean et al., 2003; Fourqurean and Rutten, 2003), physical disturbance (Ball et al., 1967; Zieman, 1982) as well as populations of herbivorous animals (Rose et al., 1999; Maciá and Lirman, 1999; Maciá, 2000; Peterson et al., 2002). Seagrass communities are highly sensitive to anthropogenic environmental change and globally they are being lost from coastal ecosystems at an alarming rate (Orth et al., 2006). The nature of the effects of controlling variables is only approximately known; research into the controls is a high priority. The health of coral reefs is dependent on the same factors (reviews in Hughes and Connell, 1999; Lirman et al., 2003; Lirman and Fong, 2007) and coral reef systems have been declining rapidly in south Florida (Porter et al., 1999) and globally (Pandolfi et al., 2003).

Channelization/Sheet Flow Barriers

Point source canals were designed to collect surface water and remove it from the landscape, thus virtually eliminating sheet flow which once dominated the western park shoreline. Road construction, much of it never utilized, in the 1920-1940 period, produced elevated structures with adjacent canal-like borrow ditches and levee structures (e.g., L-31E) with their associated canals crossing the western coast in many places (Figure 49). All are barriers to flow, some affect groundwater, and all fragment the coastal environments into small, disconnected parcels. This has a negative effect on the wetlands themselves and downstream consequences for those marine/bay ecosystems which depend on both quantity and quality of freshwater entering the estuary.

Coastal Development

Coastal development has been continuous since the late 1800s, with spurts in good economic times or during World War I and World War II, and lulls during economic downturns. The region nearest the park has recently seen an enormous expansion in urban development as former farm fields have been sold for primarily residential development. Housing now approaches the coastal levee in a number of places. Residential development puts more people near the park; this impacts resources by increasing usage of the parklands for recreation, increases pollution and changes its character and further requires measures to reduce flooding that impacts surface and groundwater flows to the park. Projections of considerable further development to south Miami-Dade County are alarming in the scope and magnitude of development planned for the park perimeter. Coastal development is an existing threat to the park, which will only become worse through time until the projected sea level rise stops it. When that happens, the inundation of many polluted sites will produce new challenges to the park.

Habitat Fragmentation

Habitat fragmentation has both a physical aspect and a biotic impact. Most new fragmentation occurs on the western coastal zone, but the park has inherited a fragmented ecosystem along its shoreline, which continues to impact the coastal wetlands and mangrove fringe. This compartmentalization of former connected wetlands is largely intact and includes many structures that have impeded flow. Negative biotic impacts to the wetlands continue, and the reduced health of the coastline communities affects those Bay ecosystems that receive services from the impacted shoreline ecosystem. Therefore, habitat fragmentation is an existing problem with fair documentation for the terrestrial environments. Bay impacts are inferred.

Dredging and filling for marinas and residential boat access, as well as channels dug through shallow water, are a minimal problem in Biscayne Bay except north of the park. The creation of deeper holes in the bottom for boating-related purposes creates sediment sinks that let sediment enter, but not leave; this affects adjacent bottom as well as cutting preexisting habitats. This aspect of fragmentation is low in the park waters because there are few dredged bottom areas.

Impacts from Fisheries Harvesting on Bay/Marine Systems

Fishing for shrimp by vessels using devices that drag on the bottom are a problem in areas where this occurs. The benthic habitats are disturbed, with damage to attached species and benthic plants documented in the past. However, the most significant damage done by fishing is on the fish populations and those species that depend on a healthy fishery. Data on this existing problem is good (see Fishes section, p. 85).

Algal Blooms

Algal blooms associated with nutrient loading have not been a major problem in the park because of excellent mixing of Bay water with the ocean. Algal blooms, when they occur, cause problems in marine areas and reefs by shading the bottom enough to reduce photosynthesis. An exceptional recent bloom in 2005, originating near the mouth of C-111 canal in Manatee Bay/Barnes Sound, spread to Card Sound and reached the southern edge of the park. Boyer (2006) examined the TP plume in the two bays south of the park. The cause was not identified; road work along US-1 was implicated in initial assessments. A small change in nutrients is thought to be the driver; if so, this indicates that minor chemical changes quickly produce blooms. Algal blooms occur in canals with high nutrient levels, such as that pass through agriculture fields west of the park. There are good phytoplankton data for Biscayne Bay. A recent macroalgal bloom along the coastline north of the park illustrates that algal blooms are a potential problem for the park's marine habitats.

Table 29. Habitat loss. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT										
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
Channelization/ Sheet Flow Barriers					F	F	F	F	I	I	F
Coastal Development	F	F	F	F	F	F	F	F	I	I	F
Habitat Fragmentation	F	F			I	I	I	I	I	I	
Impacts of Fisheries Harvesting on Bay/Marine Systems						I		G		G	
Algal blooms	I	I	I	F	I	I	I	G	I	F	I

Visitor Use and Habitat Disturbance

Because of the proximity to the population of Miami, and the generally shallow depths of the benthic marine communities of BNP, there is a marked impact by human uses of these communities. We have already discussed the numbers of boats using the park, and the direct and indirect impacts of fishing, but human visitors to BNP can have other impacts.

Visitor Impacts

See BNP General Management Plan (p. 18) for discussion of visitor impacts.

Boating Specific Impacts on Coastal/Bay/Marine Systems

Most users of BNP access it by boat or larger vessel as one would expect. Larger vessels also enter the park intentionally or by going off course when passing offshore. Vessels of any size can damage sensitive bottom and shoreline communities when they go aground or when they are in water shallow enough to allow propellers to contact the bottom. Vessel wakes erode bottoms and shorelines as they pass in, or near, the park and are a known cause of elevated turbidity. The Turkey Point oil supply barge tug is one of the best known examples. It makes about 300 trips a year through the park. NPS has settled two cases with Florida Power and Light on three incidents when the tug or oil barge grounded on sensitive habitats using the park System Resource Recovery Act. Propeller strikes are responsible for the injury and/or deaths of important marine animals such as manatees, turtles and the reef corals. Manatee no-wake zones, defined by regulators, are an attempt to manage the harm to this unique species, but are unable to completely eliminate the problem as numerous scars on most local animals attests.

Paramount among boating impacts is the effect from accidental and/or purposeful contact with the bottom, by the propeller(s) or the boat hull. Boat groundings have severe impacts in benthic marine communities. The scarring of BNP seagrass beds is particularly severe; about 10% of the seagrass beds in Biscayne Bay show moderate to severe propeller scarring (Sargent et al., 1995). The propeller scars have enduring impact on the living marine resources of BNP; individual propeller scars can take over 15 years to recolonize (Zieman, 1976). A common practice is rafts of pleasure boaters on the edges of seagrass beds and sand flats for day-long parties, which leads to the destruction of the beds. Large expanses of seagrass have been trampled and lost along tidal creeks inside of the main Keys in BNP (e.g., Sands Cut). Boats striking the reefs directly damage them by breaking coral heads and/or crushing weakened surfaces and killing polyps. Additionally, divers can impact coral reefs in the park, either by willful handling of fragile organisms or by accidental contact such as standing on top of reefs. The cumulative impacts and the landscape-scale consequences of these human visitor impacts have not been well studied.

Since April 2000, the National Park Service has prohibited the use of personal watercraft (commonly referred to as jet skis) in most national park areas, including all of BNP. Because of safety issues caused by large crowds of boats that congregate near Sands and Elliot Keys on the Columbus Day weekend, beginning September 1, 2007, park and other law enforcement began limiting the number of boats rafted or tied together to no more than five, with a minimum distance between the rafted or individual vessels of at least 100 ft at the Sands Key and University Dock anchorage areas only. The normal anchorage areas are designated as "slow speed zones" during the period of heavy use.

Large, deep-draft vessels can also cause direct damage to reefs and SAV beds by impact with the bottom; they may go aground to the extent that considerable effort and additional damage is inflicted to extract them; this has happened numerous times in the past. Even oceanographic research vessels damaged park reefs in the past. BNP staff maintains a database of boat grounding locations, shown in Figure 83.

Anyone standing on the shoreline of BNP on a calm day can see waves, caused by passing boats, striking the coast. Powered boats and ships produce seven types of waves including a bow wave and stern wave, as well as several types of internal waves in the water (Harlem, 1979). These can erode bottoms and shorelines and are reflected from hardened shorelines to do this damage repeatedly. Some of the high turbidity levels in northern Biscayne Bay have been attributed to the resuspension of bottom sediment by boats. This can be caused by direct impact with the bottom or by propellers, and it can be caused by the wave (surface and internal), which resuspends sediment by means of traction loads created at the bottom of boat-caused waves (Harlem, 1979; Wanless et al., 1984).

Boating-related negative impacts on coastal fringe wetlands from wave attack and groundings on Bay environments and offshore bottoms are an existing problem for the park. Data are limited, especially on the effects of persistent anthropogenic wave energy produced by boats.

<u>Impacts from Marina and Marine Facilities</u>

Marina and marine facilities are common in the region with two marinas located on the coast within the park, one at Black Point and the other at Homestead Bayfront Park (Convoy Point). Both are dredged holes that are sediment sinks and both are point sources of boating-related pollution (see Pollutants section, p. 124). Marine facilities are less common, as marine repair and boat construction yards are typically inland or located to the north of the park. There is an exception: the landing areas on Elliott and Sands keys used for access by visitors to those islands.

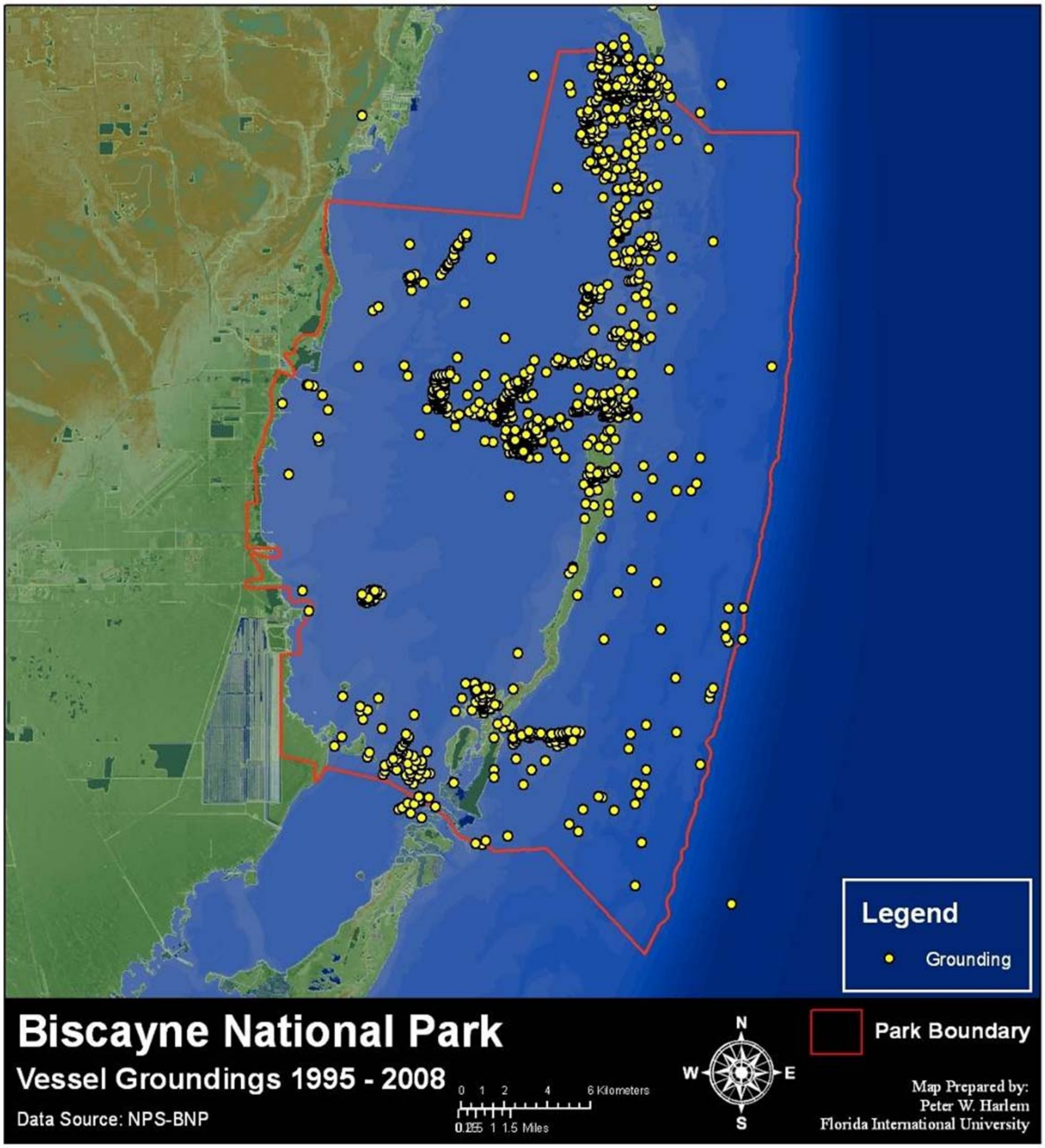


Figure 83. Vessel grounding locations for the period 1995-2008 mapped from Biscayne National Park data. Data include date of grounding, but no other aspects of each incident, and is derived from towing services that record where they refloated a vessel. Note how shallow banks like Featherbed can be identified easily, indicating the impact of small, shallow draft vessels on banks and shoals near channels.

Marinas impact the terrestrial habitats adjacent to them, as they are high traffic areas for both boats and cars, containing boat ramps and parking lots. They are an existing problem for wetlands near the facilities and a potential problem for Bay environments close to the outlets. Boat traffic is concentrated at the entrance channels and boating-related damages are higher

Table 30. Visitor use and habitat disturbance. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Visitor Impacts	I	I	I	I	I	I	I	I	I	I		
Boating Impacts on Coastal/Marine Systems					I	I	I	F	I	F		
Impacts from Marina and Marine Facilities	I	I			I	I	I	I	I	I		

there. The increasing size of recreational boats requires the existence and maintenance of the boat channels; maintenance dredging can be a problem when it occurs.

Harvest/Hunting/Take

Owing to its proximity to the greater Miami metropolitan area, there is significant exploitation of the living marine resources of BNP. Recreational and commercial fishing occur in the park. BNP's Enabling Legislation states that fishing shall be "in conformity with the laws of the State of Florida" (16 USC Sect. 410gg-2). Recreational fishing occurs in multiple habitats, in bay and ocean waters, and targets species including bonefish, snook, tarpon, permit, blue crab, stone crab, snapper, grouper, grunt, barracuda, spadefish, spiny lobster and triggerfish. Commercial fishing also occurs in bay and ocean waters and targets invertebrates (lobster, blue crab, stone crab and bait shrimp), food fish (typically members of the snapper/grouper complex; concentrating on yellowtail snapper) and baitfish (e.g., ballyhoo, Spanish sardine, thread herring and pilchard).

Sponge harvesting in Biscayne Bay dates to the 1800s, when spongers used long poles with hooks to collect them; the bay supported as many as 150 sponge boats. Set back by disease in 1905 and subsequent overfishing, the community collapsed. Sponge poaching in BNP has occurred in the past (Davies, 1998) and has been suggested as a partial cause for the decline in sponges in Biscayne Bay (Cropper and DiResta, 1999). In an effort to protect the sponge populations, the bay was officially closed to sponge harvesting in 1991.

As fishing pressure has steadily increased (due to increasing human population, increased opportunities to access park waters, increased recreational boat registrations and improvements in fishing and boating technology), BNP fisheries resources have declined. The decline is currently being addressed in a Fishery Management Plan to guide the management and conservation of fisheries and fishing experience in BISC over the next 5-10 years. The plan is a joint effort between BNP and the Florida Fish and Wildlife Conservation Commission (FWC). The Draft Environmental Impact Statement/Fisheries Management Plan presents a range of alternatives and identifies an alternative preferred by both agencies. The FMP alternatives, including the preferred alternative proposed by the NPS and FWC, and the public process for their development, are described in Appendix C.

Fishery-dependent and fishery-independent studies have revealed startling insights on the status of the park's fisheries resources and the effects of over-fishing. These include:

- Ault et al. (2001) found that 71% of the 17 species for which sufficient data were available appear to be overfished, as defined under the federal Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). An analysis of the Spawning Potential Ratios (SPR) of the fishery-targeted reef fish shows that four of five grouper species, five of six snapper species, barracuda and two of five grunt species for which there are reliable data are below the SPR that constitutes overfishing, as defined in the MSFCMA. All but three of 18 additional species assessed (for which there were less reliable, mean length observations) are likely to be overfished.

- For all harvested species analyzed in the study, the average size of fish landed was near the minimum harvest size for the past 25 years, suggesting that a majority of large fish have been removed from the population. For example, the average size of black grouper is now 40% of what it was in 1940 and the spawning stock appears to be less than 5% of its historical maximum (Ault et al., 2001).

- For 14 of 35 species analyzed, the minimum size of harvest is lower than the reported minimum size, where 50% of individuals are sexually mature. For these species, it appears that most fish are being captured before they ever have a chance to spawn. The minimum harvest size for six of these 14 species is currently set by State regulations. The remaining eight species are unregulated (Ault et al., 2001).

- In 2007, one gag grouper was landed for every ~1,566 person-hours of fishing effort in suitable grouper habitat, and one black grouper was landed for every ~1,044 person-hours of fishing effort in suitable grouper habitat (BISC Creel data).

The population structure of most of the top predators in marine benthic ecosystems (i.e., sharks, groupers, snappers, redfish, bonefish, etc.) has been drastically altered by fishing pressure. Besides the immediate impact of fishing on the exploited species, there is a concomitant effect on the populations of plants and animals at the base of the exploited species food chains caused by this exploitation. It is well-known that reductions in the biomass of top predators lead to an increase in the population size of their prey, resulting in negative impacts down the food chain to the plants. The loss of coral cover on reefs around the world have been alternatively attributed to increased growth of macroalgae caused by nutrient pollution, the so-called "bottom up" effect, or to the increase in macroalgae caused by the decrease in populations of herbivore, the so-called "top-down" effect. While the argument about the relative importance of these two effects continues in the literature, one can be certain that both bottom-up and top-down controls on benthic community structure are influencing most communities.

Besides these changes in direct consumption of prey species—or the indirect lethal impacts of fishing the top predators—there can also be important non-lethal indirect impacts. All animals, including marine species, respond to the predation threat in their environment by modifying their behavior to reduce that risk. Such indirect impacts can control the behavior of herbivores and carnivores in the marine environment (Heithaus et al., 2007; Stallings, 2008). These non-lethal, indirect impacts can have a larger influence on the structure of marine ecosystems than the direct, lethal impacts (Heithaus et al., 2008).

Widespread occurrences of fishing regulation violations (either intentional or out of ignorance) also threaten the status of fisheries resources in BNP. From 1998-2009, law enforcement rangers issued 2,437 tickets and warnings for fishing regulation violations, with more than half of those tickets and warnings issued in 2007, 2008 and 2009. The increase in fishing-related violations during the last three years can be attributed to law enforcement rangers' increased awareness of the declining fisheries' resources, as well as an improved partnership between law enforcement and resource management employees during recreational creel surveys. Fifty percent of all fishing violations between 1998-2008 were for harvesting fish smaller than the minimum size limit. Thirty-five percent of all violations were for fishing without a license. Complementing the law enforcement statistics are the data from the park's recreational creel survey program.

Creel survey data collected during 2004-2008 present some alarming statistics about common regulation violations:

- The average sizes of schoolmaster snapper landed in 2006 and lane snapper landed in 2008 were below the minimum legal size.
- In 2009, the average sizes of harvested gag grouper, red grouper, lane snapper and mutton snapper were below the minimum legal size limit.
- In 2008, nearly 40% of landed red grouper, 28.4 % of landed hogfish and 24.1% of landed mutton snapper were undersized.
- In 2009, 50% of landed red grouper and 100% of landed gag grouper were undersized.
- At least one fishing-related regulation violation was observed in 17% of all creel surveys conducted in 2009.
- From January 1, 2008 to December 31, 2009, at least one undersized fish was observed in 9.5% of hook-and-line trip landings and 20.3% of spearfishing trip landings.

In an effort to educate the fishing public and reduce the frequency of occurrence of fishing violations (whether they be intentional or out of ignorance), the park offers a "Fisheries Awareness Course" that is modeled after a "traffic school" for people receiving speeding tickets. Fishers who receive a ticket for a fishing violation may, at the discretion of the issuing ranger, attend the Fisheries Awareness Class to mitigate the ticket. The class teaches environmental stewardship of national parks, fish identification, how to access and interpret fishing regulations, the biological significance of the fishing regulations and ethical angling (e.g., catch-and-release, use of circle hooks instead of J-hooks, use of de-hooking and venting devices, proper ways to handle fish that will be released, etc.). This class, which is also free to the public, is offered monthly with English- and Spanish-language classes alternating months. At the end of 2011, over 800 people had attended the class, with 563 people attending for ticket-mitigation reasons.

Table 31. Harvesting, hunting and take. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Impacts on Vegetation		I				I		I		I		
Impacts on Animals		I				I		I		I		
Recreational Fishing				I		I	F	I	F	I		
Poaching		I		I		I		I		I		
Cultural Artifacts	I		I		I		I		I			

Exotic Species

Invasive species in the marine realm have received more attention in the past few years as it becomes clear that humans have helped disperse marine organisms around the globe (Williams, 2007; Williams and Grosholz, 2008). There are many examples of introduced animals, at all trophic levels, affecting the functioning of benthic marine communities (Williams, 2007). Introduced animals have the potential to compete with native species, to change the relative abundance of plants and animals in the community and to alter water quality.

Exotic Plants

National Park Service developed a draft Exotic Plant Management Plan/EIS in 2006 that analyses management options for exotic terrestrial plants for parks in South Florida and the Caribbean. The plan identifies the principal exotic species and options for treatment and removal. Six treatment areas were identified (Figure 84) and the species of concern in each were listed (Table 32). One relatively new and problematic species of concern on mainland uplands is *Ardisia eliptica*, which has been identified on the margins of levees adjacent to the park. Its ability to grow in low light, including underneath Brazilian pepper trees where few macrophytes can survive, spread rapidly by animal vectors (raccoon, catbird) and rapid growth to high densities (40+ plants/m^2) suggest that it will be a problem for NPS in the future.

Introduced macroalgae have been implicated in the decline of seagrasses in the Mediterranean and coral reefs worldwide; as yet, there have been no reports of adverse environmental impacts of introduced macroalgae in BNP. Seagrasses from the Old World have become established in the Caribbean (Ruiz and Ballentine, 2004), but there are no reports of introduced seagrass species in BNP. Mangrove trees have also been introduced into new environments globally, and these introductions seem to cause major changes in the structure of the food webs in coastal environments (Demopolous et al., 2007). A small population of introduced non-native mangroves from Southeast Asia has recently been discovered in Biscayne Bay, to the north of BNP. It is reasonable to assume that introductions of new mangroves, macroalgae and/or seagrass species to BNP will alter not just the composition of the plant communities, but the structure of the fish and invertebrate communities that rely on these plants as well.

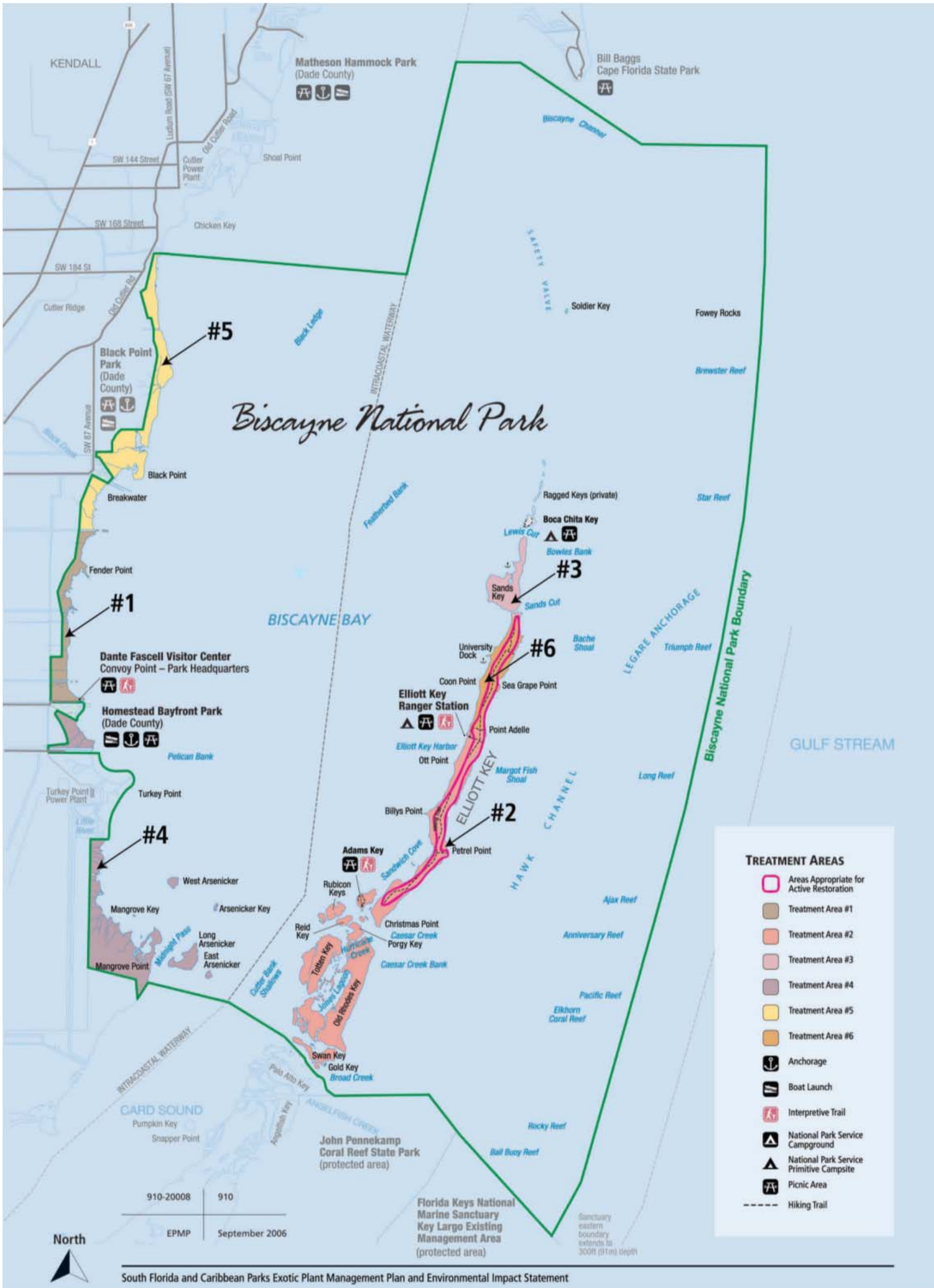


Figure 84. Location of five exotic management regions in Biscayne National Park (NPS).

Table 32. Common exotic plant species identified by NPS.

Treatment Area	Name	Exotic Species	Acres Infested
1	Coastal Wetlands South	Brazilian pepper Australian pine Thespesia Scaevola Colubrina Neyraudia	13
2	S. Elliot Key to Broad Creek	Thespesia Manilkara Australian pine Brazilian pepper Colubrina Phoenix Agave Scaevola	84
3	Sands Key	Colubrina Australian pine Thespesia Brazilian pepper Neyraudia	12
4	Mangrove Point/Arsenickers	Brazilian pepper Australian pine Thespesia Colubrina Neyraudia	14
5	Coastal Wetlands North	Australian pine	24
6	North Elliot Key	Neyraudia Brazilian pepper Thespesia Manilkara Rhoe Colubrina Agave Sansevieria Tradescantia	16

Exotic Birds

Two bird species are exotic to BNP. These are the European starling, *Sturnus vulgaris* (Figure 85) and the common myna, *Acridotheres tristis* (Figure 86).

Exotic Fish - Lionfish and Non-native Canal Fish

The Indo-Pacific lionfish (*Pterois volitans* and *P. miles*, Figure 87) is the only exotic marine fish confirmed to occur in BNP. Park biologists implemented a Lionfish Management Plan in October 2008 and documented the first occurrence of the lionfish in the park in June 2009. Lionfish have increased in abundance and distribution in the park because of their voracious appetite, cryptic behavior, high fecundity and venom that makes them unpalatable to native predators. Resource managers documented and removed lionfish from coral reef, hardbottom, seagrass and artificial habitats (e.g., wrecks, debris). By the end of 2011, over 1,000 lionfish had been removed. Efforts to manage the species and study its impacts are continuing.

Figure 85. European starlings (*Sturnus vulgaris*) (L. Karney, USFWS).

Figure 86. Common myna (*Acridotheres tristis*) (public domain).

In a 2002-2003 survey of freshwater fish occurring in the Miami-Dade system of canals that empty into Biscayne Bay (Black Creek, C-100, Florida City, Mowry, Military and Princeton), Ellis et al. (2006) found that exotic species accounted for nearly one-third of all fish species observed. The 10 species of exotic freshwater fish were spotted tilapia (*Tilapia mariae*, Figure 88), black acara (*Cichlasoma bimaculatum*, Figure 89), jewel cichlid (*Hemichromis letourneauxi*, Figure 90), Mayan cichlid (*Cichlasoma uropthalmus*, Figure 91), Midas cichlid (*Amphilophus citrinellum*, Figure 92), Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*, Figure 93), pike killifish (*Belonesox belizanus*, Figure 94), walking catfish (*Clarias batrachus*, Figure 95), grass carp (*Ctenopharyngodon idella*, Figure 96) and peacock bass (*Cichla ocellaris*, Figure 97). Spotted tilapia were the dominant species of all canal fish fauna. The grass carp was intentionally released for weed control and the peacock bass was intentionally released to control cichlid populations and to provide recreational fishing opportunities for anglers (Shafland, 1996).

Exotic Invertebrates

The cactus moth (*Cactoblastis cactorum*, Figure 98) is exotic to the United States and lays its eggs on prickly pear cactus where the larvae grow by eating the fleshy pads. This pest preys on the Florida semaphore cactus (*Consolea corallicola*), which is endemic to the Keys, and has been proposed for listing as endangered. Imported to the Caribbean and introduced to control prickly pear cacti, it arrived in the U.S. naturally or in cargo imported from the Caribbean in 1989. The cactus moth has not been observed on the park's semaphore cactus population since twice-yearly monitoring of the cactus population began in 2008.

Figure 87. Indo-Pacific lionfish (*Pterois volitans*) on ice after removal from the Biscayne National Park (NPS)

Figure 88. Spotted tilapia (*Tilapia mariae*) (N.M. Burkhead, NPS)

Figure 89. Black acara (*Cichlasoma bimaculatum*) (FFWS)

Figure 90. Jewel cichlid (*Hemichromis letourneauxi*) (Public domain)

Figure 91. Mayan cichlid (*Cichlasoma uropthalmus*) (P. Fuller, USGS)

Figure 92. Midas cichlid (*Amphilophus citrinellum*) (Public domain)

Figure 93. Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) (Public domain)

Figure 94. Pike killifish (*Belonesox belizanus*) (USGS)

Figure 95. Walking catfish (*Clarias batrachus*) (Mistvan, USGS)

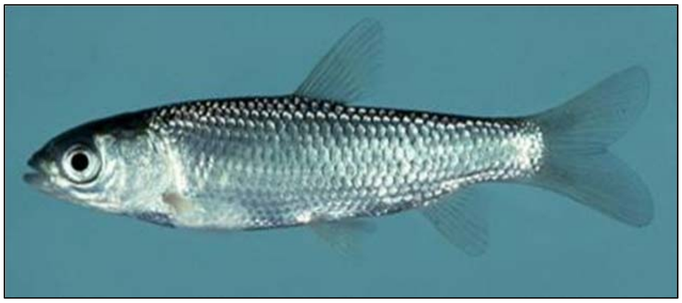


Figure 96. Grass carp (*Ctenopharyngodon idella*) (N.M. Burkehad, USGS)

Figure 97. Peacock bass (*Cichla ocellaris*) (P. Fuller, USGS)

The red imported fire ant (*Solenopsis invicta*, Figure 99) is found within the mainland and islands of the park. This species builds loose soil mounds which are aggressively defended; if the mound is disturbed, adult fire ants emerge, biting and stinging the intruder. This species is treated as needed following the Integrated Pest Management policies.

Figure 98. The exotic pest cactus moth (*Cactoblastis cactorum*) adult (Dale Habeck, USDA)

Figure 99. Red imported fire ant (*Solenopsis invicta*) (Public domain)

Exotic Mammals

Exotic mammals found in BNP include the Mexican redbellied squirrel, *Sciurus aureogaster* (Figure 100), the feral cat, *Felis domesticus* (Figure 101), and the black rat, *Rattus rattus* (Figure 102).

Figure 100. Mexican redbellied squirrel (*Sciurus aureogaster*) (NSIS.org)

Figure 101. Feral cats (*Felis domesticus*) (Public domain)

Figure 102. Black rat (*Rattus rattus*) (Public domain)

Exotic Reptiles

The following list (Table 33) of exotic reptiles has been found in BNP. Most are predatory species including the much publicized Burmese python, which was released by careless pet owners in sufficient quantities to produce abundant offspring. All are threats to the indigenous inhabitants of the park.

Table 33. Exotic reptiles in Biscayne National Park.

Common Name	Scientific Name
Argentine Tegu lizard	*Tupinambis* spp.
Brahminy blindsnake	*Ramphotyphlops braminus*
Brown basilisk lizard ("'Jesus lizard")	*Basiliscus vittatus*
Burmese python	*Python molurus bivittatus*
Cuban brown anole	*Anolis sagrei*
Green iguana	*Iguana iguana*
Indo-Pacific gecko	*Hemidactylus garnotti*
Mediterranean gecko	*Hemidactylus turcicus*
Monitor lizard	*Varanus* spp.
Tropical house gecko	*Hemidactylus mabouia*
Spectacled caiman	*Caiman crocodilus*
Argentine Tegu lizard	*Tupinambis* spp.

Table 34. Exotic species. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Exotic Plants		G		I		I		I		I		
Exotic Birds		G		I		I		I		I		
Exotic Fishes				G		F		F		F		
Exotic Invertebrates		F		I		I		I		I		
Exotic Mammals		I		I		I		I		I		
Exotic Reptiles		G		I		I		I		I		

Pests and Pathogens

In addition to herbivore and nutrient-mediated causes of mortality, diseases have been implicated in regional losses of seagrasses (Robblee et al., 1991) and corals (Richardson, 1998). The prevalence of diseases, in corals especially, seems to be on the increase over the past decade. Changes in water quality can influence the rate of disease progression in corals (Voss and Richardson, 2006) and the rate of die-off of seagrasses (Borum et al., 2005).

Table 35. Pests and pathogens. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Pests/ Pathogens of Vegetation		I		I		I		P		P		
Pests/ Pathogens of Animals		I		I		I		I		I		
Pests/ Pathogens of Birds		I		I		I		I		I		
Pest/ Pathogens of Corals								P		F		

Climate Change

All components of the park are susceptible to global changes in sea level caused by climate change. The eastern boundary of BNP is defined by a depth contour, which may cause shrinkage of the protected area within the jurisdiction of NPS, if the legal definition of that boundary is followed as sea level rises. The park's many benthic communities are located in relatively shallow water, affected by tidal fluctuation; therefore, they must be adapted to rising and lowering of the water levels and the associated changes in those levels in order to survive. Intertidal species and shallow bottom groups can become exposed at low stands and both must deal with deeper water at high tide. However, a eustatic change in sea level is directional in nature and requires a different adaptation potential for species to remain.

The global sea level rise now attributed to excess release of greenhouse gasses, particularly CO_2, and its effect on the benthic communities, will become the principal concern for managers in the future. The Intergovernmental Panel on Climate Change (IPCC) (Bindoff et al., 2007) predicted rise of slightly less than one meter by 2100, suggesting the new norm will become the migration of communities to new locations where that is possible, or complete loss of others where it is not. Management, using past principals of "stationarity" (Milly et al., 2008) that depend on static models, will have to be adapted to the new reality: each passing day brings more water over the reefs and seagrass beds of BNP. We can predict but do not yet know which predictions will prove accurate in the long term. Our predictions can be related to observations made during high tides and elevated storm tides, but ultimately, the benthic species will have to adapt to constantly evolving demands on where they can live and how successful they will be. The perceived delicate aspects of the current life cycles and food chains of the benthos over the entire region will be affected as these adjustments occur.

Any factor that affects the distribution and quality of the sediments in BNP will impact the distribution and health of the subtidal and intertidal communities. Climate change has the potential to alter sediment supply and the processes that determine the balance between sediment deposition and erosion. As rainfall patterns change over the southeastern U.S., the supply of sediments delivered to the coast could potentially increase bringing nutrients and pollutants into park waters. As pCO_2 increases in the atmosphere, it is likely that the production of calcareous sediments by marine organisms will decrease, and the dissolution of the existing calcareous sediments will increase. Sea level rise will change the strength and direction of the ocean currents that deposit and erode sedimentary deposits. The end result of these changes in the geomorphological environment could be a change in the relative importance of major benthic marine communities of BNP, since one of the main controllers of the distribution of these communities is the distribution of the sediment.

Water quality changes will cause changes in the distribution of the major benthic communities. Seagrass beds and coral reefs are particularly sensitive to changes in water quality and temperature. In BNP, there are five main processes that can/will affect water quality and, therefore, the integrity of biological communities: 1) climate-change induced changes in delivery of freshwater to BNP, which will influence salinity; 2) human alteration of surface and groundwater flow into the park for water supply and flood control in the Miami metropolitan area, which will influence salinity and nutrient delivery to the park; 3) increased nutrient delivery to the park because of wastewater, stormwater and point source discharges that will change the structure of the benthic communities; 4) increased sediment loading by land use and coastal geomorphological changes that will decrease the amount of light reaching the benthic communities; and 5) increasing discharge of pollutants into the bay that directly affect plants and animals in the benthic community, either through toxic effects or by disrupting natural signaling systems within the organisms. Water temperature is also likely to rise as an effect of climate change. Inadvertent, large-scale temperature increase "experiments," resulting from the dumping of heated cooling water from Turkey Point Power Plant in the 1960s, suggest that many of the benthic communities in BNP have very little resiliency to increases in temperature (e.g., Ferguson et al., 1969; Zieman and Wood, 1975; Zieman, 1975). Robles et al. (2005) suggests that the effects of climate change on the Spiny Lobster are unknown and that the relationship to thermal stress is unclear because of the complexity of the environment.

Climate models proposing changes in local climate on the local level have not yet been developed, however, global models suggest that South Florida will become drier. The Miami-Dade Climate Change Task Force (2008) has predicted that this will translate into the park region becoming more like the Florida Keys with similar, drier weather conditions. If this happens, rainfall will become rare and that will have a negative impact on all aspects of the freshwater system. The limited estuarine conditions now found along the western shoreline will likely diminish further. Average air temperature will probably increase, which could impact terrestrial ecosystems, as to what degree is unknown. Storm patterns will probably change as a result, and it has been suggested that hurricane frequency and intensity could increase as a result of warming of nearby oceanic waters (Figure 103).

Increased Water Temperature

Engle and Summers (1999) mapped the spatial distribution of benthic communities along the East Coast of the U.S. using cluster analysis. They found a strong correlation to summer temperatures as determinative for a latitudinal gradient in zoogeography from north to south. One cluster was centered on Biscayne Bay, which they placed as the northern boundary of the tropical fauna of the West Indian province. They concluded that temperature rise related to

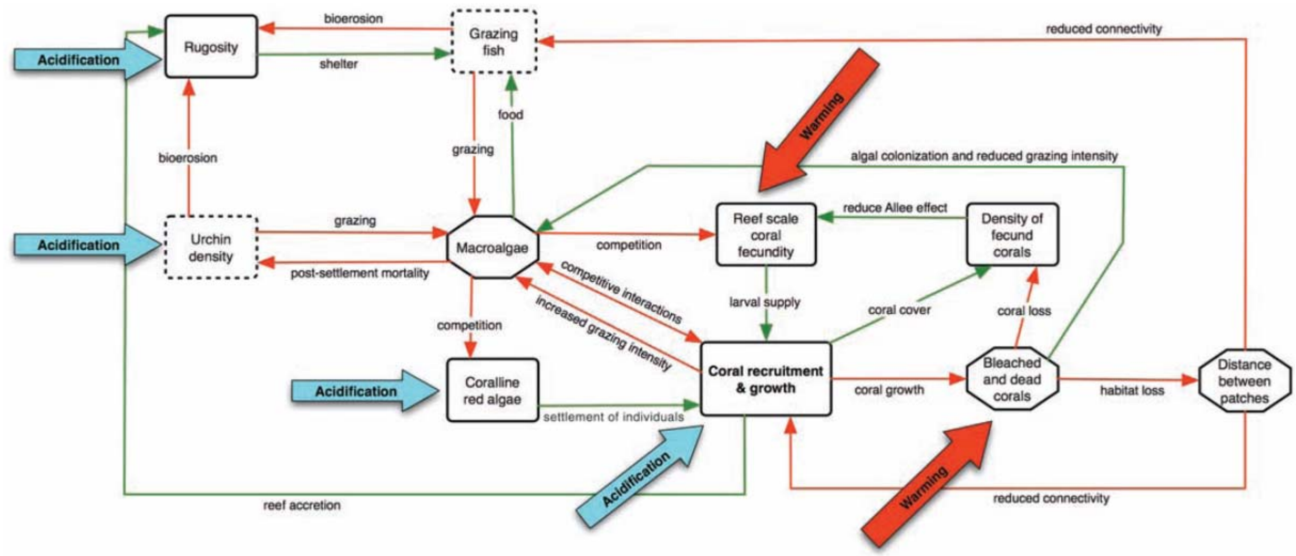


Figure 103. Box model showing ecological feedback processes caused by climate change on coral reef organisms as proposed by Hoegh-Guldberg, et al. (2007, Fig 3.). Blue arrows denote affects by acidification; red arrows denote affects by ocean warming. Small, red arrows pointing at a box indicate a decreasing influence on the box, while green arrows denote increasing influence. Boxes with dashed outlines were considered amenable to management intervention.

global climate change will cause significant changes in the boundaries and composition of the benthic zoogeographic provinces. Figure 104 shows the zoogeographic provinces. This will likely result in changes to benthic habitats as more heat-tolerant species begin to replace those less tolerant. *Thalassia* is an example of an SAV that might suffer reductions in distribution in the future. Many benthic algae may be negatively affected as well.

Sea Level Rise

Because of the sensitivity of vegetation patterns to subtle elevation differences, we expect sea level rise to have a profound effect on terrestrial vegetation. Landward (uphill) migration of mangroves is already occurring on the mainland, partly due to anthropogenic changes to the coastal water delivery systems, which are driven by sea level rise. Wanless (1982) showed upward movement of the intertidal zone at Coral Gables Waterway, caused by a slight rise (15 cm) in sea level during the latter half of the 20th century. However, the current rate of rise is faster; it might be the controlling factor on future patterns of terrestrial vegetation as more and more of the low coastal margin of the park becomes inundated by marine waters. Coronado-Molina et al. (2003) suggested that mangroves on the mainland shore may be better keep up with sea level rise than those on the Keys due to higher productivity. Harlem and Meeder (2008) showed that sea level rise of one foot would inundate much of the park shoreline at high tide, which would alter salinity regimes and favor westward migration of saltwater habitats.

One aspect of great concern is the release of sediment, and its associated nutrients and pollutants, to the marine system as coastlines erode. There are large amounts of the former locked up in coastal sediments that will enter the sea as waves and increased currents attack the existing shore deposits. While moving sediment packages are natural now, and most benthic communities are adapted to some amount of sedimentation, the loading potential from rapid sediment adjustments can only be considered a negative impact on Bay and marine/reef ecologies.

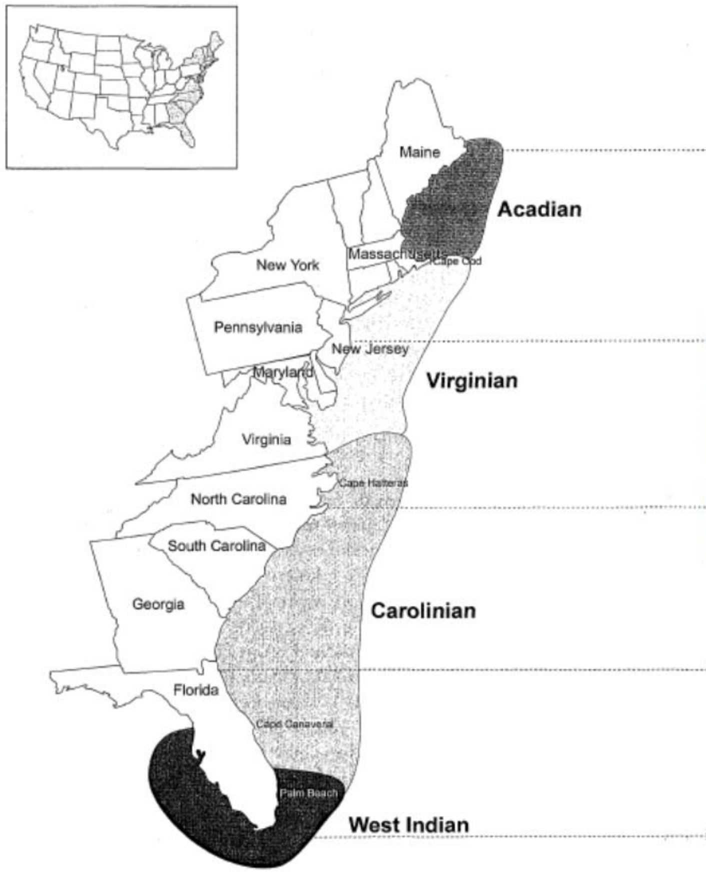


Figure 104. Engle and Summers (1999) map showing the zoogeographic provinces along the East Coast, with Biscayne National Park located in the West Indian province. They considered Biscayne Bay the northern limit of the tropical fauna in that province.

Species Range Changes

The Robles et al. (2005) study of spiny lobster, where juveniles responded to Hurricane Andrew, suggests that the increasing wave energy produced by deeper water might drive a relocation of lobster habitats. Fish species that are either depth-dependent or temperature-dependent are likely to change their habitat range. Sedimentological changes should drive similar redistribution of species because of destruction or production of habitats, or because of changes in suspended sediment patterns.

Ocean Acidification

Ocean acidification is the change in pH caused by the reaction of increased CO_2 with seawater. Seawater is under-saturated relative to carbon dioxide and thus will absorb CO_2 from the atmosphere, becoming more acidic. This pH reduction causes problems for marine organisms which use carbonate molecules to construct hard body parts or protective shells, skeletons and tests. Included in the affected groups are molluscs, foraminifera, coccolithophores, crustaceans, starfish, bryozoans and corals.

When seawater carbonate concentration is above 66 μmol/kg, the water is supersaturated. With depth (lower temperature and more pressure), the ocean becomes under-saturated and aragonite, the metastable form of calcium carbonate, is dissolved. The name given to the boundary between the two conditions of saturation is called the "saturation horizon" (Schubert et al., 2006). Octocorals (soft corals) and other marine organisms use calcite for structural support, and scleractinian corals use aragonite to build skeletons. The limit between water saturated and under-saturated in aragonite or calcite is measurable and called the “aragonite saturation horizon” (ASH) or “calcite saturation horizon” (CSH) in the case of the latter. The ASH is shallower than the CSH, and corals can thrive in saturated, but not under-saturated, waters. Carbonate-using organisms are now threatened because ocean acidification will move these boundaries upward. Guinotte et al. (2006) has projected that deep water scleractinians will be affected, with 70 percent of the world’s known deep reefs becoming under-saturated by 2100. As reef waters become more acidic, the ASH will become shallower affecting corals at those depths too. Corals below the ASH will find it more difficult to build robust skeletons, and growth rates can be expected to decrease. These skeletal changes will mean they are more easily eroded and attacked by other organisms, threatening reef health and sustainability as they also try to keep up with sea level rise.

It has been estimated that the ASH and CSH have moved upward 50-200 m since the beginning of the Industrial Revolution (Orr et al., 2005). Figure 105 shows the Atlantic Ocean ASH trend and model plots for 2100 by latitude. Figure 106 shows the historical and projected trends for the ASH vs. warm water coral locations. The park lies in an area that will be least affected by acidification if the models hold true, however, changes in the deep reefs seaward of the park should be expected in the near term, and affects will increase in shallower waters in the years after 2100. Changes in stratification of waters resulting from heating or other climate forces can also affect future pCO_2 levels, as can changes in biological productivity resulting from altered nutrient levels. As a result, the rate of change and degree of impact will be different in different ocean basins and cannot yet be predicted for BNP.

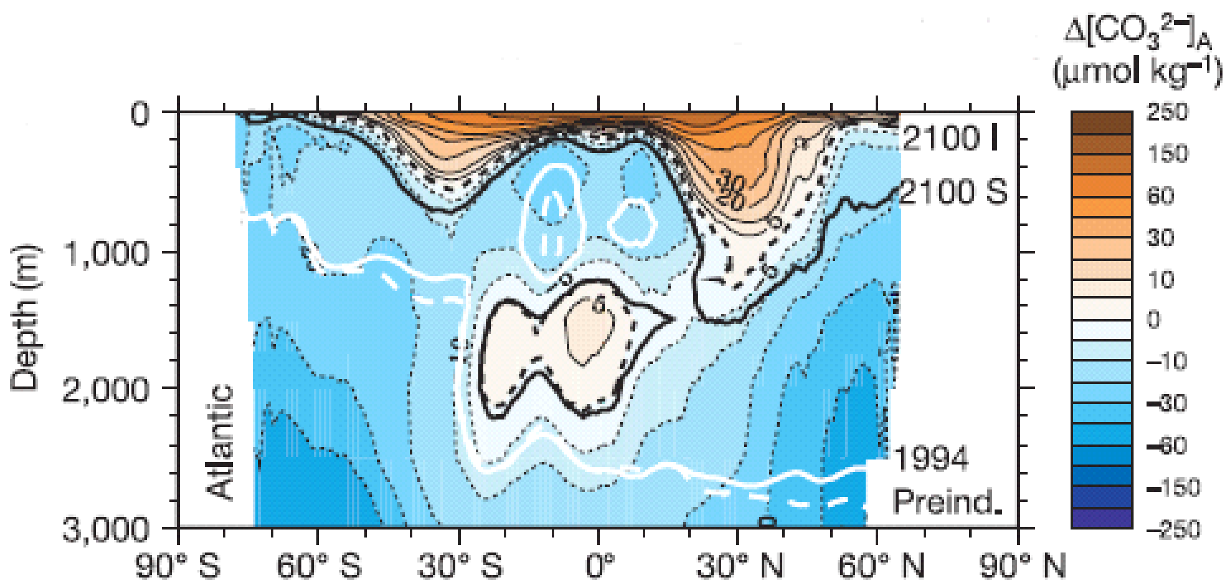


Figure 105. Depth vs. latitude plot of the aragonite saturation horizon for the Atlantic Ocean (Figure 2b from Orr et al., 2005). The pre-industrial horizon is shown as a white dotted line, the 1994 values as solid white line and the model runs for 2100 in black. Note that the North Atlantic ASH is generally deeper so acidification affects will take longer to appear.

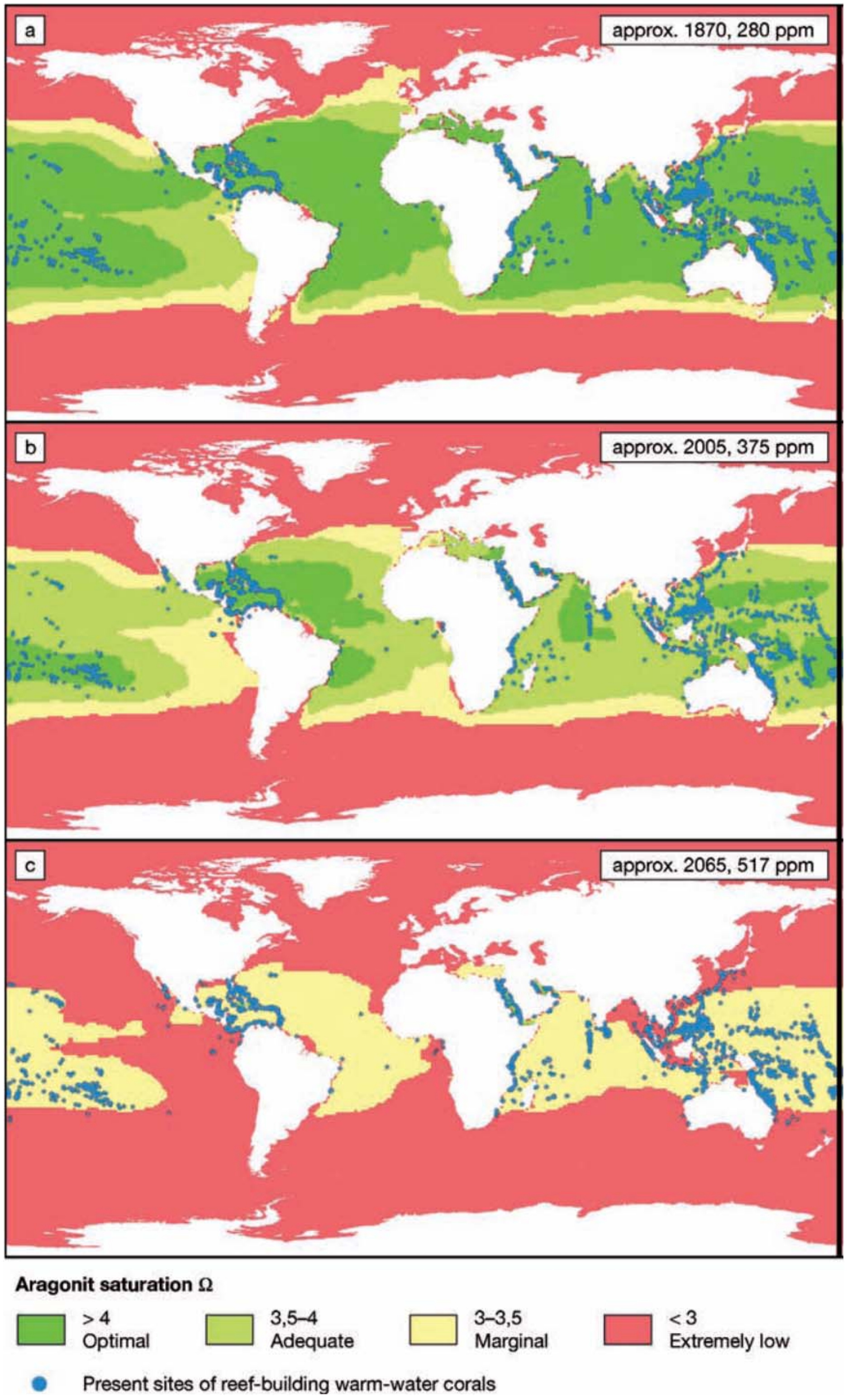


Figure 106. Comparison of aragonite saturation vs. coral reef locations for warm water corals from 1870 with projections to 2065. This suggests that future conditions for carbonate-using organisms around Florida will become marginal. (Steffen et al., 2004)

Table 36. Climate change. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Weather Changes	F	F	F	F	F	F	F	F	F	F	F	
Increased Water Temperature	I	I	I	I	I	I	I	F	I	F	I	
Sea Level Rise	I	I	I	I	I	F	I	F	I	I	G	
Species Range Changes	I	I	I	I	I	I	I	I	I	I	I	
Ocean Acidification	I	I	I	I	I	F	I	F	I	F	I	

Listed Species

Biscayne Bay is the home species described as "at-risk biota," and the status of these species is an important vital sign for BNP. The park is home to resident and migratory protected animals. The threatened West Indian manatee (*Trichechus manatus*) and the protected bottlenose dolphin (*Tursiops truncatus*) are year-round residents in the park. The manatee is an obligate herbivore that grazes seagrass beds; its fate in the park is intricately tied to the health of the seagrass beds. Bottlenose dolphin have higher success in capturing prey in the seagrass beds, which harbor fish that make up their preferred diet (Heithaus and Dill 2002), so the population of dolphin in the park is also tied to the health of the seagrass beds.

The range of five species of sea turtles includes BNP. Green sea turtles (*Chelonia mydas)*, which rely on seagrasses for food as adults, are endangered in Florida and threatened throughout the rest of their range. More carnivorous than their green sea turtle relatives, loggerhead turtles (*Caretta caretta*) are primarily benthic feeders that forage in shallow, benthic marine communities. Loggerheads are more common than green turtles in south Florida, though they are a threatened species. Endangered hawksbill sea turtles (*Eretmochelys imbricate*) are commonly seen in the park and forage in the benthic marine communities and nest on the park's beaches. The endangered leatherback sea turtle may be found in the deeper waters of BNP. Kemp's ridley turtles (*Lepidochlys kempii*) have not been documented within park boundaries.

There are a number of other protected species in BNP, including the Nassau grouper and the queen conch (*Strombus gigas*). Listed birds also use the park for portions of the year including the migratory piping plover (*Charadrius melodus*), the wood stork (*Mycteria americana*), and the least tern (*Sterna antillarum*).

Listed Plants

Endangered plants in BNP included the beach clustervine (beach jacquemontia, *Jacquemontia reclinata*) and a proposed candidate for listing, the Florida semaphore cactus (*Consolea corallicola*), which is endemic to the Florida Keys. A large plant with treelike form, its range was reduced by development, and it is now threatened by the recently arrived exotic cactus moth (*Cactoblastis cactorum*) and disease which caused rot. Originally described as native to Key Largo in 1935, it is now known only from Little Torch Key and Swan Key. Carriaga et al. (2005) states it is currently found in BNP in patches (about 580 plants) covering about four hectares; the colony's exact location is not disclosed in order to keep it intact. Several attempts to establish new colonies have failed, in part because the plant does not normally spread by sexual means.

Considered to be the rarest palm native to Florida, the endangered buccaneer palm (Sargent's palm) was found on Elliott Key and Sands Key by collectors who harvested them for ornamental use in the late 1800s. By 1991, only 50 palms were found on Elliott Key, many of which were damaged during Hurricane Andrew in August of 1992. Currently, slightly more than a dozen plants are known on Elliott Key, with another 100 plus on Long Key where they were reintroduced by recent restoration efforts.

Listed Invertebrates (Including Acroporid Corals)

The Schaus swallowtail butterfly (*Papillo aristodemus ponceanus*, Figure 107) is a large brown and yellow butterfly endemic to Florida and is restricted to tropical hardwood hammocks and associated margins; therefore, it is in decline as this habitat type has been reduced by development. It was originally listed as threatened in 1976 and changed to endangered in 1984. With a population estimated to be less than 1,200 individuals, it is the only federally listed butterfly in Florida. Figure 108 shows the location of recent observations. The Miami blue butterfly, rarely found on some of the Keys, is a candidate for listing.

The threatened elkhorn (*Acropora palmata*, Figure 109) and staghorn (*Acropora cervicornis*, Figure 110) corals are relatively widespread throughout reef habitats of the park, with particularly high densities of colonies (particularly of *A. palmata*) occurring in the park's southern reefs. Still, current distributions and densities are much less likely than they were historically (e.g., a park reef known familiarly as "Elkhorn Reef" was once a dense and expansive area of live, healthy elkhorn coral, but now consists almost entirely of dead elkhorn coral skeletons).

Two species of acroporid corals, staghorn (*Acropora cervicornis*) and elkhorn (*Acropora palmata*), were listed as threatened in 2005. Both are in decline for a variety of anthropogenic and biological reasons. All park waters east of the chain of islands that run the length of the park are included within NOAA's designated "Critical Habitat" for Acroporid corals.

Listed Birds

Endangered birds in BNP include the wood stork (Figure 111) and least tern Figure 112). The wood stork has been in decline because of habitat loss and modification; it became protected by the state before it was listed as endangered in 1984. Population loss is estimated to be more than 90% since the 1940s and breeding colonies are isolated; there are none in BNP, although the bird is sometimes seen there. Unless the bird's preferred habitats are restored, it cannot be expected to recover (Florida Fish and Wildlife Conservation Commission, 2003). The least tern is currently not listed in Florida. The piping plover (Figure 113), which uses the park's sandy beaches during migratory stops, is listed as threatened. The reduction in beach area from erosion and marine debris coverage limits the habitat space for this species.

Figure 107. Schaus swallowtail butterfly (*Papillo aristodemus ponceanus*). A synonym is *Heraclides aristodemus ponceanus* (UF-IFAS).

Figure 109. Elkhorn coral (*Acropora palmata*) colony growing on rubble hardgrounds (Caroline Rogers, USGS).

Figure 110. Staghorn coral (*Acropora cervicornis*) colony (R. Hays Cummins, Miami Univ.).

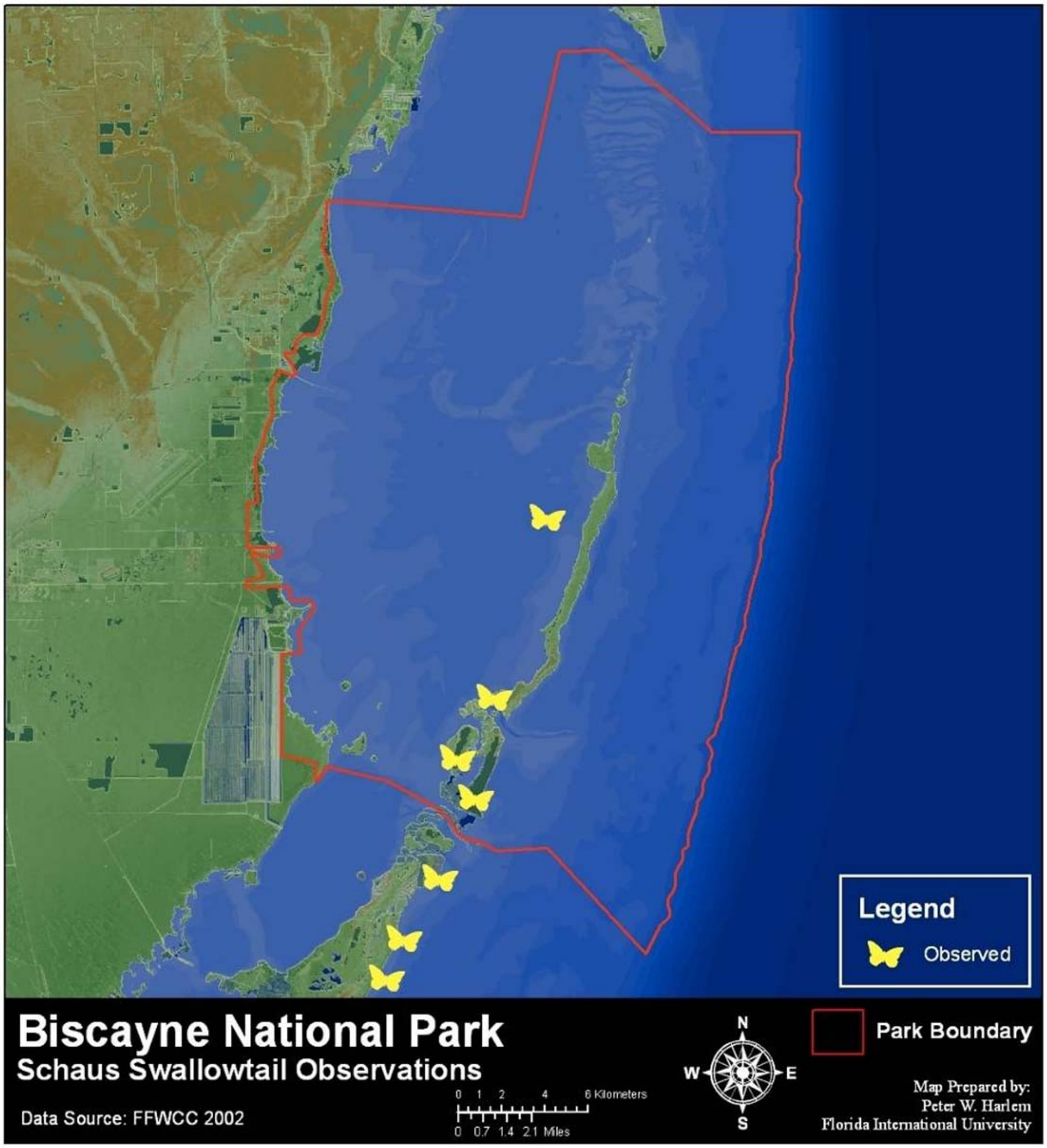


Figure 108. Locations of Schaus butterfly observations as recorded in the Florida Fish and Wildlife Conservation Commission 2002 database. The species inhabits hardwood hammocks of the upper keys.

Figure 111. Wood stork (*Mycteria americana*) (Ryan Hagerty, USFWS).

Figure 112. Least tern (*Sterna antillarum*). Doncon402 image from flickr.com.

Figure 113. Piping plover (*Charadrius melodus*) (C. Perez, USFWS).

Listed Mammals

Endangered mammals in BNP include the West Indian manatee (Figure 114) and the Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*, Figure 115).

Figure 114. West Indian manatee (*Trichechus manatus*) (USGS-Sirenia Project).

Figure 115. Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) (R. W. VanDevender, ASM).

Listed Reptiles and Amphibians

Endangered reptiles in BNP include the American crocodile (*Crocodylus acutus*, Figure 116), the green sea turtle (Figure 117) and the hawksbill sea turtle (Figure 118).

Sea turtles have historically used ocean-side beaches on Elliott, Sands and Soldier keys for nesting (Figure 51). However, the shorelines of Sands and Soldier keys are now overgrown by mangroves, making them unsuitable for nesting. Elliott Key is assumed to be the sole island currently used by sea turtles for nesting and nesting activity is presumed to be exclusively by loggerheads. From 1986-2004, 131 strandings (Table 37) occurred within BNP (Figure 119).

Adult turtles can suffer mortality due to a variety of natural and anthropogenic causes, but sea turtles are especially threatened at the vulnerable nesting stage by predation, particularly by raccoons. Light pollution, which attracts hatchlings toward coastal developments instead of toward the ocean, is a known problem for turtle hatchlings, but BNP nesting beaches are generally dark and lacking the presence of artificial light. The park has achieved good results from efforts to protect the turtle nests from predation by raccoons. Marine debris, which compromises the quality of nesting beach habitat, is removed by park staff and volunteers during organized efforts, such as Alternative Break programs. Park staff and interns monitor nesting beaches daily during sea turtle nesting season (May through October). Newly discovered nests are protected with mesh screening to deter predation and all nests are monitored until they hatch.

Figure 116. American crocodile (*Crocodylus acutus*) is threatened. (Tomás Castelazo, Wikipedia).

Figure 117. Green sea turtle (*Chelonia mydas*) (NOAA).

Figure 118. Hawksbill sea turtle (*Eretmochelys imbricata*) (Caroline Rogers, USGS).

Table 37. Turtle strandings within Biscayne National Park, 1986-2004 (FWC-FWRI).

Type	Total Number	Alive	Fresh Dead	Decomposed*
Green	56	10	11	35
Loggerhead	68	19	9	40
Hawksbill	7	2	0	5
Kemps Ridley	0	0	0	0
Total	**131**	**31**	**20**	**80**
*Combines three sub-categories				

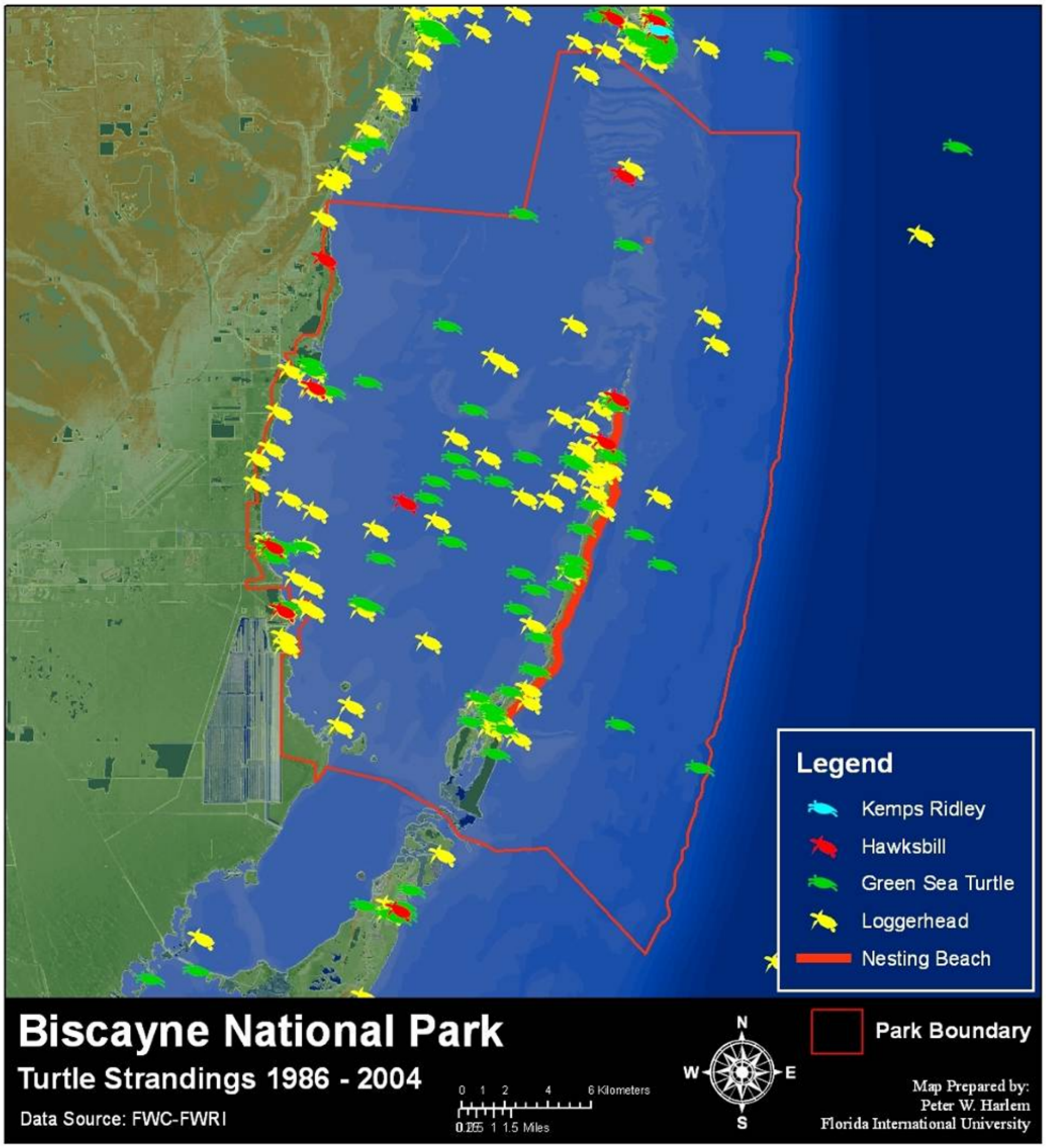


Figure 119. Location of turtle strandings in and around Biscayne National Park for 1986-2004. The single Kemps ridley was found at the north end of Bill Baggs Park on Key Biscayne. Note that the seaward edges of Elliot, Ragged and Soldier keys are nesting locations (FWC-FWRI data).

The nest is then excavated to estimate clutch size and hatching success. Table 38 summarizes the results of nest monitoring in 2008 and is an example of how park biologists assess the status of loggerhead nesting. The park believes its 2008 conservation efforts have helped as many as 300 loggerhead turtle hatchlings reach the Atlantic Ocean that might not have otherwise.

Threatened reptile species include the American alligator (*Alligator mississippiensis*, Figure 120) and the eastern indigo snake (*Drymarchon corias couperi*, Figure 121).

Listed Fish

Endangered fish species in BNP include the smalltooth sawfish (*Pristis pectinata*, Figure 122). Overfishing, entanglement in fishing nets and habitat destruction have reduced this species, which once ranged from Texas to New York, to a few areas around Florida, particularly near the Everglades. The juvenile inhabits mangrove fringe forests and the loss of those to development has had an impact in many areas of southern Florida. It became the first marine fish to be placed on the endangered list on April 1, 2003 and Florida has banned their take along with the use of gill nets. Figure 123 is derived from the National Sawfish Encounter Database maintained by the Florida Program for Shark Research at the Florida Museum of Natural History, which has 16 encounters from 1890-2008; of these, 14 are from 2000 to the present. The range of smalltooth sawfish includes most of the waters of BNP.

Table 39. Listed Species. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Plants		G		I		F		F		I		
Invertebrates (including Corals)		G		I		G		G		G		
Birds		G		G		G		G		G		
Mammals		G		G		G		G		G		
Reptiles and Amphibians		G		G		G		G		G		
Fishes		I		I		G		G		G		

Table 38. Sea turtle nest monitoring in 2008 (NPS).

Date	Identification	Outcome/Comments
May 22	False Crawl* 1	
May 22	Undetermined** 1	This nest was assessed on July 28th and produced 158 hatchlings! This nest was presumed to be a loggerhead nest;
May 28	False Crawl 2	
May 28	False Crawl 3	
June 1	Nest 1 (Loggerhead)	The nest was assessed on August 4th, and produced 49 hatchlings. Unfortunately, many of the eggs in the nest failed to completely develop.
June 12	Nest 2 (Loggerhead)	This event was undoubtedly a nest, as eggs were visible upon close inspection. Unfortunately, this nest was noticeably close to the high tide line, leaving it susceptible to flooding. Indeed, when the nest was assessed on August 25th, all 136 eggs were unhatched and immersed in water at the bottom of the nest cavity. Only 3 of the 136 eggs present had fully developed, indicating that the nest had probably been flooded early on in the nest's development.
June 13	Disturbance of Nest 2	The disturbance was most likely the activity of hungry raccoons. Luckily, the eggs were not damaged. The mesh screen was secured with extra stakes
June 25	False Crawl 4	Because it was a particularly low tide that night, the turtle's tracks across a long distance were more obvious than usual., The sea turtle had apparently attempted to dig in a couple of different locations but was unable to find a satisfactory nesting site due to thick vegetation and a large pile of debris that had washed ashore. Sadly, the turtle returned to sea without laying her eggs.
June 27	False Crawl 5	
June 29	Nest 3 (Loggerhead)	Because this nest was located very close to the high tide line, the nest was susceptible to inundation during peak high tides and storm surges. Indeed, the passing of Tropical Storm Fay likely contributed to the nest being completely immersed in seawater. Sadly, when park staff assessed this nest, none of the 140 eggs produced a hatchling sea turtle; all eggs perished prematurely due to the nest being flooded. Hopefully the female that laid this nest will learn to place future nests further up the beach to protect them from high tides and storm surges!
June 29	False Crawl 6	
July 6	False Crawl 7	
July 21	Undetermined 2	Unknown - This area where this potential nest was located was flooded during high storm activity, which also resulted in the removal and loss of the protective screens. Thus, it was impossible to locate and assess the nest after the passing of the storm.
Aug 18-19	Landfall of Tropical Storm Fay	Fay brought strong winds, rain, and storm surge, with possible flooding of nests that had yet to hatch, particularly those located close to the high tide line.
Aug 26	False Crawl 8	
Aug 26	Nest 4	As with Nest 3, this nest was located very close to the high tide line and, consequently, became inundated by higher-than-normal tides. The flooding of this nest prevented all 133 eggs contained within from fully developing and hatching. To make matters worse, this nest was also predated by large numbers of fire ants.

* False Crawl = Female landed but did not produce nest
**Undetermined = Unable to tell if nest established

Figure 120. Young American alligator (*Alligator mississippiensis*) warming itself on a fallen log (USGS).

Figure 121. Eastern indigo snake (*Drymarchon corias couperi*) (Allen Chartier, Amazilla.net).

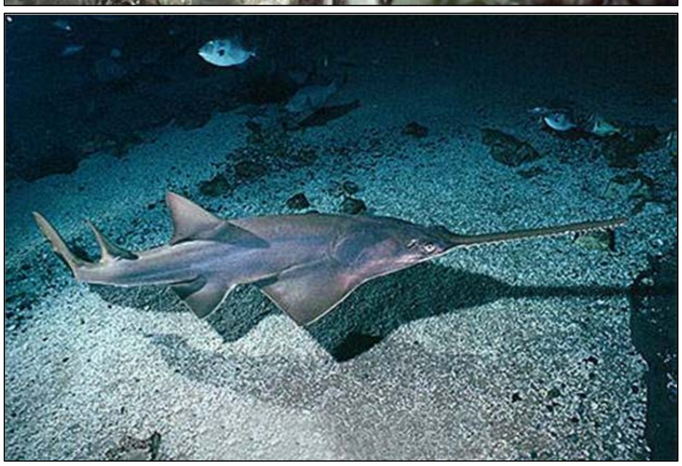


Figure 122. Smalltooth sawfish (*Pristis pectinata*) combines a shark-like body with a toothed snout (Doug Perrine, FLMNH).

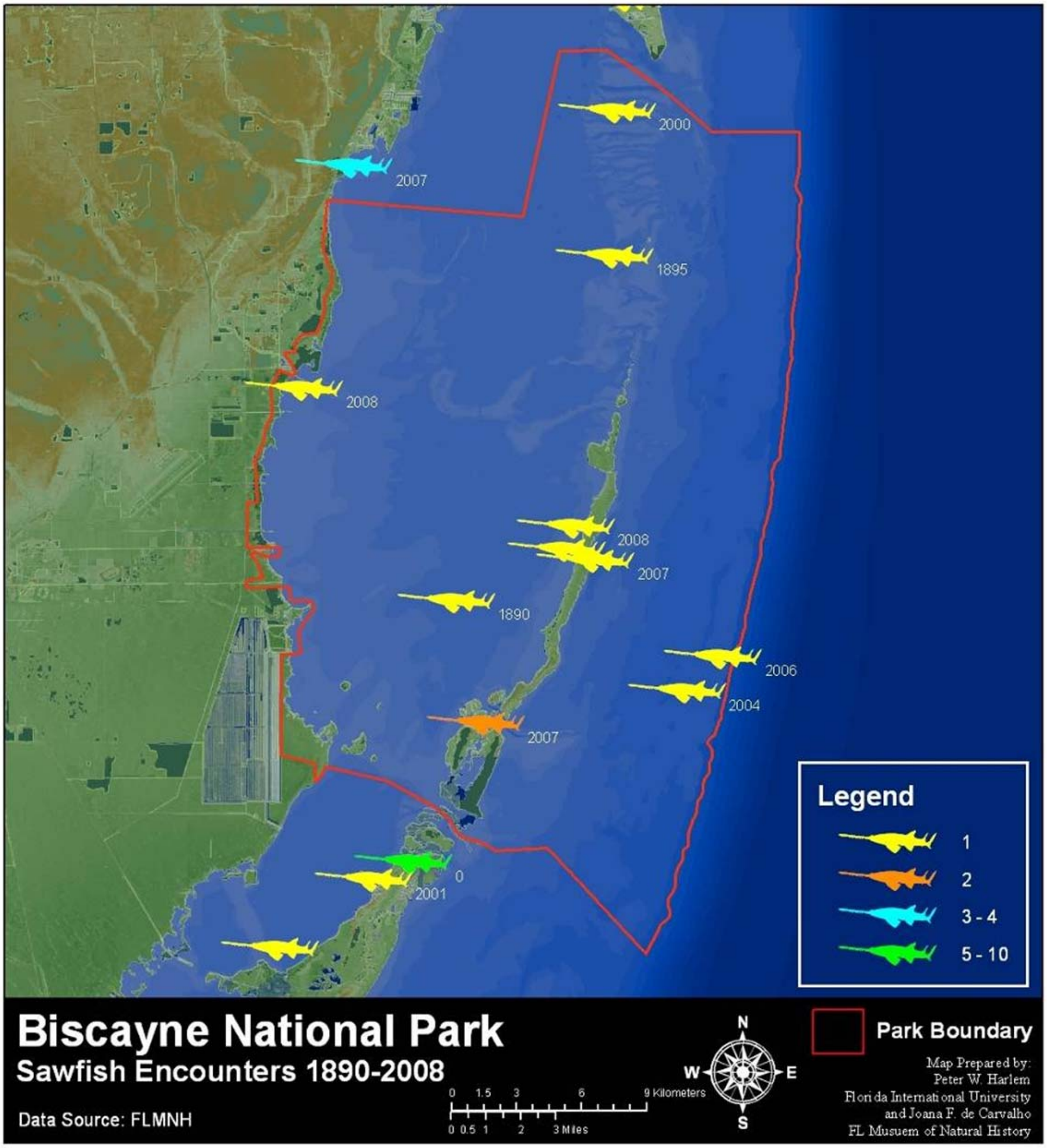


Figure 123. Location of smalltooth sawfish (*Pristis pectinata*) encounters in the National Sawfish Encounters Database from 1890-2008. Color shows the number of fish encountered at each location with the date of the observation when known (Data courtesy of Joana Fernandez de Carvalho, Florida Museum of Natural History).

Aviation Overflights

One major, two minor and several small airports are located near BNP. Homestead Air Reserve Base (formerly Homestead Air Force Base) is also located close to the park in the western watershed (Figure 124, Table 40). Miami International Airport is the major facility for civilian air traffic, which produces numerous overflights by jets and turboprop aircraft above the park during certain wind patterns. Because of concerns of residential neighborhoods, most of these overflights are at higher altitudes (above 1,500 ft AGL).

The Air Reserve Base (HARB) located east of Homestead is home of a USAF Reserve Squadron of F-16 fighter jets and U.S. Customs aviation detachments, which regularly overfly the park during training or operations. The flights are much less common than before 1992 when Hurricane Andrew destroyed portions of the air base. This led the U.S. Air Force to list the base for closing. After the hurricane, political elements in Miami-Dade County wanted to convert the base into a second major commercial airport, specializing in cargo flights, to unburden Miami International and provide an economic engine for the southern part of the county. Fierce local opposition prevented the conversion. Portions of the base were turned over to government and civilian uses. As coastal areas west of the park are developed, there has been an increase in mosquito-spraying flights, some of which are coordinated with HARB and represent a threat to park insects, as well as producing noise or other pollutants.

Table 40. Airports near Biscayne National Park (FAA, 2007).

Airport	Use Category	Distance from Park (km)	Traffic Estimate*	Comments
B & L Farms	Private	18.0	Rare	Small grass strip
Burr's Strip	Private	7.5	Rare	Small grass strip
Holly Dusting Strip	General aviation	15.5	Light	Crop dusting field
Homestead ARB	Military, government	4.2	136 flts/day	All types
Homestead General	General aviation	20.7	198 flts/day	All types
Lindbergh's Landing Airstrip	Private	18.0	Rare	Small grass strip
Kendall-Tamiami Executive	Government, general aviation	13.1	512 flts/day	All types
Mac's Field	Private	13.2	Rare	Small grass strip
Miami Gliderport	Private	16.3	Rare	Small grass strip used by sailplanes
Miami International	Civil, commercial, all types	16.5	1,054 flts/day	Main airport, all types
Miami Seaplane Base (Watson Island)	Seaplane	12.7	38 flts/week	Government Cut ship channel is runway
MJD Stolport	Private	22.2	Rare	Small grass strip
Ocean Reef Club	Private	3.4	Light	Asphalt strip
Opa Locka	Commercial, government	27.2	411 flts/day	All types
Richard's Field	Private	18.3	Rare	Small grass strip
Wright Place Stolport	Private	15.9	Rare	Small grass strip

*Numerical values are averaged from latest period available from FAA and include all types.

Light plane traffic over the park is normally coming from Tamiami or Homestead airports where both privately-owned and aircraft-for-hire are available. Traffic includes mosquito spray flights, which overfly the land bordering the west edge of the park, and whose sprays can drift into park land and affect listed species (e.g., butterflies). Heliports are plentiful in urban Miami-Dade County, and those operating in 2007 are shown in Figure 124 and listed in Table 41.

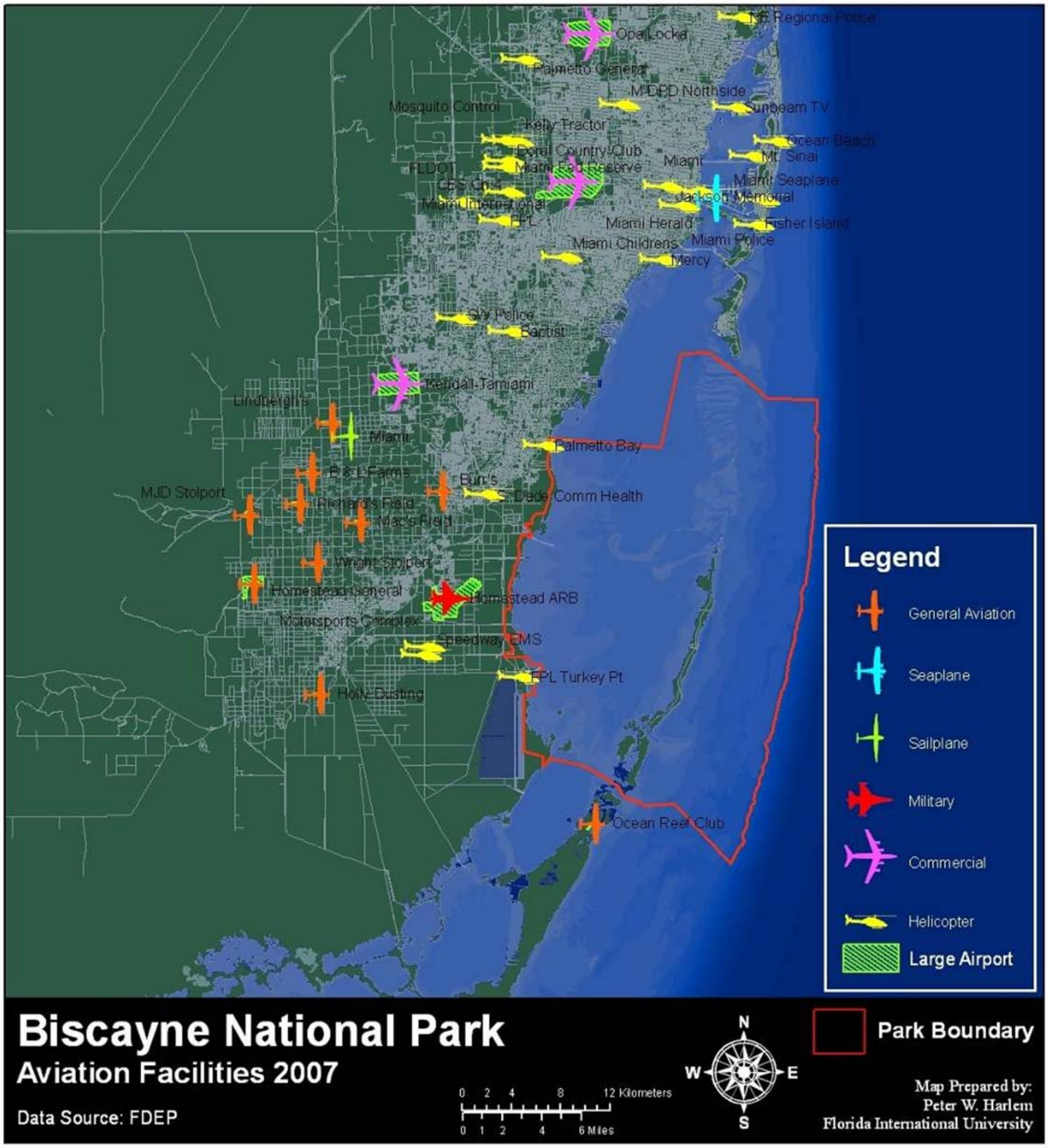


Figure 124. Location of airports and heliports near Biscayne National Park. Larger airports, shown with light green background shape, generally have higher traffic totals.

Table 41. Heliports near Biscayne National Park (2007).

Heliport	Use Category	Distance from Park (km)	Comments
Baptist Hospital	EMS	9.2	
CBS Channel 4	Private	19.2	
Dade City Mosquito Control	Government	22.5	
Doral	Private	21.1	
FLDOT District VI	Government	20.5	
FPL	Private	18.1	
FPL Turkey Pt.	Private	0.9	
Fisher Island	Private	11.3	
Homestead Motorsports Complex	Public	6.3	Used during events only
Jackson Memorial Hospital	EMS	13.7	
Kelly Tractor Co.	Private	21.9	
M-D.P.D. Northside	Law Enforcement	20.9	
Mercy Hospital	EMS	7.8	
Miami Beach PD	Law Enforcement	13.4	
Miami Childrens Hospital	EMS	12.2	
Miami Federal Reserve	Private	20.8	
Miami	Public	12.9	
Miami Herald	Private	13.3	
Miami PD	Law Enforcement	12.1	
Mt. Sinai Medical Center	EMS	16.6	
NE Regional Police	Law Enforcement	27.6	
Ocean Beach Resort	Private	18.3	
Palmetto Bay Village	Government	0.1	
Palmetto General Hospital	EMS	27.1	
S. Dade Community Health Center	EMS	3.8	
Southwest Police	Law Enforcement	12.2	
Speedway EMS	EMS	6.0	
Sunbeam TV	Private	20.2	

Aircraft Noise Pollution

Aircraft, with the exception of some lighter-than-air craft, are normally powered by internal combustion, turbine or jet engines. These produce noise, which varies depending on several variables related to the type and design of the aircraft, and whose volume can be determined by distance from the listener. As a military base, HARB produces occasional jet traffic—a significant noise impact, though normally of short duration. Noise impacts visitors to the park by diminishing the natural soundscape and can also affect some animal populations. The NPS intends to make a "Soundscape Preservation and Noise Management Plan" in 2012.

Aircraft Exhaust Pollution

Powered aircraft produce exhaust gases and particulates, which vary in type and amount depending on engine type, operational behavior and altitude. Wind can disperse this pollution to some degree by removing it from park air space, but some portion can be expected to enter the park's ecosystems where it can do damage to plants and animals. The impact of ozone produced by aircraft was briefly discussed in the HARB redevelopment environmental impact statement (Department of the Air Force, 2000), as was ozone-forming nitrogen oxide and other volatile organic compounds. At that time, air base conversion to a civilian use was not considered to have any effect on the county National Ambient Air Quality Standards or park's air quality, or produce significantly increased loading of depositional nitrogen oxide to park waters.

Aircraft Safety Issues

Aircraft over the park boundary may need to land for several reasons. Helicopters are used by researchers and others visiting the park and, with permission, can land on park property. Aircraft can also encounter difficulties of various kinds that might require emergency landings in the park. Aircraft with floats can attempt to emergency land on the waters of Biscayne Bay or offshore areas, but fixed-wing aircraft will normally crash if attempting to land, as there are few places unvegetated enough to accommodate a safe landing. One example of the problem occurred on September 21, 1965, when an armed Lockheed F-104G Starfighter jet (serial 56-0621) from the U.S. Air Force crashed on takeoff into a mangrove swamp on the shore of Biscayne Bay. The aircraft was armed with 20 mm High Explosive Incendiary ammunition for its cannon and two AIM-9 Sidewinder missiles, as well as a full fuel load. The pilot was killed and the aircraft caught fire upon crashing. Air Force EOD personnel recovered the pilot's body and destroyed the surviving explosive materials on site and were told by a Florida Fish and Game Commission ranger that the site was in crocodile habitat. Figure 125 shows the scar this accident produced in the coastal mangrove scrub.

Table 42. Aviation overflights. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT										
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
Noise Pollution		F		F		F		P		I	
Exhaust Pollution		F		F		F					
Safety Issues – Crash-related		F		F		F		I		I	I

Figure 125. Linear scar made by fighter jet which crashed near the coast between Homestead Air Force Base and the bay in 1965. Remains of the aircraft are visible at top center. Unexploded ordinance was destroyed in place by USAF EOD personnel (T. A. Morris, USAF, with permission).

Power Plants

Electrical generating power plants are located adjacent to BNP. The principal plant is Florida Power and Light's Turkey Point Nuclear facility, located just west of the park's SW corner; it includes a fossil fuel peaker plant on site. A fossil fuel plant also run by FPL, the Cutler Power Plant, is located at 14925 SW 67th Ave in Pinecrest, Florida on the shore of Biscayne Bay, a short distance northwest of the park. This plant used to be used fulltime, but is now used in peak demand periods only. The Turkey Point facility is slated to be expanded in the future to include two new nuclear reactors to upgrade output and at least one fossil fuel peaker plant was permitted on an old landfill site south of the Princeton canal, just west of the park perimeter. Table 43 shows the distance from BNP to these facilities; the locations are shown on Figure 126.

Table 43. Distance from Biscayne National Park to power plant sites.

Facility	Distance (miles)	Comment
Turkey Point	825	To center of plant
Cutler Plant	2,675	To center of plant
Permitted Peaker	910	Exact location inferred

Turkey Point Nuclear

The site includes two generating units that use oil and natural gas. Unit 1, in operation since 1967, is a 398 megawatt oil/natural gas-fired unit; Unit 2, in operation since 1968, is a 400 megawatt oil/gas-fired unit. The first two nuclear reactors (Units 3 and 4) came online in 1972 and 1973, respectively. FPL runs a barge from the Miami Seaport to Turkey Point, as many as 300 times a year, which accesses the plant via an underwater dredged channel within park waters.

In 2003, Florida Power and Light proposed expanding the Turkey Point site to add a new 1,150 megawatt combined-cycle-type natural-gas fired plant (Unit 5). Growth demand and improved reliability were reasons for the expansion; this project went online in 2007.

Cutler Power

The Florida Power and Light Cutler Power Plant, built in 1949 on partially-filled land (parts of Chapman Field), generates electricity with two fossil fuel generators (Units 5 and 6), which can produce 85 and 160 megawatts of electricity respectively. These units normally only operate when peak demand is high (in warm months, when demand for air conditioning is high). The units are cooled with water and the system is capable of using 297 million gallons/day (mgd). During the 2004-2005 running season, however, 177.4 mgd was the annual average daily flow. Exhaust gases are released through two 150 ft stacks, with gases measured at 275˚F at release (http://oaspub.epa.gov/enviro/airs_stack.report?afs_id=120250000). The plant was originally built with four fossil fuel generators, but these were shut down in steps after the opening of Turkey Point. Cutler was subsequently shut down for a time (mothballed) but restarted for peak power generation more recently. Units 5 and 6 are more modern than the original generators.

Water for the generators comes from Biscayne Bay, auxiliary saline wells (8,400 gpm) and from an intake canal. The pumps, which draw circulating water from the intake canal, can handle up to 144,000 gpm, with an additional 54,000 gpm for once-through cooling water. This water is run through the plant once and then discharged at outfall D-001. Additionally, some stormwater runoff is discharged through outfall D-003, and water derived from washing the intake screens is discharged intermittently through outfall D-004. All three outfalls are located approximately at latitude 25°37’52”N and longitude 80°17’56”W; discharge is into Biscayne Bay (Class III Outstanding Marine Waters). No chemicals are added to discharge waters, and an on-site evaporation/percolation pond is used to retain other chemically treated wastewaters which cannot be released to the bay.

Florida Department of Environmental Regulation is responsible for testing the outfall effluent to ensure the facility does not adversely affect state waters. They perform 48-hr acute toxicity and algal growth potential tests, as well as chemical analysis of the effluent from outfall D-001. The effluent water is warmer than the water taken in (Table 44) and has attracted manatees to this site in cool months. The plant adds supplemental water to the discharge to keep the temperatures below +18˚F ambient (intake water) to minimize damage to adjacent seagrasses, and required seagrass monitoring has shown an increase in coverage, density, biomass and relative condition since the supplemental cooling water program was started (Hatcher, 2005).

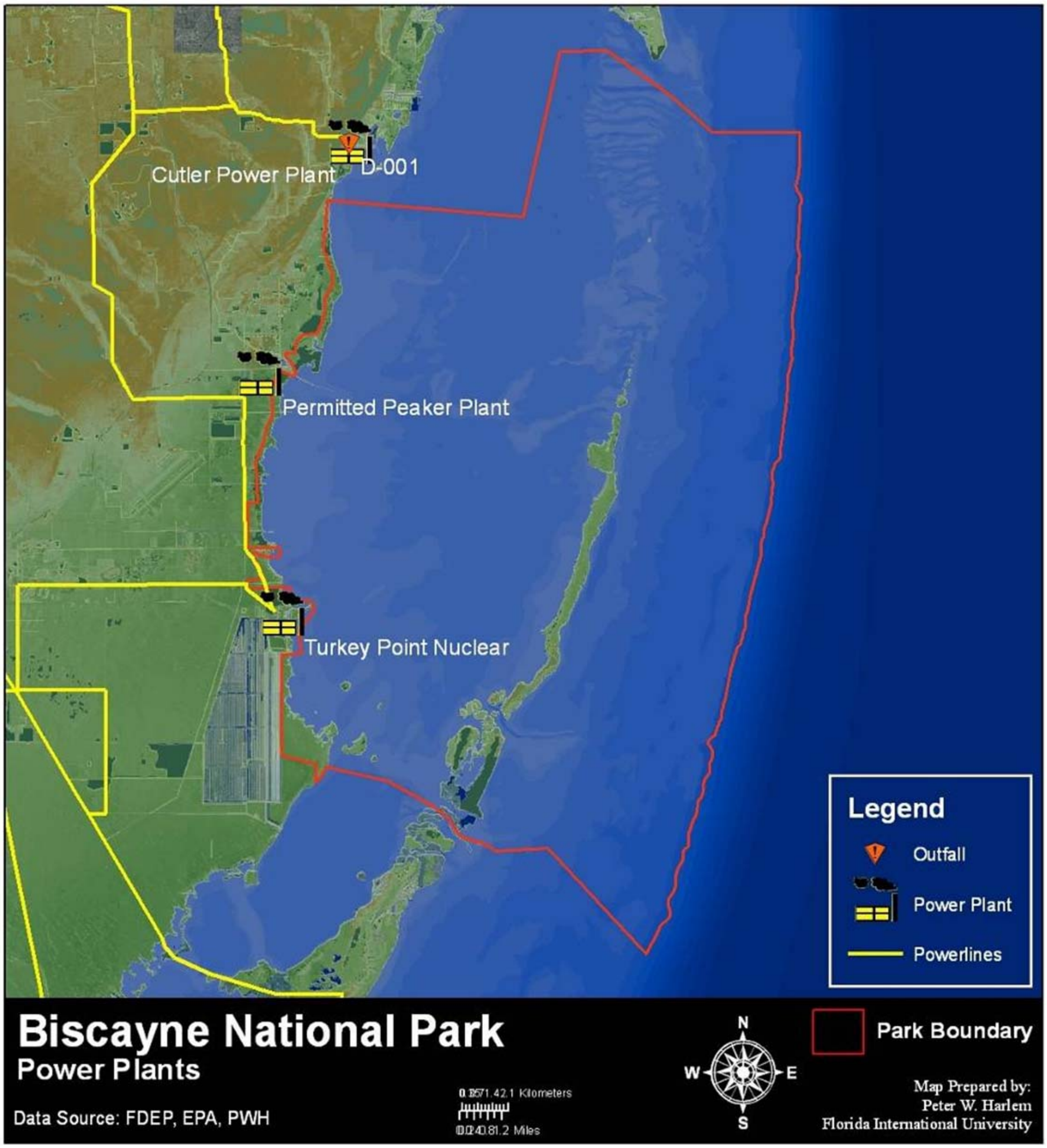


Figure 126. Location of power plants adjacent to Biscayne National Park. Outfalls are the location of outlet canals and are potential pollution-point sources. Powerline data source was incomplete and supplemented by tracing lines from recent aerial photographs.

Table 44. Cutler Power Plant 2007 water effluent temperature data. Data from EPA website.

Date	Effluent Max T (^oF)	Effluent Min T (^oF)	Intake Max T (^oF)	Intake Min T (^oF)
31-OCT-2007	97.9	89.5	90.8	85.2
30-SEP-2007	102.3	94.2	91.0	88.9
31-AUG-2007	105.3	94.5	98.2	89.7
31-JUL-2007	101.9	94.9	94.0	90.2
30-JUN-2007	100.7	90.2	96.0	86.0
31-MAY-2007	96.0	86.4	87.4	83.0
30-APR-2007	97.9	86.4	86.8	82.4

Data from 2005 sampling (Florida Department of Environmental Protection, 2005) showed the samples were not acutely toxic to the test organisms (the mysid *Americamysis bahia* and silverside fish *Menidia beryllina*). The algal growth potential was inconclusive because quantities were low and TP and Ortho P were not detected in the effluent; this also prevented calculating nitrogen to phosphorus ratios. Total ammonia concentration was 0.049 mg/L and calculated unionized ammonia concentration was <0.02 mg/L. The effluent was estimated (from meter values of 44% saturation at 34.51^{o}C) to have a dissolved oxygen content of 3.1 mg/L; this is in violation of Class III marine water criterion, which should be equal or above 4.0 mg/L. The lab measurement for DO was 5.3 mg/L. Chemical analysis from the FDEP report is shown in Table 45.

Turkey Point Expansion

On October 16, 2007, FPL proposed to add two additional 1,100 megawatt nuclear units (6 and 7) to the site, and this is undergoing evaluation with FPL, suggesting Unit 6 would go online in 2018 and Unit 7 in 2020. FPL is currently discussing using either wastewater from either the Central or South District Waste Water Treatment plants (Miami-Dade) or brackish well water from wells drilled into the "Boulder Zone" (2,800-2,400 ft down). FPL suggests that water demand will be for 60-90 mgd of cooling and process water with the higher number needed if the water is more saline. 30-45 mgd of the water will evaporate during generation and will have to be replaced each day. State regulators gave FPL the go ahead for plans for the new reactors in March, 2008. Current design plans include raising the 300-ac new reactor site to 20 ft elevation. Fill sources are unknown but one proposal suggested removing a large acreage of wetland/farmland north of the facility and a short distance west of the park.

On July 24, 2007, NPS staff met with FPL to express concerns as to the few details the company was then showing about the planned expansion. In a letter of concern following this meeting, a site of mangrove wetlands within "Environmental Protection Subarea E" located east of SW 117th Ave., and west of the existing cooling canals between SW 344th St. and theoretical SW 376th St., was planned to be used to construct access roads. Further, another 900 ac west of the park near the plant was shown as potential borrow pits for fill to raise the reactor site. NPS pointed out that the borrow area was east of the 1995 salt water intrusion line in the recharge area, which maintains the saltwater barrier line. Dragline mining of the material in this area, it was pointed out, would negatively affect the surrounding hydrology. Both features commented

Table 45. 2005 Analysis by Florida Department of Environmental Protection of Cutler Power Plant discharge from outfall D-001. Metals in µg/L unless otherwise noted. S.U. = standard units; MDG = million gallons/day.

FPL Cutler NPDES# FL 0001481	Class III Marine Stds	Effluent Limits	Effluent Samples
Aluminum	≤ 1,500	-	5 U
Arsenic	≤ 50	-	4 U
Cadmium	≤ 9.3	-	0.5 U
Calcium (mg/L)	-	-	335
Chromium-III	-	-	2 U
Copper	≤ 3.7	-	5 U
Iron	≤ 300	-	33 I
Lead	≤ 8.5	-	0.75 U
Magnesium (mg/L)	-	-	965
Nickel	≤ 8.3	-	2 U
Selenium	≤ 71	-	6 U
Silver	≤ 2.3	-	0.25 U
Zinc	≤ 86	-	3 U
Nutrients (mg/L)			
Ortho-phosphate	-	-	0.004 U
Total Phosphorus	-	-	0.02 U
Ammonia	-	-	0.049
Unionized Ammonia	-	-	≤ 0.02 c
Nitrate+Nitrite	-	-	0.046
Total Kjeldahl Nitrogen	-	-	1.3
Organic Nitrogen	-	-	1.25 c
Total Nitrogen	-	-	1.35 c
General Physical and Chemical Parameters			
pH (S.U.)	6.5-8.5	-	7.5
Conductivity (µmhos/cm)	-	-	30,020
Dissolved Oxygen (mg/L)	≥ 4.0	-	3.1
Temperature (^{o}C)	-	Report	34.5
Oil and Grease (mg/L)	≤ 5.0	-	1.7 UJ
Flow (AADF in MGD)	-	≤ 297	177.4 a
Hardness (mg/L)	-	-	4,810.4 c

a - Annual average
c - Calculated value
I - Reported value is between the laboratory method detection limit and the practical quantization limit.
J - Estimated value
U - Not detected; value reported is the minimum detection limit.

on were expected to negatively impact the remaining freshwater sheetflow to the park edge and decrease any benefit the CERP Coastal Wetlands restoration could provide, once implemented. NPS also pointed out the lands had been previously identified as providing wildlife connectivity, and are frequented by several endangered or threatened species, including the Florida panther, indigo snake, wood stork and state listed wading birds. NPS also expressed concerns about the lack of supplies of water to meet the plant's needs, disposal of same, archeological issues and the threats from sea level rise that would leave the facility as an island at some future stage (National Park Service, 2007). Figure 127 shows the proposed plan for expansion.

Proposed Peaker Plant

In 2001, Enron Corp., a now defunct Texas energy company, asked Miami-Dade County for zoning variances to erect a natural-gas-burning "peaker" plant that would sell electricity to Florida Power & Light during periods of high demand. This would have been located on a 61-ac site that was being used as a construction dump. Enron officials stated the plant would be environmentally clean and largely invisible from surrounding areas, with the notable exception of three 80 ft smokestacks; they wanted to begin construction in 2001. The plant would be run on natural gas with the option to use diesel when gas supplies became inadequate.

At the time, there were other speculators trying to build an LNG terminal in the Bahamas with a gas line across the Florida Straits to Broward County, which was thought to be capable of bringing large supplies of gas to south Florida. Opposition from NPS officials and other environmental groups was mounted, but the permit was given just before the company financially collapsed. The current status of the permit is unknown; if it is still in effect, then the plant site is a potential problem for the park.

Table 46. Power plants. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT										
KEY ISSUE	**Terrestrial**		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
Turkey Point			I	I	I	I	G	G	I	I	I
Cutler Plant	I	I	I	I	I	I	F	F	I	I	I
Turkey Point Expansion		I		I	I	I	I	I	I	I	I
Proposed Peaker Plant		I	I	I	I	I	I	I	I	I	I

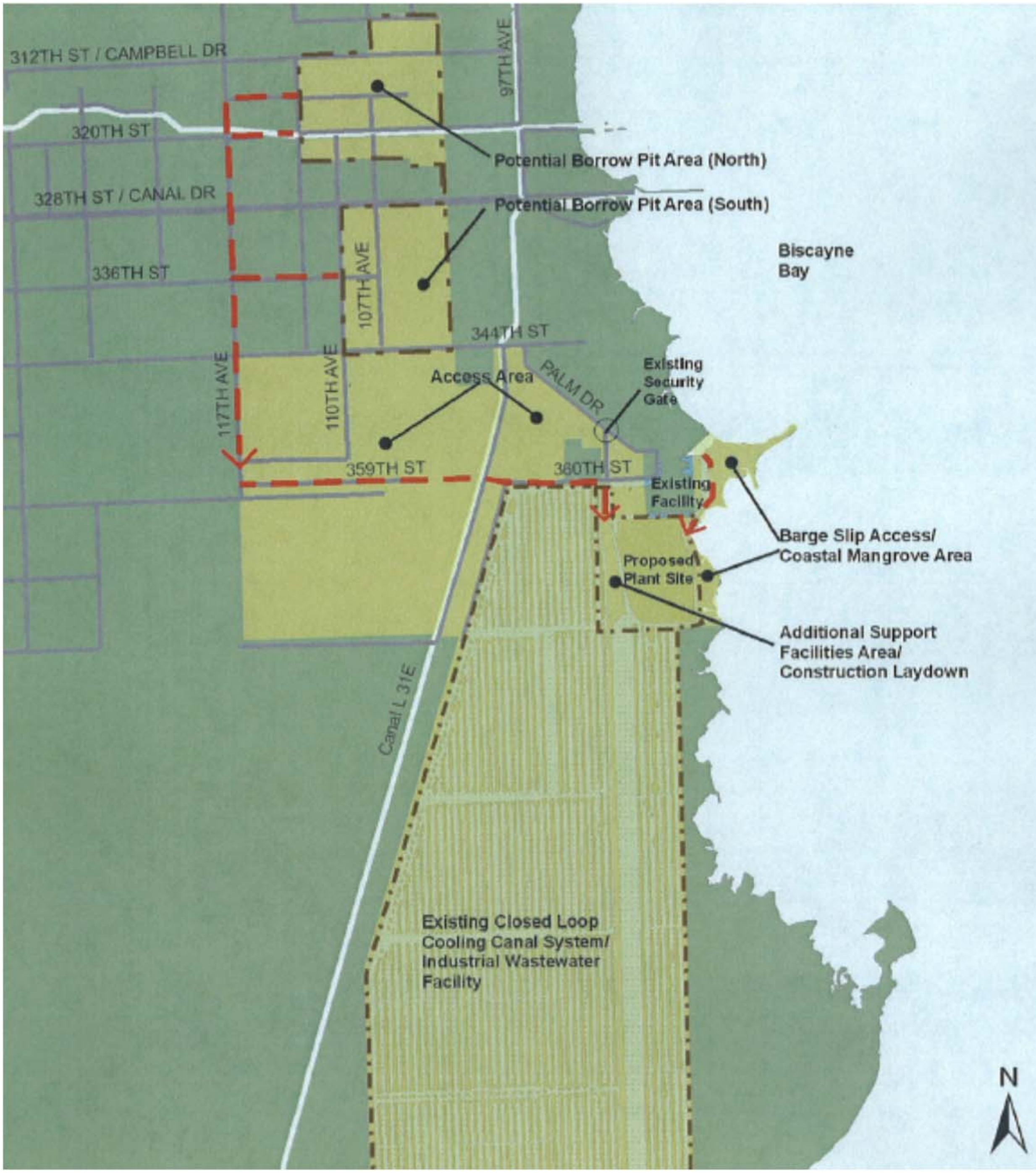


Figure 127. Proposed expansion plan for Turkey Point. Note the two large areas at the north used for borrow material needed to raise the plant site to 20 ft. The exact usage of the large "Access" areas on the north and west sides has not been made clear so far (Florida Power and Light Co., 2007).

Geophysical Threats

Earthquakes

Crustal movement and other severe geological processes can produce earthquakes. Earthquakes have been recorded in Florida, but are unknown near BNP. Tremors were reported in January 1879 between St. Augustine and Daytona Beach, in Cuba (felt in Key West) in January 1880 and in the Jacksonville area in 1886, 1893 and 1900. Captiva Island (Fort Meyers) felt shocks in November 1952. Others temblors include shocks along the Caloosahatchee River in 1930 and Tampa in 1940, but these are not thought to be seismic in origin and may have been caused by blasting (USGS, 1971). On January 19, 1942, five to seven evenly spaced tremors were felt from Miami through the Everglades. Each shock lasted about one minute and the shocks were spaced at three-minute intervals (Campbell, 1943). In Hollywood, houses shook, and at Moorehaven, south of Lake Okeechobee, 12 tremors were reported. The largest shock was magnitude 3.3.

A search on the USGS Earthquake database (NEIC) for earthquakes in the last 20 years within a 200 km radius of Biscayne Bay found several large-magnitude events (Table 47). USGS maps of seismic areas show historical quake zones in Cuba, the Bahamas and the eastern side of the Gulf of Mexico, but none in SE Florida. Earthquake shock risk is low around BNP (Figure 128).

Tsunamis

Tsunamis are large-period water waves produced by submarine earthquakes or landslides; they displace bottom substrates enough to affect large masses of water, volcanic eruptions and (rarely) asteroid strikes. The potential for tsunamis in the Atlantic Ocean is not well understood; they are a potential problem because they may have occurred in the past and might again.

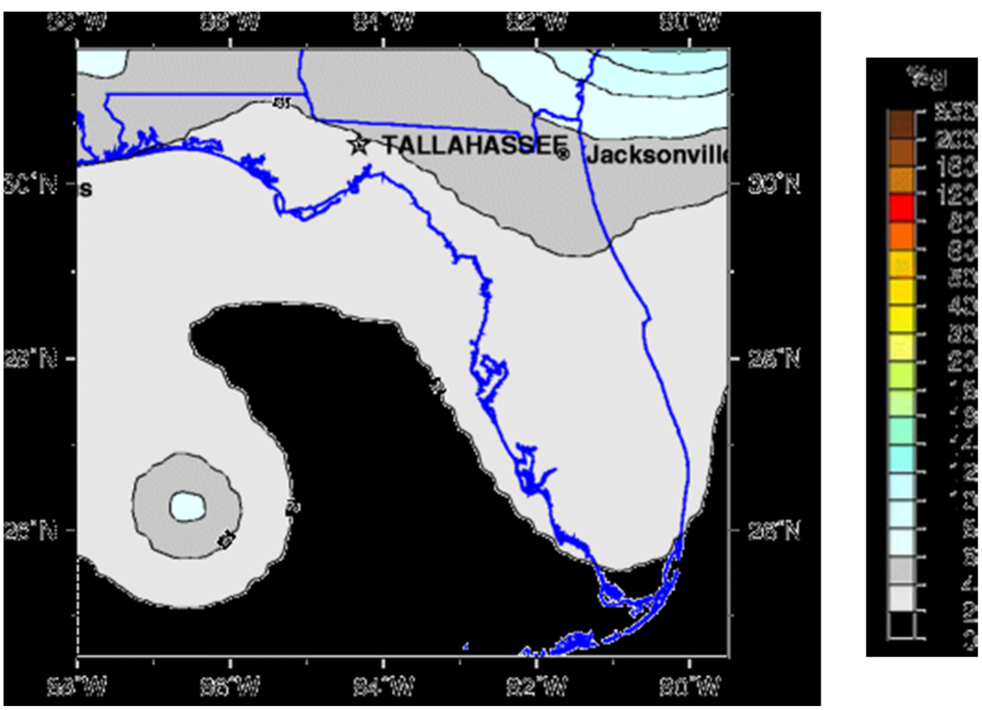


Figure 128. Earthquake peak acceleration (% g) with 2% probability of exceedence in 50 years. South Florida lies in the 0-4 % range (USGS, National Seismic Hazard Mapping Project, 2008).

Table 47. Recent large-magnitude earthquakes within 200 km of Biscayne National Park.

CAT	YEAR	MO	DA	ORIG TIME	LAT	LONG	DEP	MAGNITUDE	IEFM NFPO TFS	DIST km
PDE	1992	01	05	165849.41	25.62	79.50	100			100
PDE	1994	08	31	232954.57	25.85	78.57	33	4.70 mb GS	F	197

Tsunami waves striking the Florida coastline might be a major, though rare, geological process, which has the potential to erode coastal environments and benthic communities. They might drive sedimentological process which could further impact biotic environments. Numerous earthquake-related tsunamis have been documented around the geologically active Caribbean since the 1700s, but most had no known effect on southeast Florida. The Canary Islands, and especially the volcano Cumbre Vieja, might pose a tsunami threat to the Atlantic Ocean; volcanic activity may cause major landslides into the ocean around the islands (Ward and Day, 2001). While the model shows waves reaching Florida, a reduced impact for South Florida occurs because of the blocking effect of the Bahamas banks and associated islands. The risk of tsunamis in BNP is considered unknown.

Table 48. Geophysical threats. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

	RESOURCE COMPONENT											
KEY ISSUE	Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water	
	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	
Earthquakes	I	I	I	I	I	I	I	I	I	I	I	
Tsunamis	I	I	I	I	I	I	I	I	I	I	I	

Threat Assessments Summary

The summary threat table (Table 49) was compiled from the tables at the end of the preceding sections. Readers wishing background should visit the appropriate section after referring to the section number on the left side.

There are many threats to the resources of BNP, and many gaps in our knowledge of the functioning of the Biscayne Bay ecosystem. The summary table presents threat/stressor information for different abiotic and biotic resource components classified as terrestrial, canals, wetlands, Biscayne Bay proper, marine/reef and groundwater. Cells coded **red** highlight acknowledged current problems; cells coded **orange** highlight potential problems, and those coded **yellow** highlight areas of uncertainty about the extent of resource management problems. Cells in **green** suggest either no problems, or issues which are under control, while **blue** represent historical problems.

Given unlimited monetary, personnel and technical resources, all of the yellow, orange and red issues require research into the drivers of the resource issues. However, in practical terms, priorities must be set to wisely spend the available resources. To further guide the expenditure of resources, we have attempted to summarize the state of the knowledge base for understanding the color-coded problems using four letters to indicate whether the knowledge base is **good (G), fair (F), poor (P) or only inferred (I)**. Those identified issues with scores of I or P should be higher research priorities than those problems for which there is a fair or good level of understanding of the problem. Existing problems with a good knowledge base are candidates for management actions; while problems with less certain understanding are candidates for research. Given our understanding of the state of the natural resources of BNP, we highlight the current problems that deserve research priority.

Table 49. Summary threat assessment table. Threat color code: red = current, orange = potential, yellow = uncertain, green = none or under control, blue = historical. Knowledge base: G = good, F = fair, P = poor, I = inferred.

			RESOURCE COMPONENT										
			Terrestrial		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**
Section	**THREAT/ STRESSOR**	**KEY ISSUE**	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
4.2	Atmospheric Deposition	Acidification	F	I	F	I	F	I	F	I	F	I	I
		Chemicals and particulates	F	P	F	P	F	P	F	P	F	P	P
		Pathogens		P		P		P		P		F	
4.3	UV Impacts	UV		I		I		I		I		I	
4.4	Visibility Impairments	Air quality	G	I			G	I	G	G	G	G	
		Water turbidity			F	F	G	G	G	G	G	G	G
4.5	Ozone	Concentration	I	I	I	I	I	I	I	I	I	I	
		Air quality	I		I		I		I		I		I
4.6	Nutrient Enrichment	Nutrient enrichment	I	I	G	G	G	G	G	F	F	F	G
4.7	Microbial Contamination	Microbial contamination	I	I	F	P	I	P	I	F	I	F	I
4.8	Pollutants	Pharmaceuticals	I	I	F	F	F	F	F	F	F	F	F
		Pesticides and herbicides	F	F	F	F	F	F	F	F	F	F	F
		Metals	F	F	F	F	F	F	F	F	F	F	F
		Antifouling agents							P	P	P	P	
		PCBs and PAHs	F	F	F	F	F	F	F	F	F	F	I
		Thermal pollution			I	I	I	I	G	G	I	I	I
		Radiological contamination	I	I	I	I	I	I	I	I	I	I	I
		Marine debris	P	I	I	I	P	I	I	I	I	I	
4.9	Fire	Curtailment of historical fire patterns	P	P									
4.10	Hydrology/ Water Management	Regional level/stage			F	F	F	F	F	F	I	I	F
		Discharge			F	F	F	F	F	F	I	I	F
		Timing			F	F	F	F	F	F	I	I	F

Table 49. Summary threat assessment table (continued).

			RESOURCE COMPONENT										
			Terrestrial		**Canals**		**Wetlands**		**Biscayne Bay**		**Marine/Reef**		**Ground Water**
Section	**THREAT/ STRESSOR**	**KEY ISSUE**	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
4.11	Habitat Loss	Channelization/ sheet flow barriers					F	F	F	F	I	I	F
		Coastal development	F	F	F	F	F	F	F	F	I	I	F
		Habitat fragmentation	F	F			I	I	I	I	I	I	
		Fisheries harvest						I		G		G	
		Algal blooms			I	F			I	G	I	F	
4.12	Visitor Use and Habitat Disturbance	Visitor Impacts	I	I	I	I	I	I	I	I	I	I	
		Boating					I	I	I	F	I	F	
		Marinas and marine facilities	I	I			I	I	I	I	I	I	
4.13	Harvest/Hunting/ Take	Vegetation		I				I		I		I	
		Animals		I				I	F	I	F	I	
		Recreational fishing		I		I		I		I		I	
		Poaching		I		I		I		I		I	
		Cultural artifacts	I		I		I		I		I		
4.14	Exotic Species	Plants		G		I		I		I		I	
		Birds		G		I		I		I		I	
		Fishes				G		F		F		F	
		Invertebrates		F		I		I		I		I	
		Mammals		I		I		I		I		I	
		Reptiles		G		I		I		I		I	
4.15	Pests and Pathogens	Vegetation		I		I		I		P		P	
		Animals		I		I		I		I		I	
		Birds		I		I		I		I		I	
		Corals								P		F	

Table 49. Summary threat assessment table (continued).

			RESOURCE COMPONENT										
			Terrestrial		Canals		Wetlands		Biscayne Bay		Marine/Reef		Ground Water
Section	THREAT/ STRESSOR	KEY ISSUE	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic	Biotic	Abiotic
4.16	Climate Change	Weather changes	F	F	F	F	F	F	F	F	F	F	F
		Increased water temperature				I		I	I	F	I	F	
		Sea level rise	I	I	I	I	I	F	I	F	I	I	G
		Species range changes		I		I		I		I		I	
		Ocean acidification					I	F	I	F	I	F	
4.17	Endangered/ Listed Species	Plants		G		I		F		F		I	
		Invertebrates (including corals)		G		I		G		G		G	
		Birds		G		G		G		G		G	
		Mammals		G		G		G		G		G	
		Reptiles and amphibians		G		G		G		G		G	
		Fishes		I		I		G		G		G	
4.18	Aviation Overflights	Noise pollution		F		F		F		P		I	
		Exhaust pollution		F		F		F					
		Safety Issues – crash related		F		F		F		I		I	I
4.19	Power Plants	Turkey Point			I	I	I	I	G	G	I	I	I
		Cutler Plant	I	I	I	I	I	I	F	F	I	I	I
		Turkey Point expansion		I		I	I	I	I	I	I	I	I
		Proposed peaker plants		I	I	I	I	I	I	I	I	I	I
4.20	Geophysical Threats	Earthquakes	I	I	I	I	I	I	I	I	I	I	I
		Tsunamis	I	I	I	I	I	I	I	I	I	I	I

Recommendations and Information Needs

Recommendations and research needs were developed based on general findings and on the priorities in the Threats/Stressor Table (Table 49). The recommendations do not include all of the problems from the natural resources threat assessments (yellow, orange and red), or all of those that need more knowledge. Efforts were made to include the resource threats estimated to have the highest collective impact or are interrelated between different categories, including: 1) Geological Environment, 2) Terrestrial Environment, 3) Marine/Benthic Environment, 4) Hydrology and Water Quality and 5) Pollutants.

Geological Environment

The geological environment provides the setting for the biological habitats in BNP as it controls the location and elevation. The marine nature of the park is a result of its position on the peninsula and low elevation relative to sea level. With climate change, a better understanding of groundwater will be required because of its influence on water delivery and quality. Better knowledge of the geology will help management understand how the present environments evolved and how they will continue to evolve into the future.

Geological Mapping

Sporadic collection of geological data in the past does not provide an adequate picture of the geology of the park. The following issues relate to this lack of data:

- Limestone facies and their epikarst characteristics in the Key Largo Formation control vegetation patterns, soil development and ground water or fresh water lense maintenance on the rocky keys in BNP. A fully detailed geological mapping of the rock facies at the surface and shallow subsurface would provide this understanding, which is lacking in most biological reports.

- Geologic maps of Biscayne Bay do not identify the type of limestone under the bay, nor the location and exact nature of the contact between the Key Largo Limestone and the Miami Limestone. A full geological workup of the relationship between the two formations in the park is in order. This is significant in understanding groundwater discharge patterns, salt water intrusion and location and maintenance of fresh water lenses. This effort should include a complete description and map of the karst features in the park, as these will become more important as sea level continues to rise.

The Safety Valve Mud Bank

This unusual and spatially large complex is unique to BNP, and perhaps the world, yet it remains virtually unstudied. We recommend a complete sedimentological workup of this feature to include Holocene paleontological evolution; this should provide much better understanding of Biscayne Bay's early history and formation of the modern environments, its role in tidal restriction and tidal flux and potential effects that changing sea level will have on the sedimentation.

Karst Holes and Incised Channels

Holes and sinuous traces etched into the surface of the limestone in Biscayne Bay are readily visible in aerial photos and should be mapped. Many of these are known to have mangrove peat infillings which should be sampled for paleontological information useful in reconstructing the park's history. Since these features are normally covered by lush *Thalassia* or other seagrass beds, they probably provide the mechanism which lets benthic vegetation spread after setback by large storms. This relationship should be examined. The breaks in surface limestone may be sources for groundwater discharge and nutrient loading.

Educational Geology

The park has many unique geologic features that are not being exploited. We recommend a geology program be instituted at the park headquarters; its goal would be to identify the important features and to then teach visitors and student groups about these assets. BNP is a unique location to show how shallow water carbonate sediments are formed and accumulated, how reefs are built and the materials become fossilized, how karst processes alter the landscape and how episodic deposition affects mangrove peats and calcitic marls.

Sea Level Rise and Climate Change

A significant rise in global sea levels is predicted for the near future. This will produce changes in the physical processes in the park, many of which will be catastrophic for the park's ecology. Ultimately, the complete loss of land sections is predicted if the rise continues at its current rate; the concurrent deepening of the marine portions of the park will introduce additional management complications.

- A complete workup of the effects of sea level rise is in order, with special attention to erosion of coastlines and shallow sediments, which are likely to occur and will greatly impact the location, type and diversity of biological communities considered important now.

- It is certain that BNP mangroves will expand in certain locations and in association with some possible rates of sea level rise, while receding with other scenarios. Given good topographic control and the availability of timely, high quality imagery, a workable model could and should be developed for the terrestrial habitats. As highlighted in the Threats/Stressors Table (Table 49), there is little doubt that the effects of sea level rise on all land-based ecosystems in BNP will be a fundamental issue throughout the park's future. The possibility of drier climatic conditions will affect rainfall and decrease water discharge, with the expected enhancement of salinity and associated ecological effects.

Terrestrial Environment

The terrestrial environments of BNP, which is better known for its marine resources, include hardwood hammocks (broadleaf forest comprised of tropical upland trees) and coastal wetlands. The latter comprise the entirety of mainland BNP, while the former characterize a diverse mixture of communities on the barrier islands that form the eastern rim of Biscayne Bay. These two contrasting terrestrial ecosystems are underappreciated and critical components of the broader BNP landscape. We view the coastal wetlands as critical, primarily for their interactions with surrounding marine ecosystems, though their role in buffering nearby urbanized areas from storms may also be considerable. The significance of BNP hardwood forests lie in their great intrinsic contribution to biodiversity, in light of the diminished regional extent of tropical hammock vegetation.

With the recent completion of a very detailed map of BNP vegetation (Ruiz et al., 2008), there is little question regarding the extent and distribution of terrestrial communities in the park; their structure and function are not nearly so well understood, however. For coastal wetlands, three research questions seem paramount.

Anthropogenic Effects

Anthropogenic effects identified as especially critical include barriers to sheet flow, coastal development, habitat fragmentation, increased salinity and nutrient loadings and spatial and temporal water delivery issues. Exotic species issues and pests and pathogens are also largely anthropogenic in origin. We need to know how human activities which affect these functions also affect the structure and productivity of coastal wetlands. This effort needs to assess the water delivery to the coast in such a way as to remove the masking occurring from natural disturbance. Alterations in fire regime, driven by coastal development patterns, have impacted coastal wetlands severely, and they are one element that active management can mitigate.

Ecosystem Services

How do the structure, extent and distribution of coastal wetlands affect their ability to produce, exchange or sequester sediments, nutrients and biota bound for adjacent nearshore ecosystems? The interdependence of BNP ecosystem types is best exemplified by the adverse impacts that loss or degradation of coastal wetlands has on the biota of Biscayne Bay. The positive impact of coastal wetlands on fisheries (e.g., reef fish nursery habitat) is well-known, but quantitative relationships for south Florida have not yet been completely developed and verified.

Hammocks

BNP's hammocks provide habitat for many of the endangered birds, plants and mammals in the park. Whereas the distribution of hammocks within BNP islands is now well-known, current and comprehensive information regarding a) compositional, structural and diversity patterns within this extensive forest (including exotics), b) the physical parameters controlling hammock species, c) the nutrient relationship between rocks, groundwater, trees and litter and d) the population status of distinctive biotic elements, including the associated faunal communities, are generally lacking. With such an information void, it is no surprise that public awareness of this outstanding biological resource is limited. Increased educational and recreational access to these forests could be achieved without sacrificing their ecological integrity, and could enhance the quality and breadth of visitor experience in the park considerably.

Marine Environment

Visitor Impacts

Excessive visitor usage of park resources may result in long term effects on marine organisms. The resilience and buffer capacity of these resources, in regards to visitor use increments, must be assessed in order to adjust management plans accordingly. The impact of boaters directly on seagrass beds, bank stability and corals is poorly known.

Anthropogenic Modification of the Environment

The following issues relate to human changes to the environment:

- Water quality is likely to change in response to the growing human populations, changing land uses in south Florida and changing policies for managing freshwater resources in the BNP watershed. Changes in water quality will lead to changes in the benthic communities in Biscayne Bay, and potentially in the marine/reef environments seaward of the barrier islands. Steps should be taken to test hypotheses about water quality; benthic community relationships and a synthesis of existing and new information needs to be developed to allow for specific predictions of outcomes for planned changes in the quality or quantity of water entering the park. The relationships between altered water quality and the diseases of marine organisms also need illumination.

- Far-field human modification of the environment: While at the current time it is apparent that near-field human impacts are of primary concern, the continuing accelerating rate of climate change may soon overtake the local impacts in importance. Research should be directed toward understanding how climate change will impact the populations of individual marine organisms from the benthic communities as well as those occurring in the wetlands, Biscayne Bay and the marine/reef zones of the park, and also how climate change could change the relative dominance of species that structure the benthic communities. Of particular importance are sea level rise effects, rainfall changes, increasing temperature and increasing pCO_2 (acidification).

Impact of Removal of Fisheries Species
The following issues are related to harvesting of species for food or recreation:

- Food web impacts resulting from the removal of fisheries species need to be better understood to predict the ecosystem-scale consequences of the exploitation of fisheries' resources from the benthic marine communities of Biscayne Bay and the marine/reef regions of the park.

- Indirect impacts of removal of fisheries species: Non-lethal impacts of the removal of components of communities can have a more severe impact than the lethal impacts. Given the reduced state of top predators in the park because of fisheries, understanding how these reductions cascade through the ecosystem is vital.,

Invasive/Exotic Species
In almost every studied ecosystem, invasive species alter the structure and function of the ecosystem. It is only a matter of time before more invasive species colonize environments in the wetlands, Biscayne Bay and the marine/reef regions of BNP. For example, the arrival of the Indo-Pacific lionfish, a voracious predator with poisonous spines, has already occurred although numbers locally have not peaked as they have in other parts of the Atlantic. Cichlid fish species have displaced killifish, new species of mangroves have naturalized in Biscayne Bay, and invasive algae are rapidly spreading.

Pests and Pathogens
The role of diseases in dynamics of marine biota, especially fish, corals and seagrasses from Biscayne Bay and the marine/reef regions, need to be understood, especially in light of recent findings that degradation in water quality leads to enhanced disease progression in corals.

Small-scale Disturbances
Cumulative impacts of small disturbances on the integrity of landscapes need to be better understood. With the increasing rate of boat grounding, and the predicted increase in tropical cyclone frequency and severity with climate change, we must understand how the cumulative

impacts of small-scale disturbances scale up to determine the functioning of the benthic landscape in Biscayne Bay, the marine/reef zones and wetlands of BNP. Hurricane disturbances are much like fires in maintaining ecosystem health, but, compounded with anthropogenic disturbances, may result in irreversible changes which need to be tested and modeled.

UV Impacts

No effective research specific to South Florida, regarding ecological effects due to increase in UV irradiance, could be identified for this report. UV penetration of marine water is considered minimal; however, negative effects on phytoplankton community structures are of concern and, in combination with nutrient loading variability, could be a potential problem for Biscayne Bay.

Hydrology and Water Quality

Hydrology and Groundwater Issues

- One of the CERP projects is the Biscayne Coastal Wetlands project to restore or enhance freshwater wetlands and tidal wetlands, and to create estuarine conditions in the near shore bay habitat and the Wastewater Reuse component designed to provide additional freshwater to BNP. Waters would be either discharged through wetlands adjacent to the park, then into the park, or, under some proposals, discharged directly into the park waters. Effects of enhanced water delivery and associated ecological effects, both for the terrestrial and marine ecosystems of the park, need to be assessed.

- The few studies of groundwater entering the park have been focused on specific park areas, primarily the inshore and the reef tract to a lesser extent, and many are too limited in scope to provide the information needed by management. We note that USGS has done preliminary subsurface work in Biscayne Bay and should be encouraged to do more. The goal should be to achieve the level of understanding which can assist in water and chemical modeling of entire bay systems.

Atmospheric Deposition

Acidification of Biscayne Bay and coral reefs from increased CO_2 inputs is undocumented, but may have potentially large impacts to the aquatic ecosystem. Acidity (pH) of rainwater has been decreasing consistently in the last 25 years (Briceño and Boyer, 2008). As with the bulk of the Florida Keys reef system, we expect strong negative effects to occur as pH drops. Atmospheric nutrient-loading impacts from precipitation to Biscayne Bay are significant and well documented. Future growth and development of the airshed will only exacerbate the problem. Pathogen introduction to the reef tract continues to be a problem, but it is unknown if any new pathogens will be brought in from increased African dust storm activity.

Visibility Impairments

Natural variability in water column turbidity from tidal forces mostly dominates the light field. Increased tidal flux, coastal erosion, boating and storm activity may result in enhanced turbidity in Biscayne Bay and affect light levels for benthic communities, food web dynamics for filter-feeding organisms and environmental conditions for corals.

CERP Monitoring

The Comprehensive Everglades Restoration Plan (CERP), one of the largest ecosystem restoration programs in United States, was authorized in 2000 by the Water Resources Development Act (WRDA, 2000). The goal of the plan is to restore the Everglades and the south

Florida ecosystem, while meeting the other water-related needs of the region, including water supply and flood protection. The REstoration COordination and VERification (RECOVER, 2007) arm of CERP is charged with implementing a system-wide monitoring and assessment program to assess implementation of the plan as a biannual system status report (RECOVER, 2007). This monitoring and assessment plan is essential to determining the success of CERP and is an integral feature of the CERP Adaptive Management Program. Altered freshwater flow into Biscayne Bay is the stressor that CERP will most directly affect by modifying flow volume, timing and spatial distribution. CERP may also indirectly affect the input of solids, nutrients, toxicants and pathogens. Thus, further studies and monitoring of hydrological parameters and nutrient loadings to the park is needed.

Nutrient Enrichment

Nutrient loading from canals, groundwater and overland flows is one of the most pressing problems for Biscayne Bay. The amount of nitrogen and phosphorus added to the ecosystem are large for its size. Without coastal restoration efforts being initiated, the bay must rely on ocean dilution produced by short residence times. However, it is unclear when expected increases in nutrient loading with continued watershed development will overwhelm this dispersive capacity and lead to plankton blooms (possibly HABs). Modeling efforts should be developed to assess future nutrient loading scenarios.

Microbial Contamination

A history of fecal bacteria contamination in Biscayne Bay has been documented as a result of leakage from septic tanks and sewer line breaks. Canal inputs may be significant, as they draw contaminated groundwater to the bay, especially in the areas of landfills. As the point source discharges are replaced by more diffusive overland flow, conditions may improve. These trends need to be monitored.

Urban Growth

Growth and development in south Miami-Dade County, land adjacent to BNP, is projected to almost double its population in the next 50 years. Miami-Dade County has developed a draft master land development plan (Watershed Study) for the southern part of the county, which includes an analysis of population growth, infrastructure, agricultural and industrial development, land uses, water resources and natural communities (Kieth and Schnars, 2005). There are many concerns by Miami-Dade County, who has principal regulatory authority over Biscayne Bay water quality, about the ability to execute these projects without negative affects to the park. NPS has a need to examine the effects of current and forecasted urban development scenarios near BNP and CERP actions with respect to their predicted nutrient loading and its effect on water quality in the park.

Safe Target Levels

One of the reasons for on-going WQ problems in BNP is the unenforceability of its narrative WQ criteria. Existing OFW (anti-degradation) standards and many of the Class III standards, which are the conditions required to support the use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife, are also narrative; their applicability is limited, at best. There is not a good understanding of the impacts of nutrient inflows to Biscayne Bay on ambient nutrient levels and how they distribute and interact within this compartmentalized water body (Caccia and Boyer, 2005, 2007). Restoration objectives for

Biscayne Bay focus on restoring more natural flow of freshwater into the bay, and thereby improving natural vegetation patterns, but it is necessary to first understand the relationship between input loads and the resulting WQ in the bay; safe target levels for protecting BNP natural resources may be established prior to significant, new, human alteration.

Water Quality Monitoring

Water quality monitoring must continue. The network of canal and open bay sampling is integral in assessing status and trends for effects of future restoration and land development activities. Virtually all biotic community studies rely on good water quality data.

Model Improvement

A more comprehensive model of land use and resultant pollutant loading should be developed.

Pollutants

High Flow Events

Canals seem undoubtedly a primary potential source of pollutants to the bay. However, most canals draining into the bay have control structures that significantly minimize the transport of associated sediments to the bay, except during high flow events (prior to, during and after hurricane events). It is important to establish estimates of the particle-bound pollutant loading to the bay during such events, in order to be able to assess the ecological risk as a consequence of canal drainage.

Sediment Associated Pollutants

The presence of traditional pollutants, such as herbicides, pesticides and trace metals, represent a potential problem to the natural resources of the Biscayne Bay ecosystem due to their potential ecotoxicological effects. While a fair amount of information is available, it is insufficient to make a clear assessment of the environmental risk. Most research efforts have been focused on the analyses of pollutants in sediments of canals/rivers and the bay. These studies have clearly shown that sediments are an important source of pollutants to the bay. The particle associated pollutants are diluted by autochthonous and biogenic sediment sources in the bay, and they occur at a low pollutant load. Based on the ecological conceptual model, particle associated pollutants can be accumulated and biomagnified through the food chain and end up in upper trophic level organisms with potential toxicological effects. The continued monitoring of pollutants in sediments in the bay should be deemphasized in favor of long-term monitoring of sentinel aquatic organisms, which would be a better tool to assess the ultimate fate and potential ecological threats/stressors and ecological consequences of the incoming particle bound pollutants.

Comprehensive Ecotoxicology Study

A series of studies on the presence and toxicity of diverse pollutants have been conducted in Biscayne Bay over the last 15 years and, while they cover many locations in a wide area of the bay, they do not provide the consistency, frequency or long-term commitment needed to establish environmental threats on spatial or temporal scales. Establishing such a program is an urgent priority for the bay and should include an important ecotoxicological component for species specific to the local ecosystem. Little is known about potential effects of the new generation of pollutants, such as pharmaceuticals and personal care products, on the communities of Biscayne Bay.

Next Generation Pollutants

While most reported studies on pollutants in the bay have been focused on traditional components, such as trace metals and organic pollutants such as PCBs, PAHs and traditional organo-chlorine pesticides, little has been done to assess the presence and loadings of the next generation of pollutants, such as present-use herbicides and pesticides, antifouling agents, pharmaceuticals and personal care products. These pollutants represent a potential problem to the Biscayne Bay ecosystem due to their potential ecotoxicological effects. While a fair amount of information is available, it is insufficient to make a clear assessment regarding environmental risk. These pollutants are, to a large extent, associated with the water fraction in the dissolved phase. A comprehensive study on pollutants important in present day society in the bay needs to be performed in tandem with the corresponding ecotoxicological evaluations and risk assessment.

Marine Debris

Accumulation of marine debris has ecological as well as aesthetic consequences. Debris pollution has sources that are primarily external to the park, thanks to educational programs and enforcement. Marine debris accumulation should be monitored to assess changes over time, and cleanup initiatives and educational programs for park users should be continued and enhanced.

Marine Facilities

Marinas have been identified clearly as an important source of pollutants to Biscayne Bay. However, few studies have addressed this specific problem and, while the estimated effects are potentially significant, the lack of available information can only lead to inferences of threats and environmental stressors. More research and/or monitoring is needed and any sediment dredging activities or related remediation in existing marinas on the Biscayne Bay should be monitored for pollutant re-suspension and particle export to the park.

Aerosol Pollution

The available information on the wet/dry deposition of pollutants in Biscayne Bay is poor to fair and represents a potential problem for the park. Most aerosol sources are beyond park control, but pollutant fluxes from wet and dry deposition should be estimated; changes and variability in the composition of atmospheric deposition chemistry should be monitored.

Effect of Restoration

The potential effects of on-going and planned restoration efforts on the pollutant loading to the bay needs to be determined and monitored. The Biscayne Bay Wetlands project, the C111 Spreader Canal project and the Miami Dade Water Reuse project need to be included in any long-term assessment studies of pollutant sources to the bay.

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Appendix A: Data Tables

Table A1. South Florida Water Management Drainage Basin Summary.

BASIN	Area (Ha)	Biscayne Bay Border?	BNP Border?	Distance from Park (m)
Area B	41,330	N	N	8,687
C-1	10,190	N	N	127
C-100	10,407	N	N	32
C-102	8,631	N	N	495
C-103	12,763	N	N	35
C-111	38,539	Y	N	8,980
C-2	4,468	Y	N	6,483
C-6	7,286	Y	N	10,726
C-7	8,292	N	N	17,296
C-8	7,093	N	N	21,020
C-9 East	6,097	N	N	27,220
C-9 West	4,574	N	N	30,255
Conservation Area 3A*	51,504	N	N	40,556
Conservation Area 3B*	31,901	N	N	25,408
Coral Gables	4,946	Y	N	5,635
DA-1	2,533	Y	N	6,331
DA-2	709	Y	N	5,622
DA-3	1,040	Y	N	97
DA-4	10,347	Y	Y	0
East Collier*	12,697	N	N	53,200
Everglades National Park*	209,884	N	N	18,513
Florida City	3,081	N	N	124
Homestead	1,020	N	N	379
Intercostal*	16,579	Y	N	693
Model Land	7,295	N	N	1,751
North Canal	1,344	N	N	47
Tamiami East	4,055	Y	N	9,942

* Miami-Dade County area only

Table A2. Artificial Reefs within 5 mi of Biscayne National Park.

Name	Latitude	Longitude	Description	Deploy Date	Depth (ft)	Relief (ft)	Park Distance (m)
Biscayne	25.70438	-80.08837	120' Steel Ship "Biscayne"	12/1/1974	55	15	357
Almirante	25.41633	-80.11675	200' Steel Ship "Almirante"	4/1/1975	125	20	7,453
Belcher Barge	25.41292	-80.11910	85' Steel Barge "Belcher Barge"	10/1/1975	120	10	7,548
Santa Rita	25.38752	-80.09233	200' Steel Ship "Santa Rita"	11/1/1976	245	25	4,287
Alva Chapman Reef	25.29445	-80.15167	Two Concrete Boat Hulls & Dredge Pipe	12/31/1978	220	0	6,983
Railroad Barge	25.55070	-80.08588	100' Steel Barge "Railroad"	10/1/1980	163	11	7,074
Hopper Barge	25.61777	-80.08167	150 Foot Steel Hopper Barge	6/30/1981	163	12	6,988
Orion	25.69100	-80.08633	118' Steel Tug "Orion"	12/22/1981	88	15	1,826
Houseboat	25.66907	-80.07027	40' Steel House Boat	5/1/1982	95	0	3,705
Lakeland	25.66778	-80.08350	200' Steel Ship "Lakeland"	6/16/1982	135	25	4,330
Arida	25.68052	-80.07082	165' Steel Ship ""	6/26/1982	88	12	2,591
Star Trek	25.70003	-80.07755	200' Steel Ship "Star Trek"	7/27/1982	210	32	709
Chevron Storage Tanks	25.66725	-80.07052	50 Steel Chevron Storage Tanks	1/1/1983	84	8	3,891
Blue Fire	25.56661	-80.09052	175' Steel Ship "Blue Fire"	1/7/1983	110	20	7,668
South Seas	25.66507	-80.07028	175' Steel Ship "South Seas"	2/5/1983	73	15	4,083
Mixing Drums	25.66725	-80.07052	20 Steel Concrete Mixing Drums	10/1/1983	84	8	3,891
Pioneer One	25.53198	-80.08390	195' Steel Ship "Pioneer One"	10/4/1983	215	30	6,662
Turbine Stacks	25.48460	-80.09152	83 Steel Tanks	11/4/1983	190	0	6,645
Exhaust Stacks	25.48693	-80.09065	40 Steel Exhaust Stacks	11/4/1983	190	20	6,601
Turbine Stacks	25.48495	-80.09195	43 Fp&L Smoke Stacks	12/6/1983	190	20	6,694
Moby One	25.62333	-80.08167	75 Foot Wooden Shrimp Boat The "Moby One"	12/31/1983	97	10	6,999
Ultra Freeze	25.62902	-80.08692	195' Steel Ship "Ultra Freeze"	7/5/1984	120	45	7,537
Mercy Hospital Reef (Bay)	25.73805	-80.21167	Concrete Rubble, Bicycle Racks, Vessels, Concrete I Beams	12/31/1984	10	4	387

Table A2. Artificial Reefs within 5 mi of Biscayne National Park (continued).

Name	Latitude	Longitude	Description	Deploy Date	Depth (ft)	Relief (ft)	Park Distance (m)
Proteus	25.70547	-80.08733	220' Steel Ship "Proteus"	1/24/1985	72	18	233
Sir Scott	25.52982	-80.08738	267' Steel Ship "Sir Scott"	2/1/1985	220	65	6,975
Barge	25.66907	-80.07027	100' Steel Barge	10/1/1985	100	8	3,705
Belcher Barge	25.69683	-80.08800	195' Steel Barge "Belcher Barge"	11/26/1985	58	10	1,192
Doc De Milly	25.36772	-80.13135	287' Steel Freighter "Doc De Milly."	3/6/1986	140	50	7,642
St. Anne D' Auray	25.59782	-80.07792	110' Steel Freighter "St. Anne D' Auray."	3/28/1986	68	28	6,614
Mystic Isle	25.68793	-80.06747	103' Steel Ferry The "Mystic Isle"	5/30/1986	185	35	1,702
Bridge	25.66698	-80.06760	500 Tons Concrete/Bridge	7/1/1986	135	15	3,758
Lady Free Schooner	25.69083	-80.07883	90 Foot Sailing Schooner The "Lady Free"	12/31/1986	60	5	1,735
Sheri-Lynn	25.66817	-80.07038	235' Steel Ship "Sheri-Lyn"	6/18/1987	100	15	3,798

Table A3. Tree Species Found within 10 km of Biscayne National Park. Native and naturalized tree species found within 10 km of Biscayne National Park (Little, 1978). Many of these are found within the park boundary.

Scientific name	Common Name	Scientific name	Common Name
Acacia choriophylla	cinnecord	*Ilex cassine*	dahoon holly
Acer rubrum	red maple	*Ilex krugiana*	tawnberry holly
Alvaradoa amorphoides	Mexican alvaradoa	*Ilex longipes*	Georgia holly
Amphitecna latifolia	black calabash	*Jaacquinia keyensis*	joewood
Amyris balsamijera	balsam torchwood	*Krugiodendron ferreum*	leadwood
Amyris elemijera	torchwood	*Laguncularia racemosa*	white mangrove
Annona glabra	pond apple	*Licaria triandra*	Florida licaria
Ardisia escallonioides	marlberry	*Lyonia ferruginea*	tree lyonia
Avicennia germinans	black mangrove	*Lysiloma latisiliquum*	Bahama lysiloma
Baccharis halimifolia	eastern baccharis	*Magnolia virginiana*	sweetbay
Bourreria ovata	Bahama strongbark	*Manilkara bahamensis*	wild dilly
Bumelia celastrina	saffron palm	*Mastichodendron joetidissimum*	false mastic
Bursera simaruba	gumbo limbo	*Maytenus phyllanthoides*	Florida mayten
Byrsonima lucida	key byrsonima	*M etopium toxijerum*	Florida poisontree
Calyptranthes pallens	pale lidflower	*Morus rubra*	red mulberry
Calyptranthes zuzygium	myrtle of the river	*Myrcianthes fragrans*	twinberry stopper
Canella winterana	canella	*Myrica cerifera*	southern bayberry
Capparis cynophallophora	Jamaica caper	*Nectandra coriacea*	Florida nectandra
Capparis flexuosa	limber caper	*Persea borbonia*	redbay
Celtis laevigata	sugarberry	*Picramnia pentandra*	bitterbush
Cephalanthus occidentalis	buttonbush	*Pinus elliottii*	slash pine
Cereus robinii	key tree cactus	*Piscidia piscipula*	Florida fishpoison tree
Chrysobalanus icaco	cocoplum	*Pithecellobium guadalupense*	Guadaloupe blackbead
Chrysophyllum olivijorme	satinleaf	*Pithecellobium unguis-cati*	catclaw blackbead
Citharexylum fruticosum	Florida fiddlewood	*Prunus myrtifolia*	West Indies cherry
Coccoloba diversifolia	pigeon plum	*Pseudophoenix sargentii*	buccaneer palm
Coccoloba uvijera	seagrape	*Psidium longipes*	long stalk stopper
Coccothrinax argentata	Florida silverpalm	*Quercus chapmanii*	Chapman oak
Colubrina arborescens	coffee colubrina	*Quercus laurifolia*	laurel oak
Colubrina cubensis	Cuba colubrina	*Quercus myrtifolia*	myrtle oak
Colubrina elliptica	soldierwood	*Quercus virginiana*	live oak
Conocarpus erectus	button mangrove	*Rapanea punctata*	Florida rapanea
Cordia sebestena	Geiger tree	*Reynosia septentrionalis*	darling palm
Crossopetalum rhacoma	crossopetalum	*Rhizophora mangle*	red mangrove
Diospyros virginiana	common persimmon	*Rhus copallina*	shinning sumac

Table A3. Tree Species Found within 10 km of Biscayne National Park (continued).

Scientific name	Common Name	Scientific name	Common Name
Dipholis salicifolia	willow bustic	*Roystonea elata*	Florida royalpalm
Dodonaea viscosa	hopbush	*Sabal palmetto*	cabbage palmetto
Drypetes diversifolia	milkbark	*Salix caroliniana*	Coastal Plain willow
Drypetes lateriflora	Guiana plum	*Sambucus canadensis*	American elder
Erythrina herbacea	southeastern coralbean	*Sapindus saponaria*	wingleaf soapberry
Eugenia axillaris	white stopper	*Schaefferia frutescens*	Florida boxwood
Eugenia conjusa	redberry stopper	*Schoepfia chrysophylloides*	graytwig
Eugenia joetida	boxleaf stopper	*Serenoa repens*	saw palmetto
Exostema caribaeum	princewood	*Simarouba glauca*	paradise tree
Exothea paniculata	inkwood	*Solanum erianthum*	mullein nightshade
Ficus aurea	strangler fig	*Suriana maritima*	bay cedar
Ficus citrifolia	shortleaf fig	*Swietenia mahagoni*	West Indies mahogany
Forestiera segregata	Florida privet	*Taxodium distichum*	Baldcypress
Genipa clusiifolia	seven year apple	*Tetrazygia bicolor*	Florida tetrazygia
Guaiacum sanctum	roughbark lignumvitae	*Thrinax morrisii*	key thatchpalm
Guapira discolor	blolly	*T hrinax radiata*	Florida thatchpalm
Guettarda elliptica	elliptic leaf velvetseed	*Trema lamarckiana*	West Indies trema
Guettarda scabra	roughleaf velvetseed	*Trema micrantha*	Florida trema
Gymnanthes lucida	oysterwood	*Ximenia americana*	tallowwood
Hamelia patens	scarletbush	*Yucca aloifolia*	aloe yucca
Hippomane mancinella	manchineel	*Zanthoxylum coriaceum*	Biscayne prickly ash
Hypelate trifoliata	hypelate	*Zanthoxylum fagara*	lime prickly ash
Genipa clusiifolia	seven year apple	*Tetrazygia bicolor*	Florida tetrazygia
Guaiacum sanctum	roughbark lignumvitae	*Thrinax morrisii*	key thatchpalm
Guapira discolor	blolly	*T hrinax radiata*	Florida thatchpalm
Guettarda elliptica	elliptic leaf velvetseed	*Trema lamarckiana*	West Indies trema
Guettarda scabra	roughleaf velvetseed	*Trema micrantha*	Florida trema
Gymnanthes lucida	oysterwood	*Ximenia americana*	tallowwood
Hamelia patens	scarletbush	*Yucca aloifolia*	aloe yucca
Hippomane mancinella	manchineel	*Zanthoxylum coriaceum*	Biscayne prickly ash
Hypelate trifoliata	hypelate	*Zanthoxylum fagara*	lime prickly ash
Gymnanthes lucida	oysterwood	*Ximenia americana*	tallowwood
Hamelia patens	scarletbush	*Yucca aloifolia*	aloe yucca
Hippomane mancinella	manchineel	*Zanthoxylum coriaceum*	Biscayne prickly ash
Hypelate trifoliata	hypelate	*Zanthoxylum fagara*	lime prickly ash

Table A4. Vegetation Types on the Mainland of Biscayne National Park. Vegetation types on mainland of Biscayne National Park (Ruiz et al., 2008).

Class	Type	Area (km^2)	Percent	Total Area BNP (km^2)	Percent of Total Land
Forest	Black Mangrove	0.0571	0.4	0.457	1.47
	Buttonwood	0	0	0.081	0.26
	White Mangrove	0	0	0	0
	Red Mangrove	0.4478	3.2	0.767	2.48
	Mixed Mangrove	5.2444	37.3	6.354	20.53
	Coastal Hardwood Hammock	0	0	7.023	22.69
	Coastal Dune Hammock	0	0	0.034	0.11
Woodland	Black Mangrove	0.1343	1	0.319	1.03
	Buttonwood	0	0	0.115	0.37
	White Mangrove	0	0	0.042	0.14
	Mixed Mangrove	0.0229	0.2	0.12	0.39
	Upland Hardwood	0	0	0.027	0.09
Shrubland	Black Mangrove	0	0	0.081	0.26
	Buttonwood	0	0	0.093	0.3
	White Mangrove	0.0097	0.1	0.021	0.07
	Red Mangrove	0.4085	2.9	2.934	9.48
	Mixed Mangrove	1.6943	12.1	4.794	15.49
	Coastal Hardwood	0	0	0.063	0.2
Scrub	Black Mangrove	0	0	0.101	0.33
	White Mangrove	0	0	0.03	0.1
	Red Mangrove	4.9972	35.5	5.804	18.75
	Mixed Mangrove	0.5742	4.1	0.948	3.06
	Upland	0	0	0.002	0.01
	Upland Hardwood	0	0	0.015	0.05
Marsh	Graminoid Salt Marsh	0.0341	0.2	0.035	0.11
	Herbaceous Salt	0	0	0.001	0
	Succulent Salt	0	0	0.004	0.01
	Graminoid Freshwater Prairie	0	0	0.017	0.05
Dune	Mixed Herbaceous	0	0	0.009	0.03
Exotic	Exotic	0.0314	0.2	0.082	0.26
Other	Barren Microkarst	0	0	0.02	0.06
	Barren Salt Flat	0	0	0.004	0.01
	Beach	0	0	0.022	0.07
	Lightning Gap	0.0013	0	0.001	0
	Littoral Zone	0	0	0.002	0.01
	Water	0.1738	1.2	0.214	0.69
	Anthropogenic	0.2248	1.6	0.322	1.04
Total		**14.1**	**100**	**31**	**100**

Table A5. Vegetation Types on the Islands of Biscayne National Park. Vegetation types on islands of Biscayne National Park (Ruiz et al., 2008).

Class	Type	Area (km^2)	Percent	Total Area BNP (km^2)	Percent of Total Land
Forest	Black Mangrove	0.399	2.4	0.457	1.47
	Buttonwood	0.081	0.5	0.081	0.26
	White Mangrove	0	0.0	0	0
	Red Mangrove	0.319	1.9	0.767	2.48
	Mixed Mangrove	1.11	6.6	6.354	20.53
	Coastal Hardwood Hammock	7.023	41.6	7.023	22.69
	Coastal Dune Hammock	0.034	0.2	0.034	0.11
Woodland	Black Mangrove	0.185	1.1	0.319	1.03
	Buttonwood	0.115	0.7	0.115	0.37
	White Mangrove	0.042	0.2	0.042	0.14
	Mixed Mangrove	0.097	0.6	0.12	0.39
	Upland Hardwood	0.027	0.2	0.027	0.09
Shrubland	Black Mangrove	0.081	0.5	0.081	0.26
	Buttonwood	0.093	0.6	0.093	0.3
	White Mangrove	0.011	0.1	0.021	0.07
	Red Mangrove	2.525	14.9	2.934	9.48
	Mixed Mangrove	3.1	18.3	4.794	15.49
	Coastal Hardwood	0.063	0.4	0.063	0.2
Scrub	Black Mangrove	0.101	0.6	0.101	0.33
	White Mangrove	0.03	0.2	0.03	0.1
	Red Mangrove	0.807	4.8	5.804	18.75
	Mixed Mangrove	0.374	2.2	0.948	3.06
	Upland Scrub	0.002	0.0	0.002	0.01
	Upland Hardwood	0.015	0.1	0.015	0.05
Marsh	Graminoid Salt	0.0005	0.0	0.035	0.11
	Herbaceous Salt	0.001	0.0	0.001	0
	Succulent Salt	0.004	0.0	0.004	0.01
	Graminoid Freshwater Prairie	0.017	0.1	0.017	0.05
Dune	Mixed Herbaceous	0.009	0.1	0.009	0.03

Table A5. Vegetation Types on the Islands of Biscayne National Park (continued).

Class	Type	Area (km^2)	Percent	Total Area BNP (km^2)	Percent of Total Land
Exotic	Exotic	0.051	0.3	0.082	0.26
Other	Barren Microkarst	0.02	0.1	0.02	0.06
	Barren Salt Flat	0.004	0.0	0.004	0.01
	Beach	0.022	0.1	0.022	0.07
	Lightning Gap	0.0001	0.0	0.001	0
	Littoral Zone	0.002	0.0	0.002	0.01
	Water	0.04	0.2	0.214	0.69
	Anthropogenic	0.097	0.6	0.322	1.04
Total		**17**	**100**	**31**	**100**

Table A6. Mollusc Species Identified from Biscayne Bay and Vicinity. Representative mollusc species reported from Biscayne National Park and vicinity (Bartsch, 1937; USGS; Gaiser et al., 2006).

Type	Species	Common Name
Bivalve	*Americardia guppyi*	Guppy strawberry-cockle
	Anomalocardia auberiana	Venus
	Arcopsis adamsi	Cancellate ark
	Argopecten irradians	Bay scallop
	Brachidontes exustus	Scorched mussel
	Cardita floridana	Cardita
	Chione cancellata	Cross-barred venus
	Codakia orbicularis	Dwarf tiger lucine
	Codakia sp. aff. *orbiculata*	Dwarf tiger lucine
	Codakia sp.	Lucine
	Crassostrea virginica	Eastern oyster
	Cumingea tellinoides	Tellin semele
	Cyrenoida floridana	Florida marsh clam
	Erycina sp.	
	Eupera cubensis	Mottled fingernailclam
	Geukensia demissa	Ribbed mussel
	Glycymeris sp. (juvenile)	Bittersweet
	Gouldia cerina	Waxy gouldclam
	Laevicardium mortoni	Yellow eggcockle
	Laevicardium sp.	Eggcockle
	Leptonacid	
	Lima sp.	File clam
	Limaria sp. cf. *L. pellucida*	Antillean fileclam
	Linga amiantus	
	Lucina pectinata	Thick lucine
	Lucina sp.	Lucine
	Lucinisca nassula	Woven lucine
	Macoma sp.	
	Mysella sp.	
	Mysella planulata	Atlantic flat lepton
	Mytilid	Mussel
	Mytilopsis leucophaeata	Dark false mussel
	Nucula proxima	Atlantic nutclam
	Ostrea equestris	Crested oyster
	Parastarte triquetra	Brown gemclam
	Parvilucina costata	Costate lucine
	Parvilucina multilineata	Many-line lucine
	Pectinid fragment	
	Pitar fulminatus	Venus
	Pitar simpsoni	Venus

Table A6. Mollusc Species Identified from Biscayne National Park (continued).

Type	Species	Common Name
	Pleuromeris tridenta	
	Polymesoda maritima	Southern marshclam
	Pteria longisquamosa	Scaly wing-oyster
	Rare Pelecypods	
	Semele bellastriata	
	Tagelus sp.	Tagelus
	Tellina mera	Tellin
	Tellina similis	Tellin
	Tellina sp.	Tellin
	Tellina texana	Tellin
Bivalve	*Transennella* sp.	
	Uniomerus obesus	Southern pondhorn
	Rare Pelecypods	
	Semele bellastriata	
	Tagelus sp.	Tagelus
	Tellina mera	Tellin
	Tellina similis	Tellin
	Tellina sp.	Tellin
	Tellina texana	Tellin
	Transennella sp.	
	Uniomerus obesus	Southern pondhorn
	Acteocina canaliculata	Channeled barrel-bubble
	Acteon sp.	
	Alvania auberiana	West Indian alvania
	Amaea retifera	
	Anachis avara	Greedy dovesnail
	Arene sp.	Cyclosteme
	Batillaria minima	
	Bittiolum varium	Grass cerith
	Bittiolum varium (juvenile)	Grass cerith
	Bulimulidae	
Gastropod	*Bulla striata*	Striate bubble
	Caecum cornucopiae	
	Caecum pulchellum	Beautiful caecum
	Cantharus sp.	Seabream
	Cerithidea costata	Horn shell
	Cerithidea sp.	Horn shell
	Cerithiopsis emersoni	
	Cerithiopsis greeni	
	Cerithiopsis sp.	
	Cerithium muscarum	Vertagus
	Cerithium sp.	Vertagus

Table A6. Mollusc Species Identified from Biscayne National Park (continued).

Type	Species	Common Name
Gastropod	*Cerodrillia thea*	
	Columbella mercatoria?	Dove shell
	Conidae (juvenile)	
	Crassispira sp.	
	Crepidula sp.	Slipper limpet
	Cyclostremiscus suppressus	
	Cyroturris cerinella?	
	Daedalochila uvulifera	Peninsula Liptooth
	Deformed gastropods	
	Dentalium sp.	Tuskshell
	Dentimargo sp.	
	Diodora listeri	Lister's keyhole limpet
	Discus? sp.	
	Epitonium rupicola	
	Epontium sp.	
	Eulima sp.	
	Eulimidae	
	Eulithidium affine	
	Fasciolaria sp.	Filamentous horse conch
	Ferrissia peninsulae	Spotted snailfish
	Finella sp.	
	Gastrocopta sp.	
	Gyraulus parvus	Ash gyro
	Haminoea elegans	Elegant glassy-bubble
	Helisoma duryl	
	Helisoma sp.	Rams-horn
	Hyalina sp.	
	Hydrobiidae	
	Kurtziella cerina?	
	Latirus sp. (juvenile)	Stone shell
	Lithopoma americanum	
	Littoridinops sp.	Hydrobiid
	Longchaeus crenulatus	
	Marginellid	
	Marshallora nigrocincta	Black-line triphora
	Melampus coffeus	Coffee melampus
	Melampus sp.	Melampus
	Melanoides tuberculata	Red-rimmed melania
	Melongena corona	Crown conch
	Menetus dilutatus	
	Mitra nodulosa	Miter shell
	Mitrella nitens	

Table A6. Mollusc Species Identified from Biscayne National Park (continued).

Type	Species	Common Name
Gastropod	*Mitrella ocellata*	
	Modulus modulus	
	Monolispira albinodata	
	Monolispira leucocyma	
	Murexiella glypta? (juvenile)	Carved murex
	Muricidae sp.	
	Nassarius albus	Nassa
	Nassarius vibex	Bruised nassa
	Naticid	Moonshell
	Nerita sp.	Nerite
	Neritina virginea	Nerite
	Odostomia laevigata	
	Odostomia sp. aff. *O. simplex*	
	Olivella sp.	
	Olivella pusilla	
	Onchidella sp.	Onchidella
	Patelloida pustulata	Sugar limpet
	Patelloida sp.?	Limpet
	Persicula fluctata	
	Persicula sp.	
	Physa sp.	Physa
	Physella cubensis	Carib physa
	Physella heterostropha	Pewter physa
	Pilsbryspira leucocyma	White-knob drillia
	Planorbella duryi	Seminole rams-horn
	Planorbella scalaris	Mesa rams-horn
	Planorbella trivolvis	Marsh rams-horn
	Pleuroploca gigantea	Florida horse conch
	Polygyra cereolus	Southern Flatcoil
	Pomacea depressa	Apple snail
	Pomacea paludosa	
	Prunum sp. aff. *apicinum*	
	Pyramidellidae	
	Rare Gastropods	
	Rictaxis punctostriatus	Spotted rictaxis
	Rissoidae	
	Rissoina browniana	
	Rissoina cancellata	
	Rissoina multicostata	
	Rissoina sp.	
	Schwartziella catesbyana	
	Schwartziella spp.	

Table A6. Mollusc Species Identified from Biscayne National Park (continued).

Type	Species	Common Name
Gastropod	*Siphonaria* sp.	False limpet
	Stellatoma stellata	
	Strombus alatus	Florida fighting conch
	Strombus gigas	Queen conch
	Succinea sp.	
	Succinea barberi	Sanibel ambersnail
	Tegula fasciata	Turbine snail
	Teinostoma biscaynense	Biscayne vitrinella
	Thais sp.	Rock shell
	Triphora sp.	
	Triptychus niveus	
	Trivia quadripunctata?	
	Truncatella sp.	
	Truncatella spp.	
	Turbo castaneus	Chestnut turban
	Turbonilla abrupta	
	Turbonilla sp.	
	Turbonilla unilirata	
	Turrid	
	Turridae sp.	
	Turritella exoleta	Turret shell
	Turritella sp.	Turret shell
	Vermicularia spirata	
	Vexillum arestum	
	Vexillum exiguum	
	Vexillum hanleyi	
	Vitrinellid	
	Vitrinidae	
	Volvarina sp. aff. *avena*	
	Zebina browniana	

Table A7. Butterfly Species Expected in Biscayne National Park. Butterfly species known from Biscayne National Park and vicinity. Data from Miami-Dade Parks Department.

Group	Scientific Name	Common Name
Papilionidae – Swallowtails	*Battus philenor*	Pipevine Swallowtail
	Battus polydamas	Polydamas Swallowtail
	Eurytides marcellus	Zebra Swallowtail
	Papilio aristodemus;Heraclides aristodemus	Schaus' Swallowtail
	Papilio cresphontes	Giant Swallowtail
	Papilio glaucus	E. Tiger Swallowtail
	Papilio palamedes	Palamedes Swallowtail
	Papilio polyxenes	Black Swallowtail
	Papilio troilus	Spicebush Swallowtail
	Papilio andraemon	Bahamian Swallowtail
Pieridae – Whites and Sulphurs	*Appias drusilla*	Florida or Tropical White
	Ascia monuste	Great Southern White
	Pontia protodice	Checkered White
	Pieris rapae	Cabbage White Butterfly
	Eurema daira	Barred Yellow
	Eurema lisa	Little Yellow or Sulphur
	Eurema nicippe	Sleepy Orange
	Eurema dina	Dina Yellow or Sulfur
	Eurema nise	Mimosa Yellow
	Eurema nise nise	Jamaican Sulphur
	Phoebis statira	Statira Sulphur
	Kricogonia lyside	Lyside Sulphur
	Nathalis iole	Dainty Sulphur
	Phoebis agarithe	Large Orange Sulphur
	Phoebis philea	Orange-barred Sulphur
	Phoebis sennae	Cloudless Sulphur
	Colias eurytheme	Orange Sulphur
	Zerene cesonia	Southern Dogface
Lycaenidae – Gossamer Winged Butterflies	*Brephidium isophthalma*	Eastern Pygmy Blue
	Calycopis cecrops	Red-banded Hairstreak
	Electrostrymon angelia	Fulvous Hairstreak
Satyridae – Satyrs & Wood Nymphs	*Hermeuptychia sosybius*	Carolina Satyr
	Neonympha areolata	Georgia Satyr
Danaidae – Milkweed Butterflies	*Danaus eresimus*	Soldier
	Danaus gilippus	Queen
	Danaus plexippus	Monarch
Riodinidae – Metalmarks	*Calephelis virginiensis*	Little Metalmark

Table A7. Butterfly Species Expected in Biscayne National Park (continued).

Group	Scientific Name	Common Name
Magathymidae – Giant Skippers	*Megathymus cofaqui*	Cofaqui Skipper
	Megathymus yuccae	Yuccae Skipper
Hesperiidae – Skippers	*Ancyloxypha numitor*	Least Skipper
	Asbolis capucinus	Monk Skipper
	Atalopedes campestris	Sachem
	Atrytone arogos	Arogos Skipper
	Anatrytone logan	Delaware Skipper
	Atrytonopsis hianna	Dusted Skipper
	Calpodes ethlius	Brazilian Skipper
	Copaeodes minima	Southern Skipperling
	Cymaenes tripunctus	Three-spotted Skipper
	Epargyreus clarus	Silver-spotted Skipper
	Epargyreus zestos	Zestos Skipper
	Ephyriades brunneus	Florida Duskywing
	Erynnis horatius	Horace's – Horatio's Duskywing
	Erynnis juvenalis	Juvenal's Duskywing
	Erynnis zarucco	Zarucco Duskywing
	Staphylus hayhurstii	Hayhurst's Scallopwing or Scalloped Sootywing
	Euphyes arpa	Palmetto Skipper
	Euphyes pilatka	Palatka Skipper
	Euphyes vestris	Dun Skipper
	Eumaeus atala	Atala
	Fixsenia favonius	Southern Hairstreak
	Hemiargus ceraunus	Ceraunus Blue
	Hemiargus thomasi	Miami Blue
	Leptotes cassius	Cassius Blue
	Hemiargus ammon	Nickerbean Blue
	Strymon acis	Bartram's Scrub-Hairstreak
	Strymon martialis	Martial Scrub-Hairstreak
	Strymon melinus	Gray Hairstreak
	Chlorostrymon maesites	Amethyst Hairstreak or Maesites Hairstreak
	Chlorostrymon simaethis	Silver-banded Hairstreak or Simaethis Hairstreak
	Parrhasius m-album	White M Hairstreak
	Strymon istapa or *Strymon columella*	Columella Hairstreak or Mallow Scrub-Hairstreak
	Ministrymon azia	Azia Hairstreak or Gray Ministreak
Nymphalidae – Brush Footed Butterflies	*Agraulis vanillae*	Gulf Fritillary
	Anaea floridalis	Florida Leafwing

Table A7. Butterfly Species Expected in Biscayne National Park (continued).

Group	Scientific Name	Common Name
Nymphalidae – Brush Footed Butterflies	*Asterocampa clyton*	Tawny Emperor
	Anartia jatrophae	White Peacock
	Dryas julia	Julia Heliconian
	Eunica monima	Dingy Purplewing
	Eunica tatila	Florida Purplewing
	Euptoieta claudia	Variegated Fritillary
	Heliconius charithonius	Zebra Heliconian
	Hypolimnas misippus	Mimic
	Limenitis archippus	Dark Viceroy
	Marpesia petreus	Ruddy Daggerwing
	Nymphalis antiopa	Mourning Cloak
	Phyciodes frisia	Cuban Crescent
	Phyciodes tharos	Pearl Crescent
	Phyciodes phaon	Painted or Phaon Crescent
	Polygonia interrogationis	Questionmark
	Junonia coenia	Tropical or Common Buckey
	Junonia evarete	Mangrove Buckeye
	Siproeta stelenes	Malachite
	Vanessa atalanta	Red Admiral
	Vanessa cardui	Painted Lady
	Vanessa virginiensis	American Lady
	Euphyes berryi	Berry's Skipper
	Hesperia attalus	Dotted Skipper
	Hesperia meskei	Meske's Skipper
	Hylephila phyleus	Fiery Skipper
	Lerema accius	Clouded Skipper
	Lerodea eufala	Eufala Skipper
	Nastra lherminier	Swarthy Skipper
	Nastra neamathla	Neamathala Skipper
	Oligoria maculata	Twin-spot – Two-spotted Skipper
	Panoquina ocola	Ocola Skipper
	Panoquina panoquin	Salt Marsh Skipper
	Panoquina panoquinoides	Obscure Skipper
	Phocides pigmalion	Mangrove Skipper
	Poanes aaroni	Aaron's Skipper
	Polites baracoa	Baracoa Skipper
	Polites themistocles	Tawny-edged Skipper
	Polites vibex	Whirlabout
	Polygonus leo	Hammock Skipper
	Problema byssus	Byssus Skipper

Table A7. Butterfly Species Expected in Biscayne National Park (continued).

Group	Scientific Name	Common Name
Nymphalidae – Brush Footed Butterflies	*Pyrgus communis*	Checkered Skipper
	Pyrgus oileus	Tropical Checkered-Skipper
	Thorybes pylades	Northern Cloudywing
	Urbanus dorantes	Dorantes Longtail
	Urbanus proteus	Long-tailed Skipper
	Wallengrenia otho	Southern Broken-Dash

Table A8. Fish Species in Biscayne National Park.

Scientific Name	Common Name	Scientific Name	Common Name
Abudefduf saxatilis	Sergeant Major	*Halichoeres* var. spp.	Wrasse
Abudefduf taurus	Night Sergeant	*Harengula* 2 spp.	Herring/Sardine
Acanthemblemaria aspera	Roughhead Blenny	*Hemicaranx amblyrhynchus*	Bluntnose Jack
Acanthemblemaria chaplini	Papillose Blenny	*Hemiemblemaria simulus*	Wrasse Blenny
Acanthurus bahianus	Ocean Surgeon	*Hemipteronotus* 2 spp.	Razorfish
Acanthurus chirurgus	Doctorfish	*Hemiramphus balao*	Balao
Acanthurus coeruleus	Blue Tang	*Hemiramphus brasiliensis*	Ballyhoo
Acanthurus randalli	Gulf Surgeonfish	*Hippocampus* 2 spp.	Seahorse
Achirus lineatus	Lined Sole	*Hirundichthys* 5 spp.	Angelfish
Aetobatus narinari	Spotted Eagle Ray	*Hirundichthys affinis*	Fourwing Flyingfish
Ahlia egmontis	Key Worm Eel	*Histrio histrio*	Sargassumfish
Albula vulpes	Bonefish	*Holacanthus ciliarisd*	Queen Angelfish
Alectis ciliaris	African Pompano	*Holocentrus* var. spp.	Squirrelfish
Alphestes afer	Mutton Hamlet	*Hypleurochilus* 2 spp.	Blenny
Aluterus var. spp.	Filefish	*Hypoatherina harringtonensis*	Reef Silverside
Amblycirrhitus pinos	Red-spotted Hawkfish	*Hypoplectrus* 4 spp.	Hamlet
Anarchias similis	Pygmy moray	*Hyporhamphus unifasciatus*	Halfbeak Silverstripe Halfbeak
Anarchopterus criniger	Fringed Pipefish	*Hypsoblennius hentz*	Feather Blenny
Anchoa var. spp.	Anchovy	*Ichthyapus ophioneus*	Finless Snake Eel Surf Eel
Anguilla rostrata	American Eel	*Istiophorus platypterus*	Atlantic Sailfish
Anisotremus surinamensis	Black Margate	*Jenkinsia lamprotaenia*	Dwarf Herring
Anisotremus virginiscus	Porkfish	*Kaupichthys hyoproroides*	False Moray
Antennarius var. spp.	Frogfish	*Kyphosus* 2 spp.	Chub
Apogon maculatus	Flamefish	*Labrisomus* 6 spp.	Blenny
Apogon var. spp.	Cardinalfish	*Lachnolaimus maximus*	Hogfish
Archosargus rhomboidalis	Sea Bream	*Lactophrys* 3 spp.	Trunkfish
Ariomma regulus	Spotted Driftfish	*Lactophrys quadricornis*	Scrawled Cowfish
Ariosoma impressa	Bandtooth Conger	*Lepophidium brevibarbe*	Blackedge Cusk-eel
Arius felis	Hardhead Catfish	*Letharchus velifer*	Sailfin Eel
Astrapogon stellatus	Conchfish	*Liopropoma* 2 spp.	Bass
Astroscopus y-graecum	Southern Stargazer	*Lobotes surinamensis*	Tripletail
Atherinomorus stipes	Hardhead Silverfish	*Loglossus calliurus*	Blue Goby
Aulostomus maculatus	Trumpetfish	*Lophogobius cyprinoides*	Crested Goby
Bagre marinus	Gafftopsail Catfish	*Lutjanus* 7 spp.	Snapper
Bairdiella batabana	Blue Croaker	*Lutjanus griseus*	Mangrove Snapper
Bairdiella chrysoura	Silver Perch	*Lythrypnus* 2 spp.	Goby
Balistes capriscus	Gray Triggerfish	*Malacanthus plumieri*	Sand Tilefish
Balistes vetula	Queen Triggerfish	*Malacoctenus* 3 spp.	Blenny

Table A8. Fish Species in Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Barbulifer ceuthoecus	Bearded Goby	*Manta birostris*	Atlantic Manta/Manta
Bascanichthys teres	Sooty Eel	*Manta birostris*	Manta Ray
Bascanichthys var. spp.	Goby	*Megalops atlanticus*	Tarpon
Bodianus pulchellus	Spotfin Hogfish	*Menticirrhus americanus*	Southern Kingfish
Bodianus rufus	Spanish Hogfish	*Microdesmus longipinnis*	Pink Wormfish
Bothus ocellatus	Eyed Flounder	*Micrognathus* 3 spp.	Pipefish
bryx dunckeri	Pugnose Pipefish	*Microgobius* 3 spp.	Goby
Calamus var. spp.	Porgy	*Microphis brachyurus*	Opossum Pipefish Shorttailed Pipefish
Canthidermis sufflamen	Ocean Triggerfish	*Micropogonias undulatus*	Atlantic Croaker
Canthigaster rostrata	Sharpnose Puffer	*Microspathodon chrysurus*	Yellowtail Damselfish
Caranx bartholomaei	Yellowjack	*Monacanthus* 4 spp.	Filefish
Caranx crysos	Bluerunner	*Moringua edwardsi*	Spaghetti Eel
Caranx hippos	Crevalle Jack	*Mugil* 3 spp.	Mullet
Caranx latus	Horse-eye Jack	*Mulloidichthys martinicus*	Yellow Goatfish
Caranx ruber	Bar Jack	*Mustelus canis*	Smooth Dogfish
Carapus bermudensis	Atlantic Pearlfish	*Mycteroperca* 4 spp.	Grouper
Carcharhinus acronotus	Black-nose Shark	*Myrichthys* 2 spp.	Eel
Carcharhinus leucas	Bull Shark	*Myripristis jacobus*	Blackbar Soldierfish
Carcharhinus limbatus	Black-tip Shark	*Myrophis punctatus*	Speckled Worm Eel
Carcharhinus obscurus	Dusky Shark	*Narcine brasiliensis*	Lesser Electric Ray
Carcharhinus perezii	Caribbean Reef Shark	*Naucrates ductor*	Pilotfish
Carcharhinus signatus	Night Shark	*Negaprion brevirostris*	Lemon Shark
Centropomus undecimalis	Common Snook	*Nes longus*	Orangespotted Goby
Centropomus var. spp.	Snook	*Nicholsina usta*	Emerald Parrotfish
Cephalopholis cruentata	Graysby	*Nomeus grovovii*	Man-of-War Fish
Cephalopholis fulva	Coney Grouper	*Ocyurus chrysurus*	Yellowtail Snapper
Cerdale floridana	Pugjaw Wormfish	*Odontoscion dentex*	Reef Croaker
Chaenopsis ocellata	Bluethroat Pikeblenny	*Ogcocephalus* 3 spp.	Batfish
Chaetodipterus faber	Atlantic Spadefish	*Ogilbia cayorum*	Key Brotula
Chaetodon var. spp.	Butterflyfish	*Oligoplites saurus*	Leatherjack/Leatherjacket
Chasmodes saburrae	Florida Blenny	*Ophichthus* 2 spp.	Eel
Chilomycterus var. spp.	Burrfish	*Ophidion* 2 spp.	Cusk Eel
Chriodorus atherinoides	Hardhead Halfbeak	*Ophioblennius atlanticus*	Redlip Blenny
Chromis cyanea	Blue Chromis	*Opisthonema oglinum*	Atlantic Thread Herring
Chromis enchrysurus	Yellowtail Reeffish	*Opistognathus* 4 spp.	Jawfish
Chromis insolata	Sunshinefish	*Orthopristis chrysoptera*	Pigfish
Chromis multilineata	Brown Chromis	*Parablennius marmoreus*	Seaweed Blenny
Chromis scotti	Purple Reeffish	*Paraclinus* 5 spp.	Blenny
Citharichthys var. spp.	Whiff	*Paraconger caudilimbatus*	Margintail Conger
Clepticus parrae	Creole Wrasse	*Paradiplogrammus bairdi*	Lancer Dragonet

Table A8. Fish Species in Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Conger oceanicus	Conger Eel	*Paralichthys albigutta*	Gulf Flounder
Conger triporiceps	Manytooth Conger	*Paranthias furcifer*	Creole Fish
Coralliozetus var. spp.	Blenny	*Parexocoetus brachypterus*	Sailfin Flyingfish
Coryphaena equiselis	Pompano Dolphin	*Parophidion schmiditi*	Dusky Cusk Eel
Coryphaena hippurus	Dolphin	*Pempheris schomburgki*	Glassy Sweeper
Coryphopterus var. spp.	Goby	*Petrotyx sanguineus*	Redfin Brotula
Cosmocampus var. spp.	Pipefish	*Platybelone argalus*	Keeltail Needlefish
Cryptotomus roseus	Bluelip Parrotfish	*Platygillellus rubrocinctus*	Saddle Stargazer
Cynoscion regalis	Weakfish	*Poecilia latipinna*	Sailfin Molly
Cynoscion var. spp.	Seatrout	*Pomacanthus arcuatus*	Gray Angelfish
Cyprinodon variegatus	Sheepshead Minnow	*Pomacanthus* var. spp.	Angelfish
Cypselurus var. spp.	Flyingfish	*Pomacentrus* 5 spp.	Damselfish
Dactylopterus volitans	Flying Gurnard	*Pomadasys crocro*	Burro Grunt
Dactyloscopus var. spp.	Stargazer	*Pomatomus saltatrix*	Bluefish
Dasyatis americana	Southern Stingray	*Porichthys plectrodon*	Atlantic Midshipman
Dasyatis sabina	Atlantic Stingray	*Priacanthus cruentatus*	Bulleye Glasseye Snapper
Dasyatis say	Bluntnose Stingray	*Priolepis hipoliti*	Rusty Goby
Decapterus var. spp.	Scad	*Prionotus* 4 spp.	Searobin
Dermatolepis inermis	Marbled Grouper	*Pristigenys alta*	Short Bigeye
Diapterus auratus	Irish Pompano	*Pristis pectinata*	Smalltooth Sawfish
Diapterus plumieri	Striped Mojarra	*Prognichthys gibbifrons*	Bluntnose Flyingfish
Diodon holocanthus	Balloonfish	*Psenes cyanophrys*	Freckled Driftfish
Diodon hystrix	Porcupinefish	*Pseudogramma gregoryi*	Reef Bass
Diplectrum var. spp.	Perch	*Pseudupeneus maculatus*	Spotted Goatfish
Diplogrammus pauciradiatus	Spotted Dragonet	*Rachycentron canadum*	Cobia
Doratonotus megalepis	Dwarf Wrasse	*Raja texana*	Roundel Skate
Dormitator maculatus	Fat Sleeper	*Remora* 2 spp.	Remora
Echeneis naucrates	Sharksucker	*Rhinobatos lentiginosus*	Atlantic Guitarfish
Echeneis neucratoides	Whitefin Sharksucker	*Rhinoptera bonasus*	Cownose Ray
Echidna catenata	Chain Moray	*Rhizoprionodon terraenovae*	Atlantic Sharpnose Shark
Elagatis bipinnulata	Rainbow Runner	*Rhomboplites aurorubens*	Vermillion Snapper
Eleotris pisonis	Spinycheek sleeper	*Rivulus marmoratus*	Mangrove Rivulus
Elops saurus	Ladyfish	*Rypticus* 3 spp.	Soapfish
Emblemaria bottomei	Midnight Blenny	*Sarda sarda*	Bonito
Emmelichthyops atlanticus	Bonnetmouth	*Sardinella aurita*	Round Sardinella
Enchelycore nigricans	Viper Moray	*Scartella cristata*	Molly Miller
Enneanectes altivelis	Lofty Triplefin	*Scarus* var. spp.	Parrotfish
Entomacrodus nigricans	Pearl Blenny	*Scomberomorus* 3 spp.	Mackerel

Table A8. Fish Species in Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Epinephelus drummondhayi	Speckled Hind	*Scorpaena* var. spp.	Scorpionfish
Epinephelus guttatus	Red Hind	*Scorpaenodes tredecimspinosus*	Deepreef Scorpionfish
Epinephelus guttatus	Rock Hind	*Selar crumenophthalmus*	Bigeye Scad
Epinephelus itajara	Goliath Grouper	*Selene setapinnis*	Atlantic Moonfish
Epinephelus morio	Red Grouper	*Selene vomer*	Lookdown
Epinephelus nigritus	Warsaw Grouper	*Seriola dumerili*	Greater Amberjack
Epinephelus niveatus	Snowy Grouper	*Seriola zonata*	Banded Rudderfish
Epinephelus striatus	Nassau Grouper	*Serranus* 4 spp.	Bass
Equetus acuminatus	High-hat	*Sparisoma* var. spp.	Parrotfish
Equetus lanceolatus	Jackknife Fish	*Sphoeroides* 3 spp.	Puffer
Equetus punctatus	Spotted Drum	*Sphyraena* 2 spp.	Sennet
Equetus umbrosus	Cubbyu	*Sphyrna* 4 spp.	Hammerhead Shark
Erotelis smaragdus	Emerald Sleeper	*Starksia ocellata*	Checkerd Blenny
Eucinostomus var. spp.	Mojarra	*Stathmonotus* 2 spp.	Blenny
Euthynnus alletteratus	False Albacore/Little Tunny	*Strongylura* 2 spp.	Needlefish
Evorthodus lyricus	Lyre Goby	*Strongylura marina*	Atlantic Needlefish
Exocoetus obtusirostris	Oceanic Two-wing	*Syacium* 2 spp.	Flounder
Floridichthys carpio	Goldspotted Killifish	*Symphurus plagiusa*	Blackcheek Tonguefish
Gambusia holbrooki	Mosquitofish	*Syngnathus* 7 spp.	Pipefish
Gambusia rhizophorae	Mangrove Gambusia	*Synodus synodus*	Red Lizardfish
Gerres cinereus	Yellowfin Mojarra	*Thalassoma bifasciatum*	Bluehead
Gillellus greyae	Arrow Stargazer	*Torpedo nobiliana*	Atlantic Torpedo Ray
Gnathagnus egregius	Freckled Stargazer	*Trachinocephalus myops*	Snakefish
Gnatholepis thompsoni	Goldspot Goby	*Trachinotus carolinus*	Florida Pompano
Gobiesox strumosus	Skilletfish	*Trachinotus falcatus*	Permit
Gobionellus stigmaturus	Spottail Goby	*Trachinotus goodei*	Palometa
Gobionellus var. spp.	Goby	var. *Adinia*	Killifish species
Gobiosoma var. spp.	Goby	var*. Fundulus*	Killifish species
Gymnothorax var. spp.	Moray Eel	*Enneanectes* var. spp.	Triplefin
Gymnura micrura	Smooth Butterfly Ray	*Fistularia tabacaria*	Tobacco Trumpetfish Bluespotted Cornetfish
Haemulon album	Margate	*Galeocerdo cuvier*	Tiger Shark
Haemulon var. spp.	Grunt	*Opsanus* 2 spp.	Toadfish
Halichoeres bivittatus	Slippery Dick	*Plydactylus* 3 spp.	Threadfin
Emblemaria bottomei	Midnight Blenny	*Sarda sarda*	Bonito
Emmelichthyops atlanticus	Bonnetmouth	*Sardinella aurita*	Round Sardinella
Enchelycore nigricans	Viper Moray	*Scartella cristata*	Molly Miller
Enneanectes altivelis	Lofty Triplefin	*Scarus* var. spp.	Parrotfish
Entomacrodus nigricans	Pearl Blenny	*Scomberomorus* 3 spp.	Mackerel

Table A8. Fish Species in Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Epinephelus drummondhayi	Speckled Hind	*Scorpaena* var. spp.	Scorpionfish
Epinephelus guttatus	Red Hind	*Scorpaenodes tredecimspinosus*	Deepreef Scorpionfish
Epinephelus guttatus	Rock Hind	*Selar crumenophthalmus*	Bigeye Scad
Epinephelus itajara	Goliath Grouper	*Selene setapinnis*	Atlantic Moonfish
Epinephelus morio	Red Grouper	*Selene vomer*	Lookdown
Epinephelus nigritus	Warsaw Grouper	*Seriola dumerili*	Greater Amberjack
Epinephelus niveatus	Snowy Grouper	*Seriola zonata*	Banded Rudderfish
Epinephelus striatus	Nassau Grouper	*Serranus* 4 spp.	Bass
Equetus acuminatus	High-hat	*Sparisoma* var. spp.	Parrotfish
Equetus lanceolatus	Jackknife Fish	*Sphoeroides* 3 spp.	Puffer
Equetus punctatus	Spotted Drum	*Sphyraena* 2 spp.	Sennet
Equetus umbrosus	Cubbyu	*Sphyrna* 4 spp.	Hammerhead Shark
Erotelis smaragdus	Emerald Sleeper	*Starksia ocellata*	Checkerd Blenny
Eucinostomus var. spp.	Mojarra	*Stathmonotus* 2 spp.	Blenny
Euthynnus alletteratus	False Albacore/Little Tunny	*Strongylura* 2 spp.	Needlefish
Evorthodus lyricus	Lyre Goby	*Strongylura marina*	Atlantic Needlefish
Exocoetus obtusirostris	Oceanic Two-wing	*Syacium* 2 spp.	Flounder
Floridichthys carpio	Goldspotted Killifish	*Symphurus plagiusa*	Blackcheek Tonguefish
Gambusia holbrooki	Mosquitofish	*Syngnathus* 7 spp.	Pipefish
Gambusia rhizophorae	Mangrove Gambusia	*Synodus synodus*	Red Lizardfish
Gerres cinereus	Yellowfin Mojarra	*Thalassoma bifasciatum*	Bluehead
Gillellus greyae	Arrow Stargazer	*Torpedo nobiliana*	Atlantic Torpedo Ray
Gnathagnus egregius	Freckled Stargazer	*Trachinocephalus myops*	Snakefish
Gnatholepis thompsoni	Goldspot Goby	*Trachinotus carolinus*	Florida Pompano
Gobiesox strumosus	Skilletfish	*Trachinotus falcatus*	Permit
Gobionellus stigmaturus	Spottail Goby	*Trachinotus goodei*	Palometa
Gobionellus var. spp.	Goby	var. *Adinia*	Killifish species
Gobiosoma var. spp.	Goby	var. *Fundulus*	Killifish species
Gymnothorax var. spp.	Moray Eel	*Enneanectes* var. spp.	Triplefin
Gymnura micrura	Smooth Butterfly Ray	*Fistularia tabacaria*	Tobacco Trumpetfish Bluespotted Cornetfish
Haemulon album	Margate	*Galeocerdo cuvier*	Tiger Shark
Haemulon var. spp.	Grunt	*Opsanus* 2 spp.	Toadfish
Halichoeres bivittatus	Slippery Dick	*Plydactylus* 3 spp.	Threadfin

Table A9. Birds Known to Inhabit Biscayne National Park.

Scientific Name	Common Name	Scientific Name	Common Name
Accipiter cooperii	Cooper's Hawk	*Helmitheros vermivorus*	Worm-eating Warbler
Accipiter striatus	Sharp-shinned Hawk	*Himantopus mexicanus*	Black-necked Stilt
Actitis macularia	Spotted Sandpiper	*Hirundo rustica*	Barn Swallow
Agelaius phoeniceus	Red-winged Blackbird	*Icterus galbula*	Baltimore Oriole
Ajaia ajaja	Roseate Spoonbill	*Lanius ludovicianus*	Loggerhead Shrike
Ammodramus savannarum	Grasshopper Sparrow	*Larus argentatus*	Herring Gull
Anas acuta	Northern Pintail	*Larus atricilla*	Laughing Gull
Anas discors	Blue-winged Teal	*Larus delawarensis*	Ring-billed Gull
Anhinga anhinga	Anhinga	*Larus fuscus*	Lesser Black-backed Gull
Anous stolidus	Brown Noddy	*Larus marinus*	Great Black-backed Gull
Aramus guarauna	Limpkin	*Larus philadelphia*	Bonaparte's Gull
Archilochus colubirs	Ruby-throated Hummingbird	*Limnodromus griseus*	Short-billed Dowitcher
Ardea alba	Great Egret	*Limosa fedoa*	Marbled Godwit
Ardea herodias	Great Blue Heron	*Melanerpes carolinus*	Red-bellied Woodpecker
Arenaria interpres	Ruddy Turnstone	*Melanitta nigra*	Black Scoter
Aythya affinis	Lesser Scaup	*Mergus serrator*	Red-breasted Merganser
Bartramia longicauda	Upland Sandpiper	*Mimus polyglottus*	Northern Mockingbird
Bombycilla cedrorum	Cedar Waxwing	*Mniotilta varia*	Black-and-White Warbler
Branta bernicla	Brant	*Morus bassanus*	Northern Gannet
Bubulcus ibis	Cattle Egret	*Mycteria americana*	Wood Stork
Bucephala albeola	Bufflehead	*Myiarchus crinitus*	Great Crested Flycatcher
Buteo brachyurus	Short-tailed Hawk	*Myiarchus sagrae*	La Sagra's Flycatcher
Buteo jamaicensis	Red-tailed Hawk	*Numenius phaeopus*	Whimbrel
Buteo lineatus	Red Shouldered Hawk	*Nyctanassa violacea*	Yellow-crowned Night-Heron
Buteo platypterus	Broad-winged Hawk	*Nycticorax nycticorax*	Black-crowned Night-heron
Butorides virescens	Green Heron	*Oceanites oceanicus*	Wilson's Storm-Petrel
Calidris alba	Sanderling	*Oporornis agilis*	Connecticut Warbler
Calidris alpina	Dunlin	*Otus asio*	Eastern Screech-owl
Calidris canutus	Red Knot	*Pandion haliaetus*	Osprey
Calidris maritima	Purple Sandpiper	*Parula americana*	Northern Parula
Calidris mauri	Western Sandpiper	*Passer montanus*	House Sparrow
Calidris minutilla	Least Sandpiper	*Passerculus sandwichensis*	Savannah Sparrow
Caprimulgus carolinensis	Chuck-will's Widow	*Passerina ciris*	Painted Bunting
Caprimulgus vociferus	Whip-poor-will	*Passerina cyanea*	Indigo Bunting
Cardinalis cardinalis	Northern Cardinal	*Pelecanus erythrorhynchos*	American White Pelican

Table A9. Birds Known to Inhabit Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Carduelis tristis	American Goldfinch	*Pelecanus occidentalis*	Brown Pelican
Cathartes aura	Turkey Vulture	*Phalacrocorax auritus*	Double-crested Cormorant
Catharus fuscescens	Veery	*Phalaropus fulicaria*	Red Phalarope
Catharus minimus	Gray-cheeked Thrush	*Pheucticus ludovicianus*	Rose-breasted Grosbeak
Catharus ustulatus	Swainson's Thrush	*Phoenicopterus ruber*<>	Caribbean Flamingo
Catoptrophorus semipalmatus	Willet	*Piranga olivacea*	Scarlet Tanager
Cavia immer	Common Loon	*Piranga rubra*	Summer Tanager
Ceryle alcyon	Belted Kingfisher	*Plegadis falcinellus*	Glossy Ibis
Charadrius melodus	Piping Plover	*Pluvialis squatarola*	Black-bellied Plover
Charadrius semipalmatus	Semipalmated Plover	*Podiceps auritus*	Horned Grebe
Charadrius vociferus	Killdeer	*Podilymbus podiceps*	Pied-billed Grebe
Charadrius wilsonia	Wilson's Plover	*Polioptila caerulea*	Blue-gray Gnatcatcher
Chordeiles minor	Common Nighthawk	*Progne subis*	Purple Martin
Circus cyaneus	Northern Harrier	*Protonotaria citrea*	Prothonotary Warbler
Coccyzus americanus	Yellow-billed Cuckoo	*Quiscalus major*	Boat-tailed Grackle
Coccyzus minor	Mangrove Cuckoo	*Quiscalus quiscula*	Common Grackle
Colaptes auratus	Northern Flicker	*Rallus longirostris*	Clapper Rail
Colinus virginianus	Northern Bobwhite	*Regulus calendula*	Ruby-crowned Kinglet
Columba leucocephala	White-crowned Pigeon	*Riparia riparia*	Bank Swallow
Columba livia	Rock Dove	*Rostrhamus sociabilis*	Snail Kite
Columbina passerina	Common Ground-dove	*Rynchops niger*	Black Skimmer
Coragyps atratus	Black Vulture	*Sayornis phoebe*	Eastern Phoebe
Corvus brachyrhynchos	American Crow	*Seiurus aurocapillus*	Ovenbird
Corvus ossifragus	Fish Crow	*Seiurus motacilla*	Louisiana Waterthrush
Cyanocitta cristata	Blue Jay	*Seiurus noveboracensis*	Northern Waterthrush
Dendrocygna bicolor	Fulvous Whistling-Duck	*Setophaga ruticilla*	American Redstart
Dendroica caerulescens	Black-throated Blue Warbler	*Sphyrapicus varius*	Yellow-bellied Sapsucker
Dendroica coronata	Yellow-rumped Warbler	*Stelgidopteryx serripennis*	Northern Rough-winged Swallow
Dendroica dominica	Yellow-throated Warbler	*Stercorarius pomarinus*	Pomarine Jaeger
Dendroica kirtlandii	Kirtland's Warbler	*Sterna anaethetus*	Bridled Tern
Dendroica magnolia	Magnolia Warbler	*Sterna antillarum*	Least Tern
Dendroica palmarum	Palm Warbler	*Sterna caspia*	Caspian Tern
Dendroica palmarum	Palm Warbler	*Sterna forsteri*	Forster's Tern
Dendroica petechia	Yellow Warbler	*Sterna fuscata*	Sooty Tern
Dendroica pinus	Pine Warbler	*Sterna hirundo*	Common Tern
Dendroica striata	Blackpoll Warbler	*Sterna maxima*	Royal Tern
Dendroica tigrina	Cape May Warbler	*Sterna sandvicensis*	Sandwich Tern
Dendroica virens	Black-throated Green	*Streptopelia decaocto*	Eurasian Collared-Dove
Dendroica discolor	Prairie Warbler	*Sturnus vulgaris*	European Starling
Dolichonyx oryzivorus	Bobolink	*Sula dactylatra*	Masked Booby

Table A9. Birds Known to Inhabit Biscayne National Park (continued).

Scientific Name	Common Name	Scientific Name	Common Name
Dumetella carolinensis	Gray Catbird	*Sula leucogaster*	Brown Booby
Egretta caerulea	Little Blue Heron	*Sula nebouxii*	Blue-footed Booby
Egretta rufescens	Reddish Egret	*Tachycineta bicolor*	Tree Swallow
Egretta thula	Snowy Egret	*Toxostoma rufum*	Brown Thrasher
Egretta tricolor	Tricolored Heron	*Tringa flavipes*	Lesser Yellowlegs
Elanoides forticatus	Swallow-tailed Kite	*Tringa melanoleuca*	Greater Yellowlegs
Empidonax minimus	Least Flycatcher	*Troglodytes aedon*	House Wren
Eudocimus albus	White Ibis	*Turdus migratorius*	American Robin
Falco columbarius	Merlin	*Tyrannus dominicensis*	Gray Kingbird
Falco peregrinus	Peregrine Falcon	*Tyrannus tyrannus*	Eastern Kingbird
Falco sparverius	American Kestrel	*Tyrannus verticalis*	Western Kingbird
Fregata magnificens	Magnificent Frigatebird	*Vermivora celata*	Orange-crowned Warbler
Fulica americana	American Coot	*Vermivora peregrina*	Tennessee Warbler
Gallinago gallinago	Common Snipe	*Vireo altiloquus*	Black-whiskered Vireo
Gallinula chloropus	Common Moorhen	*Vireo griseus*	White-eyed Vireo
Geothlypis trichas	Common Yellowthroat	*Vireo olivaceus*	Red-eyed Vireo
Geotrygon chrysia	Key West Quail-Dove	*Vireo solitarius*	Solitary Vireo
Guiraca caerulea	Blue Grosbeak	*Zenaida asiatica*	White-winged Dove
Haematopus palliatus	American Oystercatcher	*Zenaida macroura*	Mourning Dove

Appendix B: Terrestrial Vegetation Maps

The following maps are derived from the Biscayne National Park vegetation map by Ruiz et al. (2010, in press). They were made from a GIS data layer provided by the authors. Each map is followed by a table of areas for the mapped vegetation types.

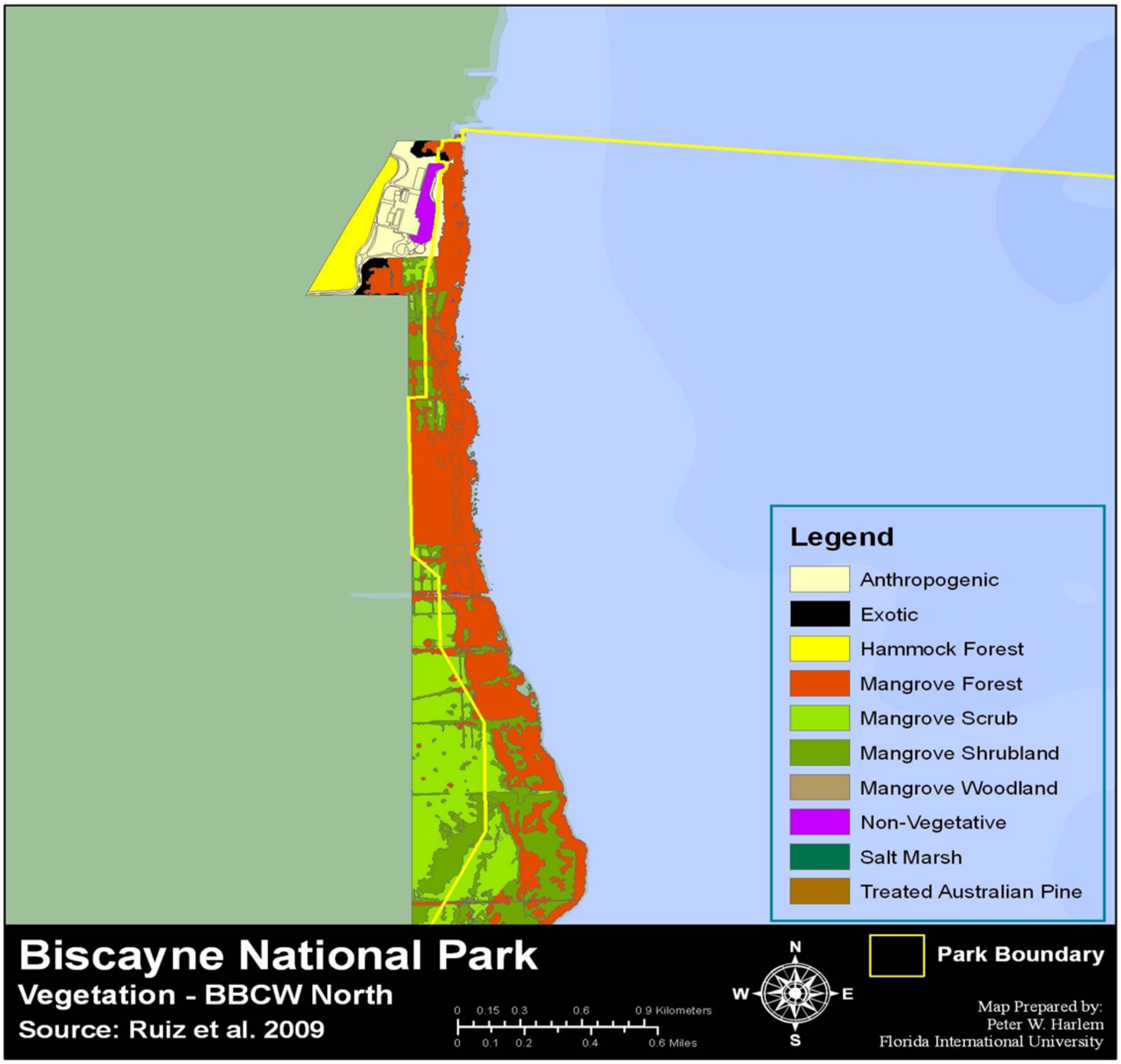

Figure B1. Vegetation patterns for the northern portion of the Biscayne Bay Coastal Wetland. Note that the area around the Palmetto Bay Village Hall (ex-Burger King building) is included as is a section of Cutler Bay, just west of the park boundary (yellow line). Almost all the park land is mangrove of one subtype or another.

Table B1. Coverage classes in the Upper Biscayne Bay Coastal Wetland in Figure B1. Data from Ruiz et al. (2010).

Type	m^2	Percent
Mixed Mangrove Forest	764,677.84	37.39
Mixed Mangrove Shrubland	387,759.07	18.96
Red Mangrove Scrub	320,351.52	15.66
Mixed Mangrove Scrub	178,102.57	8.71
Anthropogenic	167,065.00	8.17
Coastal Hardwood Hammock	88,506.58	4.33
Black Mangrove Forest	56,851.89	2.78
Water	30,872.23	1.51
Exotic	23,640.31	1.16
Red Mangrove Shrubland	14,502.48	0.71
Red Mangrove Forest	12,303.69	0.60
Gramminoid Salt Marsh	548.90	0.03
Lightning Gap	199.10	0.01
Total	**2,045,381.18**	**100.00**

Table B2. Coverage classes in the Upper-middle Biscayne Bay Coastal Wetland in Figure B2. Data from Ruiz et al. (2010).

Type	m^2	Percent
Mixed Mangrove Forest	1,698,482.23	51.49
Red Mangrove Scrub	613,971.53	18.61
Mixed Mangrove Shrubland	512,070.01	15.52
Anthropogenic	343,030.68	10.40
Red Mangrove Shrubland	46,322.93	1.40
Black Mangrove Woodland	32,435.06	0.98
Mixed Mangrove Scrub	26,968.54	0.82
Water	9,387.63	0.28
Exotic	7,565.95	0.23
Red Mangrove Forest	6,852.45	0.21
Black Mangrove Shrubland	809.31	0.02
Black Mangrove Forest	319.46	0.01
Lightning Gap	245.34	0.01
Total	**3,298,461.12**	**100.00**

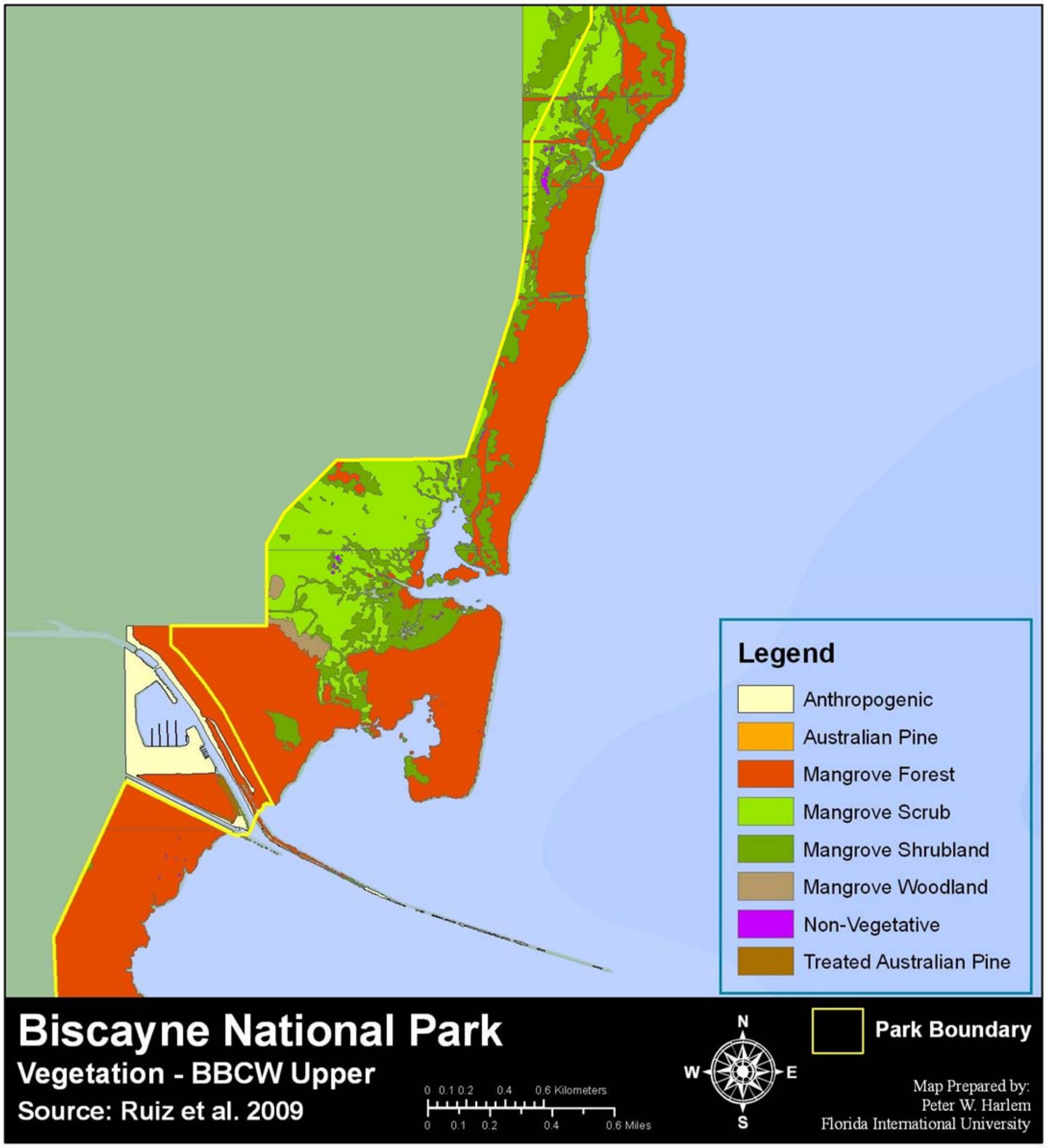

Figure B2. Vegetation patterns for the upper-middle portion of the Biscayne Bay Coastal Wetland in the vicinity of Black Point. Note that a section of Cutler Bay just west of the park boundary (red line) is included as is the Black Point Marina. Almost all the park land is mangrove of one subtype or another.

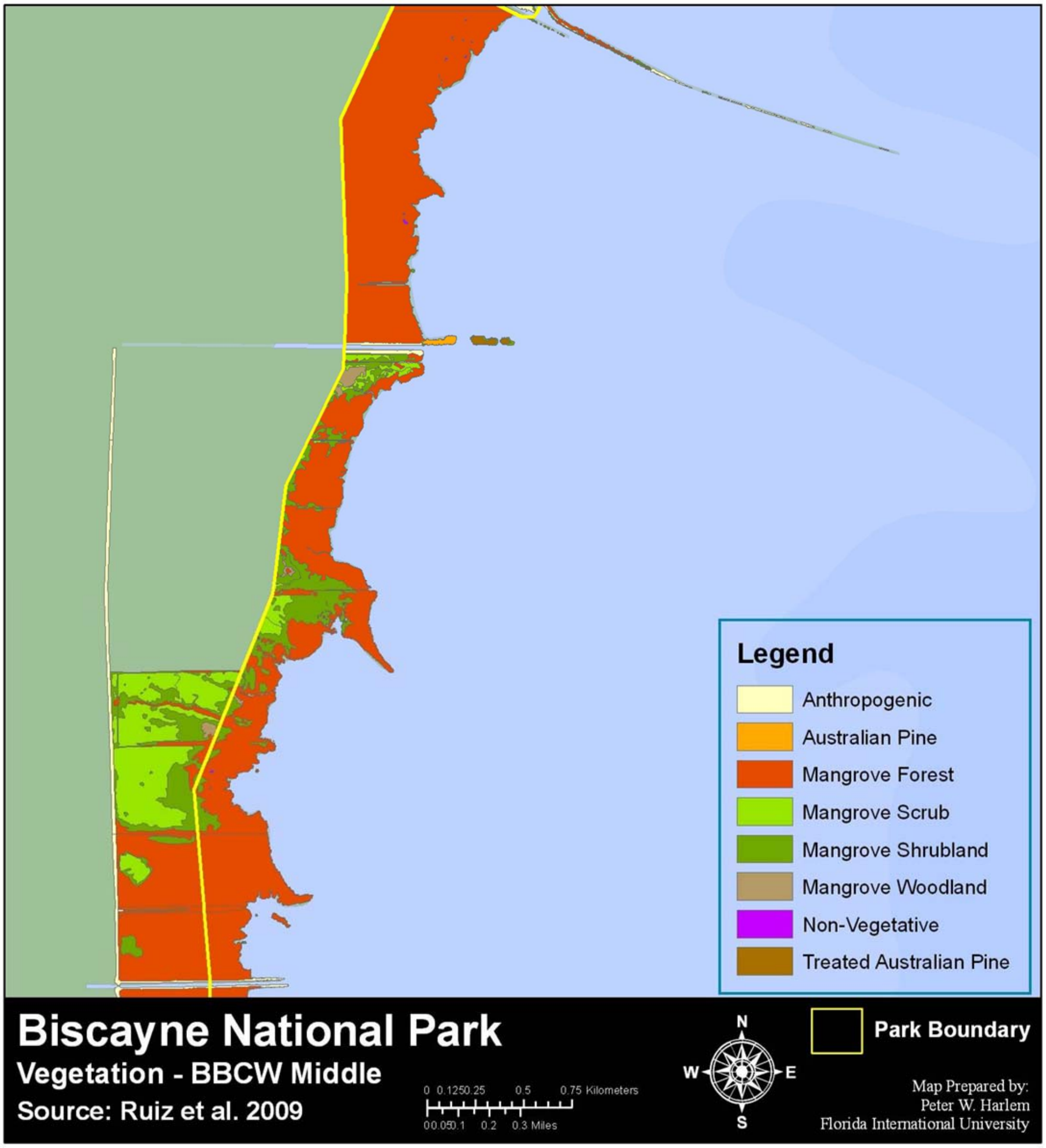

Figure B3. Vegetation patterns for the lower-middle portion of the Biscayne Bay Coastal Wetland in the vicinity of Fender Point. Note that the section west of the park boundary (red line) to L-31E levee is included. Almost all the park land is mangrove of one subtype or another.

Table B3. Coverage classes in the Lower-Middle Biscayne Bay Coastal Wetland in Figure B3. Data from Ruiz et al. (2010).

Type	m^2	Percent
Mixed Mangrove Forest	1772,838.92	69.16
Mixed Mangrove Shrubland	343,013.71	13.38
Red Mangrove Scrub	192,780.37	7.52
Mixed Mangrove Scrub	127,266.10	4.96
Anthropogenic	70,120.90	2.74
Red Mangrove Forest	21,253.45	0.83
Mixed Mangrove Woodland	19,337.16	0.75
Exotic	12,865.82	0.50
Red Mangrove Shrubland	1,623.26	0.06
Water	1,435.78	0.06
Lightning Gap	783.33	0.03
Total	**2,563,318.8**	**100.00**

Table B4. Coverage classes in the Southern Biscayne Bay Coastal Wetland in Figure B4. Data from Ruiz et al. (2010).

Type	m^2	Percent
Red Mangrove Scrub	2,345,701.08	45.92
Mixed Mangrove Forest	1,153,300.28	22.58
Mixed Mangrove Shrubland	511,844.80	10.02
Anthropogenic	436,247.21	8.54
Mixed Mangrove Scrub	410,875.54	8.04
Gramminoid Salt Marsh	93,449.99	1.83
Gramminoid Freshwater Prairie	53,874.07	1.05
Exotic	52,055.70	1.02
Water	12,589.70	0.25
Buttonwood Shrubland	12,449.19	0.24
White Mangrove Shrubland	9,732.03	0.19
Red Mangrove Forest	8,893.75	0.17
Mixed Mangrove Woodland	3,856.19	0.08
White Mangrove Scrub	1,833.71	0.04
Red Mangrove Shrubland	708.21	0.01
Coastal Hardwood Shrubland	394.67	0.01
Lightning Gap	154.33	0.00
Black Mangrove Forest	136.07	0.00
Total	**5,108,096.52**	**100.00**

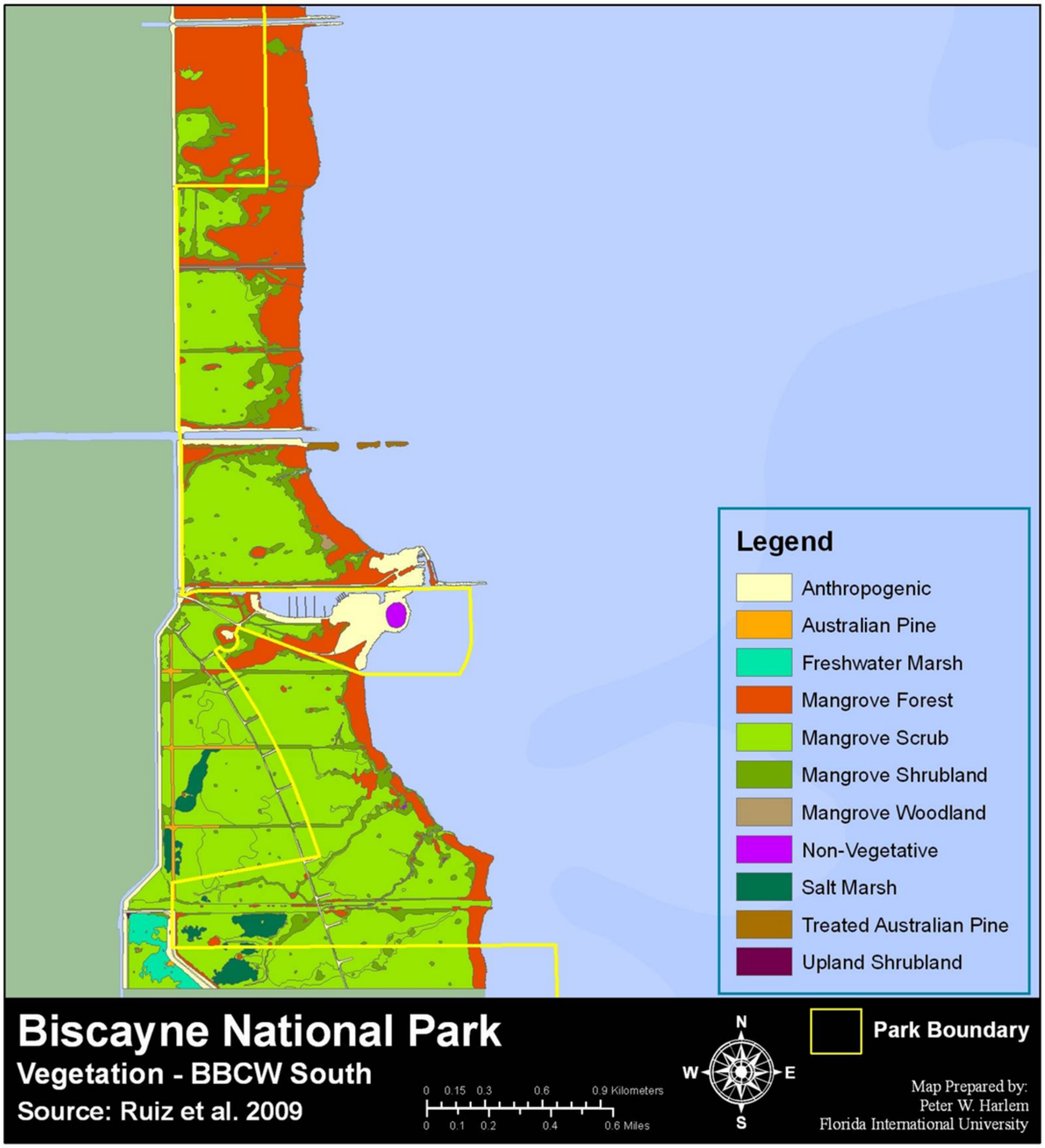

Figure B4. Vegetation patterns for the southern portion of the Biscayne Bay Coastal Wetland in the vicinity of Convoy Point. Note that the section west of the park boundary (red line) to L-31E levee is included. In the southwest corner are located several small salt marshes surrounded by the dominant scrub mangroves.

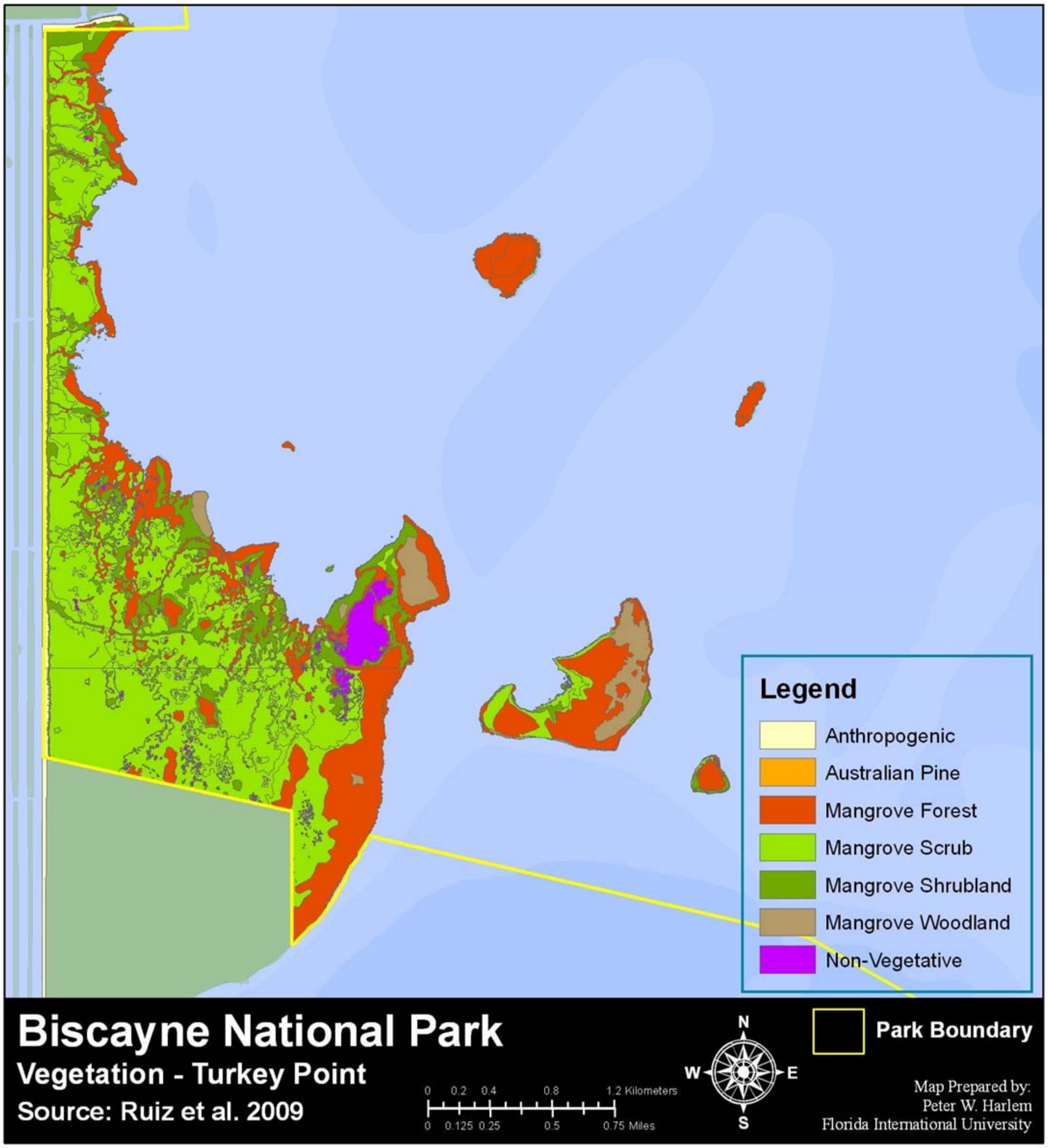

Figure B5. Vegetation patterns for the area south of Turkey Point, including Mangrove Point and the Arsenicker Keys. Parkland here abuts the cooling canal network associated with the FPL power plant and is dominated by scrub mangroves.

Table B5. Coverage classes south of Turkey Point Power Plant in Figure B5. Data from Ruiz et al. (2010).

Type	m^2	Percent
Red Mangrove Scrub	2,847,421.41	46.56
Mixed Mangrove Forest	981,931.92	16.05
Red Mangrove Forest	445,591.64	7.29
Mixed Mangrove Shrubland	394,933.06	6.46
Red Mangrove Shrubland	371,569.47	6.08
Mixed Mangrove Scrub	290,793.64	4.75
Black Mangrove Woodland	236,983.35	3.87
Black Mangrove Forest	235,256.76	3.85
Water	159,385.74	2.61
Anthropogenic	140,044.97	2.29
Buttonwood Woodland	6,994.79	0.11
Mixed Mangrove Woodland	4,221.20	0.07
Exotic	919.00	0.02
Lightning Gap	50.92	0.00
Total	**6,116,097.87**	**100**

Table B6. Coverage classes at Soldier Key in Figure B6. Data from Ruiz et al. (2010).

Type	m^2	Percent
Mixed Herbaceous Dune	2,941.03	29.99
Mixed Mangrove Forest	2,114.41	21.56
Mixed Mangrove Shrubland	1,810.57	18.46
Mixed Mangrove Scrub	1,688.81	17.22
White Mangrove Scrub	663.93	6.77
Red Mangrove Shrubland	210.23	2.14
White Mangrove Shrubland	171.06	1.74
Anthropogenic	107.81	1.10
Beach	59.27	0.60
Succulent Salt Marsh	38.92	0.40
Total	**9,806.04**	**100.00**

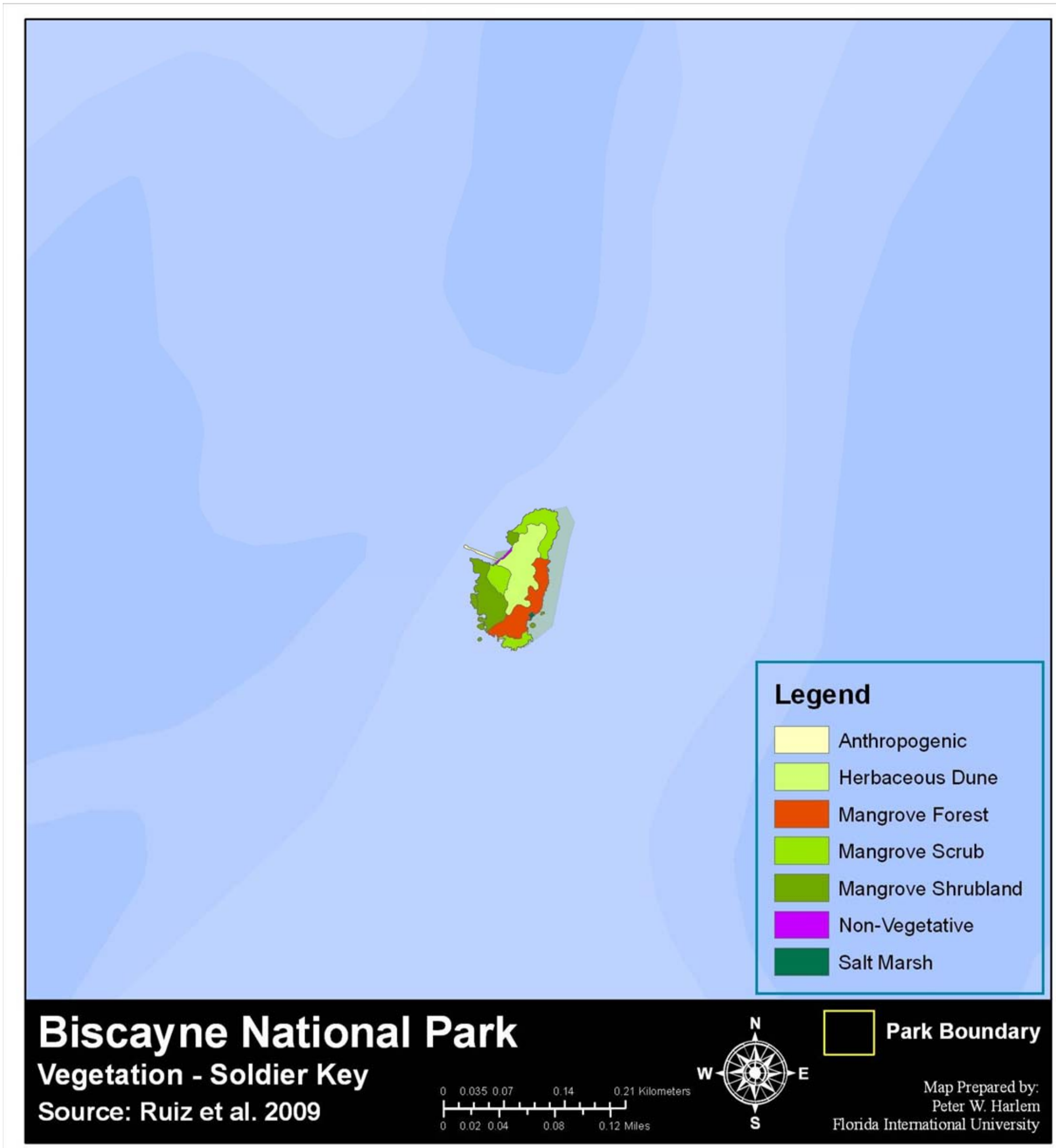

Figure B6. Vegetation patterns for Soldier Key. Slightly modified prior to becoming part of Biscayne National Park, this limestone outcrop is mangrove dominated with a mixed species herbaceous community growing on the outcrop (dune in source data). There used to be a second Soldier Key outcrop to the south of this island, but it disappeared prior to the late 1800s. These features are the last expression of the Key Largo Limestone ridge before it dives below the sediments opposite Key Biscayne.

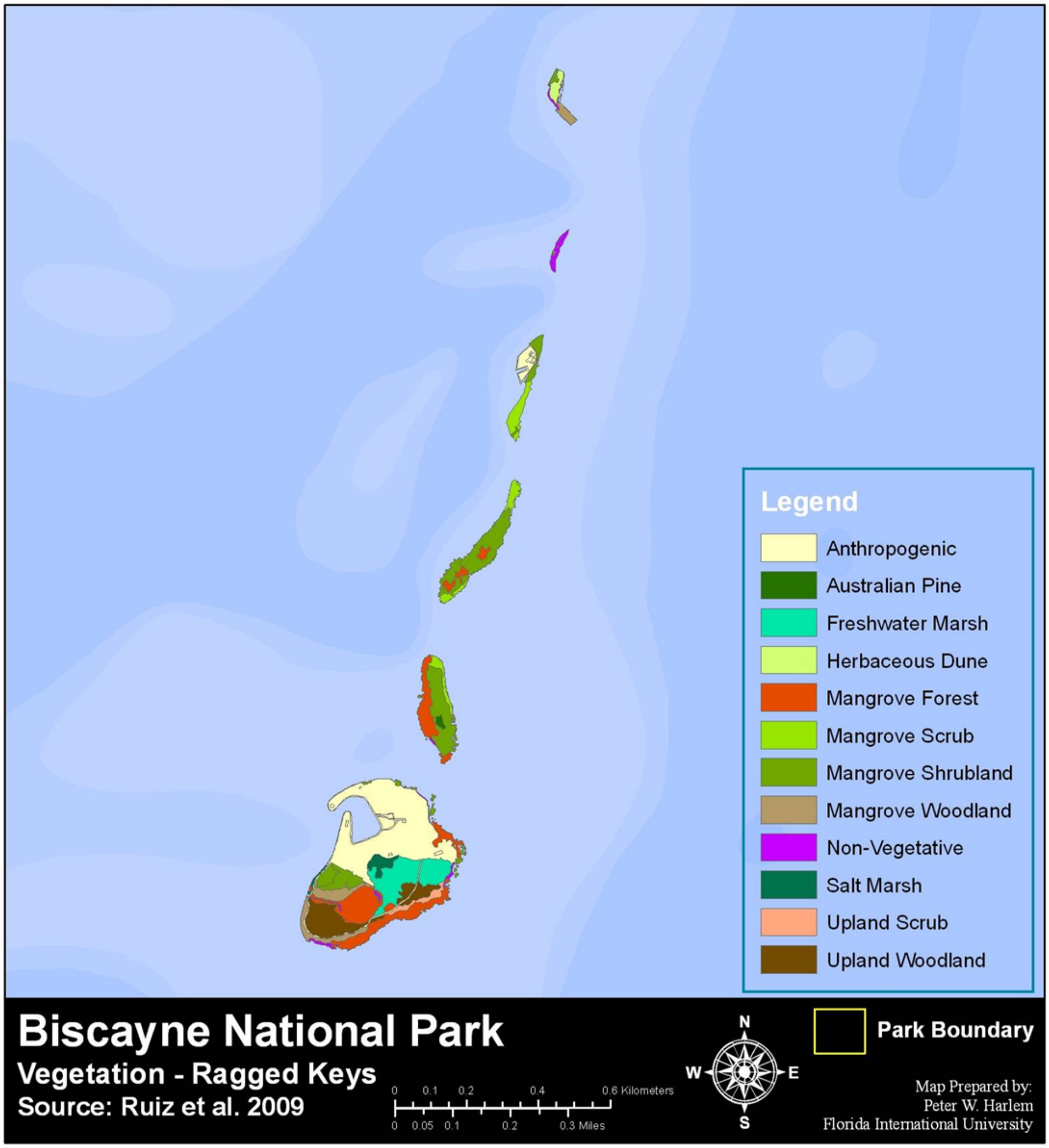

Figure B7. Vegetation patterns for the Ragged Keys including Boca Chica. The latter island has been partially filled with material from the small man made harbor and is large enough to support small areas with upland species. Otherwise mangroves are dominant in this highly diverse area.

Table B7. Coverage classes at the Ragged Keys in Figure B7. Data from Ruiz et al. (2010).

Type	m^2	Percent
Anthropogenic	57,835.69	31.42
Mixed Mangrove Forest	20,564.45	11.17
Gramminoid Freshwater Prairie	16,834.63	9.15
Upland Hardwood Woodland	14,553.66	7.91
Mixed Mangrove Shrubland	13,587.25	7.38
Red Mangrove Shrubland	11,827.71	6.43
Red Mangrove Forest	6,640.28	3.61
White Mangrove Shrubland	4,682.86	2.54
Black Mangrove Shrubland	4,072.47	2.21
White Mangrove Scrub	3,775.74	2.05
Black Mangrove Woodland	3,647.05	1.98
Buttonwood Woodland	3,362.23	1.83
Red Mangrove Scrub	3,288.86	1.79
Buttonwood Forest	3,192.74	1.73
Succulent Salt Marsh	2,812.15	1.53
Upland Scrub	2,309.30	1.25
Beach	1,960.76	1.07
Mixed Mangrove Scrub	1,907.58	1.04
Mixed Herbaceous Dune	1,893.46	1.03
Littoral Zone	1,700.39	0.92
Mixed Mangrove Woodland	1,441.50	0.78
Exotic	634.26	0.34
Water	520.01	0.28
Herbaceous Salt Marsh	513.49	0.28
Buttonwood Shrubland	218.40	0.12
Black Mangrove Forest	176.55	0.10
White Mangrove Forest	111.97	0.06
Total	**184,065.46**	**100.00**

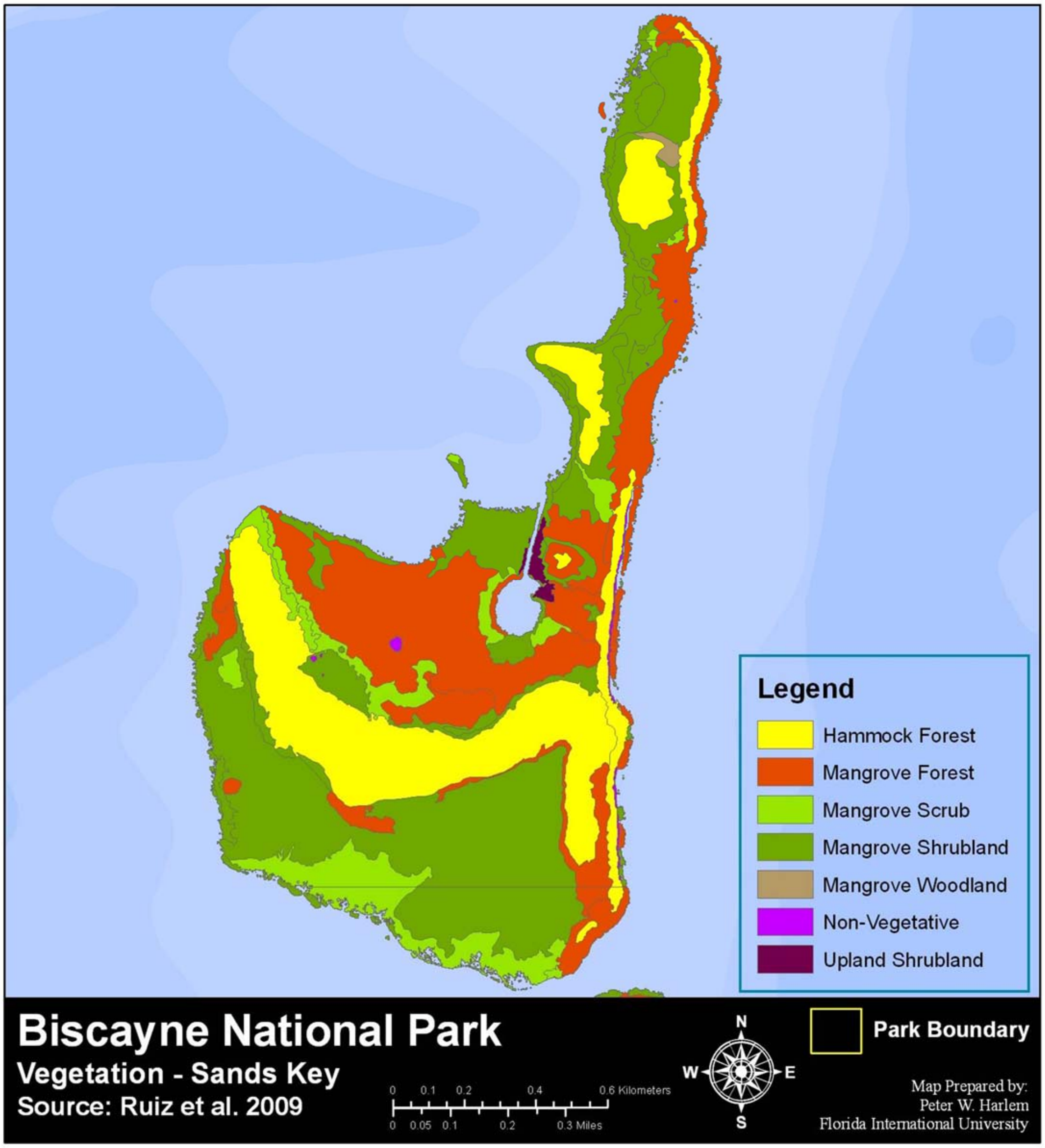

Figure B8. Vegetation patterns for Sands Key. This island is an excellent place to show how the mangrove and hardwood hammocks are controlled by the karst surface of the Key Largo Limestone. Hammocks occupy raised portions of the limestone, while mangrove dominates the lower margins. The hole in the island is a relict karst dissolution feature (doline) which was slightly modified during construction of the small access channel.

Table B8. Coverage classes at Sands Key in Figure B8. Data from Ruiz et al. (2010).

Type	m^2	Percent
Mixed Mangrove Shrubland	534,226.21	32.57
Coastal Hardwood Hammock	342,578.95	20.89
Mixed Mangrove Forest	334,090.90	20.37
Red Mangrove Shrubland	116,180.00	7.08
Red Mangrove Scrub	95,785.50	5.84
Black Mangrove Forest	44,507.21	2.71
Buttonwood Forest	41,168.47	2.51
Mixed Mangrove Scrub	38,244.60	2.33
Coastal Dune Hammock	34,299.81	2.09
Buttonwood Shrubland	15,873.79	0.97
White Mangrove Scrub	13,435.73	0.82
Red Mangrove Forest	11,675.05	0.71
Coastal Hardwood Shrubland	7,516.33	0.46
Buttonwood Woodland	4,597.48	0.28
Beach	4,482.17	0.27
Water	1,516.10	0.09
Total	**1,640,178.32**	**100.00**

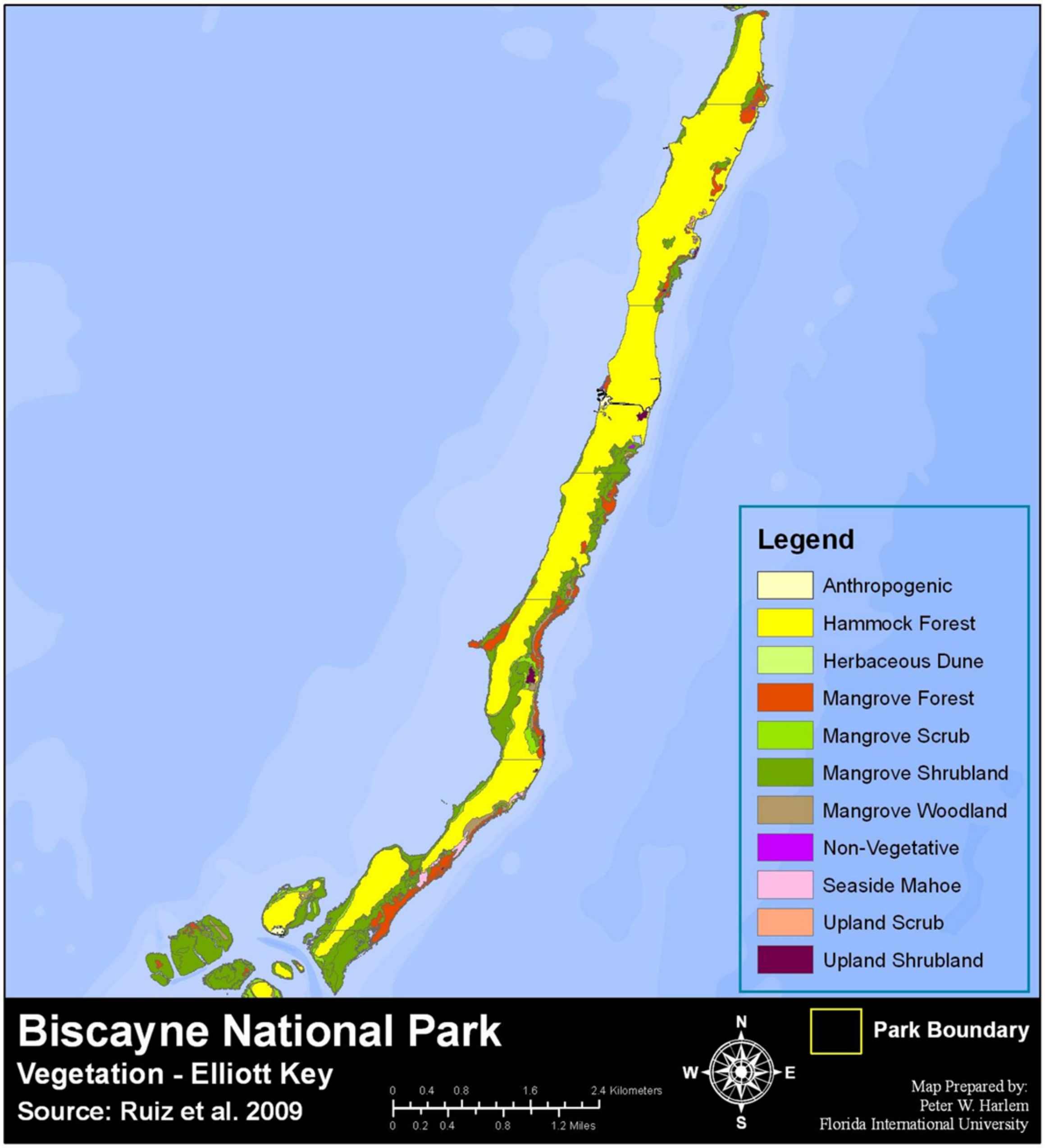

Figure B9. Vegetation patterns for Elliott Key. Two-thirds of this island has coastal hardwood hammock species growing on the elevated coralline limestone, with mangrove along the margins.

Table B9. Coverage classes at Elliott Key in Figure B9. Data from Ruiz et al. (2010).

Type	**m^2**	**Percent**
Coastal Hardwood Hammock	4,613,497.04	66.01
Mixed Mangrove Shrubland	1,130,294.71	16.17
Mixed Mangrove Forest	354,202.42	5.07
Red Mangrove Shrubland	242,180.19	3.46
Mixed Mangrove Scrub	143,030.80	2.05
Red Mangrove Forest	98,107.76	1.40
Exotic	49,408.79	0.71
Mixed Mangrove Woodland	40,231.93	0.58
Buttonwood Woodland	39,635.44	0.57
Coastal Hardwood Shrubland	37,952.26	0.54
Black Mangrove Shrubland	36,067.89	0.52
White Mangrove Woodland	31,941.64	0.46
Anthropogenic	26,264.82	0.38
Buttonwood Shrubland	25,278.17	0.36
Buttonwood Forest	25,130.55	0.36
Red Mangrove Scrub	19,106.12	0.27
Black Mangrove Forest	15,541.36	0.22
Upland Hardwood Scrub	14,750.85	0.21
Upland Hardwood Woodland	11,975.39	0.17
Beach	11,850.21	0.17
Water	8,247.68	0.12
Black Mangrove Scrub	4,704.90	0.07
Barren Salt Flat	4,048.63	0.06
Mixed Herbaceous Dune	3,988.74	0.06
White Mangrove Shrubland	2,045.98	0.03
Total	**6,989,484.29**	**100.00**

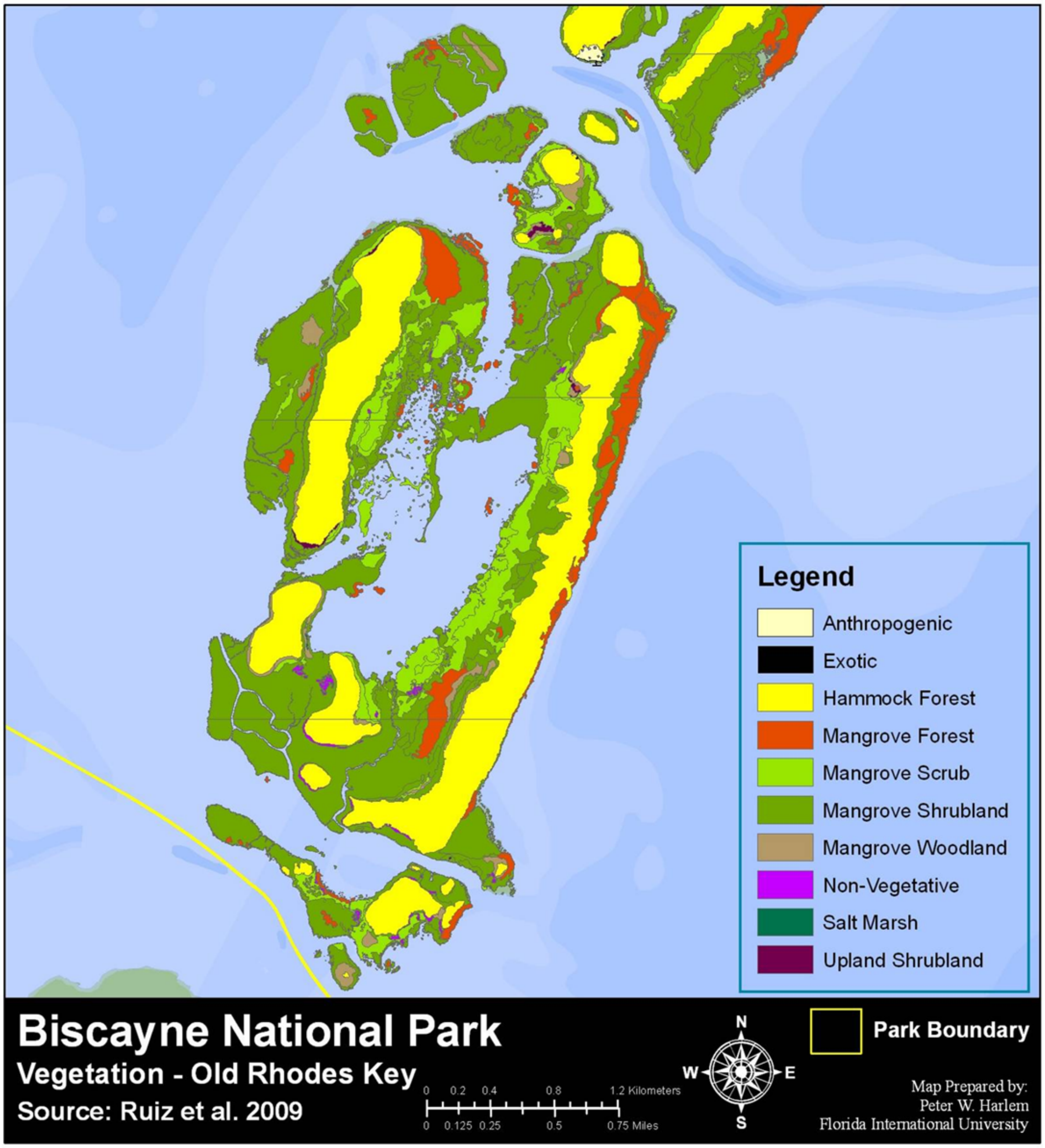

Figure B10. Vegetation patterns for Old Rhodes Key, Totten Key and the associated smaller islands. Each of the main islands is inhabited with hardwood hammocks growing on the elevated limestone ridges. Mangroves have expanded somewhat in the interior lagoon between the two main islands. About a third of the cover is hardwood hammock species.

Table B10. Coverage classes at Old Rhodes Key/Totten Key complex in Figure B10. Data from Ruiz et al. (2010).

Type	m^2	Percent
Red Mangrove Shrubland	2,128,334.53	29.10
Coastal Hardwood Hammock	2,065,867.19	28.24
Mixed Mangrove Shrubland	1,405,182.26	19.21
Red Mangrove Scrub	637,025.89	8.71
Mixed Mangrove Forest	214,055.17	2.93
Red Mangrove Forest	173,487.35	2.37
Mixed Mangrove Scrub	146,182.94	2.00
Black Mangrove Scrub	93,745.89	1.28
Black Mangrove Forest	91,972.45	1.26
Buttonwood Woodland	60,317.68	0.82
Mixed Mangrove Woodland	55,064.29	0.75
Buttonwood Shrubland	51,732.10	0.71
Black Mangrove Woodland	46,418.77	0.63
Black Mangrove Shrubland	40,615.50	0.56
Water	29,017.21	0.40
Barren Microkarst	19,807.32	0.27
Coastal Hardwood Shrubland	17,784.30	0.24
White Mangrove Scrub	12,392.96	0.17
Buttonwood Forest	11,239.53	0.15
White Mangrove Woodland	8,830.00	0.12
White Mangrove Shrubland	4,460.45	0.06
Succulent Salt Marsh	812.92	0.01
Exotic	562.35	0.01
Anthropogenic	104.91	0.00
Total	**7,315,013.99**	**100.00**

Appendix C: Joint Fishery Management Plan

Biscayne National Park's Fishery Management Plan (FMP) is the result of a cooperative effort between the park (BNP) and the Florida Fish and Wildlife Conservation Commission (FWC). The plan will guide fishery management decisions in BNP for the next 5-10 years by setting desired future conditions for the park's fishery resources. Following the plan's approval, the FWC would then propose park-specific state fishing regulations designed to achieve the desired future conditions. Scoping for the draft plan took place in 2001, and a stakeholder Working Group provided recommendations, virtually all of which were incorporated into the draft plan. Three well-attended public meetings for the release of the draft plan were held in 2009.

The plan presents a range of alternatives being considered for the BNP FMP and identifies an alternative preferred by both agencies. BNP hosts both commercial and recreational fishers, and increases in South Florida's boating and fishing population, combined with improved fishing and boating technology, pose a threat to the long-term sustainability of fishery-related resources of BNP. A fishery management plan is deemed necessary to guide sustainable use of BNP's fishery-related resources, as recent studies (Ault et al., 2001, 2007; Kellison et al., 2011; and park creel survey data [unpubl.]) suggest that many of BNP's fisheries resources are in decline. The development of the alternatives, and the identification of the preferred alternative, was based on a combination of public input (derived from three public comment periods and three series of public meetings and the input of the FMP Working Group), inter-agency meetings and environmental and socioeconomic analyses contained within the plan.

Fishery Management Directives

While BNP's enabling legislation establishes that fishing will continue to occur in BNP waters in accordance with state regulations, BNP must also manage its fishery resources according to park and NPS mandates and legislation. For example, Congress directed that "the Secretary of the Interior, after consultation with appropriate officials of the State, may designate species for which, areas and times within which, and methods by which fishing is prohibited, limited, or otherwise regulated in the interest of sound conservation to achieve the purposes for which the park was established" (16 USC § 410gg-2). Thus, even though fishing regulations in BNP waters should conform to state regulations, the Secretary of the Interior has the ability to establish additional fishing regulations for BNP.

Complicating this issue, however, is the provision that expansion areas donated by the State after the act's effective date must be in conformance with state law. In terms of management, Biscayne National Park can be divided into two zones: a) the original monument zone, in which fishing regulations follow State regulations, with the opportunity for the Secretary of the Interior to enforce additional regulations as deemed necessary, and b) the expansion zone, in which State regulations are enforced, and where the Secretary of the Interior cannot institute additional regulations (16 USC § 410gg-2). Due to the complex nature of the legislations, policies and other management directives; however, it is in the best interest of the public and BNP staff to manage fisheries uniformly within the park. Uniform regulations across all of BNP, regardless of the applicable regulatory authority, will allow for the most effective resource management and can ensure that visitors have a high-quality fishing experience.

The Fishery Management Plan is designed to guide fisheries policies in the park, yet it will fall hierarchically under the park's General Management Plan. With minor exceptions, fishing in BNP follows State of Florida Fishing Regulations, as determined by the FWC. Recreational fishing, which occurs in multiple habitats in both bay and ocean waters, targets species such as bonefish, snook, tarpon, permit, blue crab, stone crab, snapper, grouper, grunt, barracuda, spadefish, spiny lobster and triggerfish. Commercial fishing also occurs in both bay and ocean waters, and it targets numerous species including invertebrates (lobster, blue crab, stone crab, and bait shrimp), food fish (typically members of the snapper/grouper complex; concentrated on yellowtail snapper) and baitfish (e.g., ballyhoo, Spanish sardine, thread herring and pilchard). Park visitors fishing in the park can freely remove as many lionfish as desired; this exotic species is not managed by NPS of FWC for fisheries purposes (i.e. this species does not have a minimum size limit, a bag limit, closed season, etc.).

Overview of Alternatives

Five alternatives were analyzed for impacts of actions on the environment and are summarized below. Alternative 4 (Rebuild and Conserve Park Fisheries Resources) results in the best and most equitable balance between conservation, enjoyment and extractive uses of BNP's fishery resources, and thus is identified as the Preferred Alternative.

Alternative 1 – Maintain Status Quo

Alternative 1, the no-action alternative, serves as a basis of comparison with the other alternatives. Alternative 1 would continue current fisheries management according to the park's enabling legislation, established NPS management policies and existing authorities, and in conjunction with state fishery regulations. No regulatory changes would be triggered by the establishment of the FMP. Regulatory changes would occur only if mandated by the FWC following their normal rule-making process, or through the federal regulatory and public review process.

Alternative 2 – Maintain At or Above Current Levels

Under Alternative 2, a minor change from current management strategies would take place. Park fisheries resources and habitat conditions would be maintained at or above current levels. Recreational (per person) harvest (i.e., bag limits), numbers of commercial fishers and fishing-related habitat impacts (those caused directly or indirectly by fishing activities) would be maintained at or below current levels. Additional park-specific regulations and management actions would be enacted only if park fisheries resources or recreational fishing experiences decline, or if fishing-related habitat impacts increase from current levels. Law enforcement staffing and enforcement strategies, as well as education and coordination efforts, would not change from current levels. Specific management measures would occur as follows:

- Fishery-targeted fish and invertebrates populations would be maintained at current levels. Park fisheries resources would not likely differ in abundance or average size from those outside the park—unless populations decline in areas adjacent to the park. Park-specific management actions would be enacted only if populations or mean sizes in the park declined below current levels.

- Satisfaction of fishers would be maintained at or above 80%. If the level of satisfaction decreased below 80%, BNP would make further efforts to identify the characteristics of a fishing outing that are most important to providing a satisfying experience (i.e., through interviews and surveys), and make subsequent efforts to provide those characteristics (staff and funding dependent).

- New commercial fisheries would not be allowed to develop within the park.

- Future growth in the number of commercial fishermen would be prevented. All commercial fishers would be required to purchase a limited-entry, Special Use Permit from the park superintendent. The permit would be transferable and would require annual renewal for each year during which landings are reported.

- BNP would seek to establish an annual permit system for commercial guides operating in the park.

- Shrimp trawlers would be subject to inspection by park staff to ensure that trawl gear is in compliance with FWC regulations.

- Management actions to reduce the level and impact of debris associated with recreational and commercial fisheries would be considered if an increase above current levels is observed. Such actions could include increased removal efforts by park staff and partner groups, increased education efforts or spatial closures. Additionally, BNP would explore the feasibility and effectiveness of establishing a regulation to restrict traps from hardbottom habitat (staff and funding dependent).

- BNP would investigate the feasibility of establishment of a stamp associated with the FWC recreational fishing license that would enable the license holder to fish in BNP, and that would fund additional enforcement efforts by the FWC in BNP.

Alternative 3 – Improve Over Current Levels

Under Alternative 3, a moderate change from current management strategies would occur. Improvement from the current condition of park fisheries resources would be sought through moderate decreases in recreational harvest, limits on spearfishing and establishment of a recreational permit system. Numbers of commercial fishers would remain at current levels or decrease over time, and fishing-related habitat impacts would be reduced. This alternative would require implementation of new regulations governing fishing activities within the park.

Specific management measures would occur as follows. This alternative would result in the same actions described in Alternative 2, as well as in the actions below:

- Management actions would be enacted (in conjunction with the FWC) to increase the abundance and average size of fishery-targeted fish and invertebrate species within the park by at least 10% over current conditions and over conditions in similar habitats outside the park. Initially, these efforts would be focused on frequently harvested species such as grouper, snapper, hogfish and spiny lobster, which studies have indicated have already been negatively affected by fishing impacts. Future efforts, as deemed appropriate given the best available data, could include less-impacted species such as grunt and barracuda as well as catch-and release species such as bonefish and permit.

- Spearfishing would be limited to gear lacking a trigger mechanism (e.g., the Hawaiian sling model). The use of air-providing equipment (e.g., scuba and hookah) while spearfishing would be prohibited. These regulations are expected to improve fisheries resources by reducing the harvest of undersized fish, since park data reveal that spearfishers are more than twice as likely as anglers to take at least one undersized fish per trip, this is likely due to failure to correct for underwater magnification.

- BNP would seek to establish a "recreational boat use" annual permit, in the form of a sticker to be placed on each permitted boat. The permit would be required for all vessels involved in recreational activities (e.g., fishing, diving, swimming, birding etc.) or not underway (with exceptions for boat engine or vessel malfunction). The permit would *not* be required for boaters navigating through the park but not utilizing it for recreation.

- Commercial fishers would be required to purchase a limited-entry, Special Use Permit from the park superintendent. The permit in this alternative differs from the one described in Alternative 2 in that the permit would be non-transferable for the first five years. Permits would require annual renewal, and would be "use or lose" such that a permit could not be renewed if 1) it was not renewed the previous year or 2) no catch was reported in the previous year.

- BNP would work to establish a trap-free zone north and east of park headquarters at Convoy Point where deployment of commercial or recreational crab traps would not occur. The purpose of the zone would be to provide a natural viewscape for visitors viewing the park from the Visitor Center, as well as to avoid conflicts with other recreational activities (e.g., windsurfing, canoeing and kayaking) occurring in this high visitor-use area. BNP and the FWC would work with industry to seek voluntary compliance with the trap-free zone; if unsuccessful, BNP and the FWC would explore the possibility of establishing an official closure.

- BNP will seek to have FWC eliminate the two-day recreational lobster sport season in the park to protect coral reef habitat from diver-related damage.

- BNP will seek to have FWC establish coral reef protection areas (CRPAs) to delineate coral reef habitat on which lobster and crab traps could not be deployed. Traps within the CRPAs could be moved outside CRPA boundaries by authorized FWC or park staff or other authorized personnel.

Alternative 4 (Preferred Alternative) – Rebuild and Conserve Park Fisheries Resources
Under Alternative 4, a considerable change from current management strategies would occur. Substantial improvement in park fisheries resources status and a further reduction in fishing-related habitat impacts would be sought. Numbers of commercial fishers would decrease over time via establishment of a non-transferable permit system. This alternative would require considerable changes to current fishing regulations within the park.

Specific management measures would occur as follows. This alternative would result in the same actions described in Alternative 3, as well as the actions below:

- Management actions would be enacted (in conjunction with the FWC) to increase the abundance and average size of targeted fish and invertebrate species within the park by at least 20% over current conditions and over conditions in similar habitat outside the park. Initial and future efforts would remain as described in Alternative 3.

- As in Alternative 3, all commercial fishers would be required to purchase a limited-entry, Special Use Permit from the park superintendent. The permit in this alternative differs from that described in Alternative 3 in that it would be permanently non-transferable. Permits would require annual renewal, and would be "use or lose" such that a permit could not be renewed if 1) it was not renewed the previous year or 2) no catch was reported in the previous year.

- As in Alternative 3, BNP would seek to have FWC establish coral reef protection areas (CRPAs) to delineate coral reef habitat where lobster and crab traps could not be deployed. Additionally, under Alternative 4, the trap number from traps observed within CRPAs would be recorded, and traps with three or more recorded violations could be confiscated from park waters.

- BNP would propose a no-trawl zone within Biscayne Bay where commercial shrimp trawling would be prohibited. This zone would protect juvenile fish and invertebrates commonly caught as bycatch in trawls, as well as protect essential fish habitat.

Alternative 5 (Environmentally Preferred Alternative) – Restore Park Fisheries Resources
Alternative 5 would bring a substantial improvement in park fisheries resources status to conditions similar to pre-exploitation levels and a further decline in fishing-related habitat impacts would be sought. Numbers of commercial fishers would decrease over time via establishment of a non-transferable permit system. Among the five alternatives, this alternative would require the most extreme changes to current fishing regulations within the park. Alternative 5 was identified by the NPS as the Environmentally Preferred Alternative.

Specific management measures would occur as follows. This alternative would result in the same actions described in Alternative 4, as well as the actions below.

- Management actions (in conjunction with the FWC) would to restore the abundance and average size of targeted fish and invertebrate species in the park to within 20% of historic, pre-exploited levels. Initial and future efforts would be as described in Alternative 3.

- Spearfishing would be prohibited within the park.

Status
The Fishery Management Plan received concurrence from the State of Florida and federal agencies. Following the Biological Opinion, being prepared by the National Marine Fisheries Service for this plan, the NPS expects to draft a Record of Decision, after which the FWC could begin its rulemaking process for the park-specific, State fishing regulations.

NPS 169/117834, December 2012

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