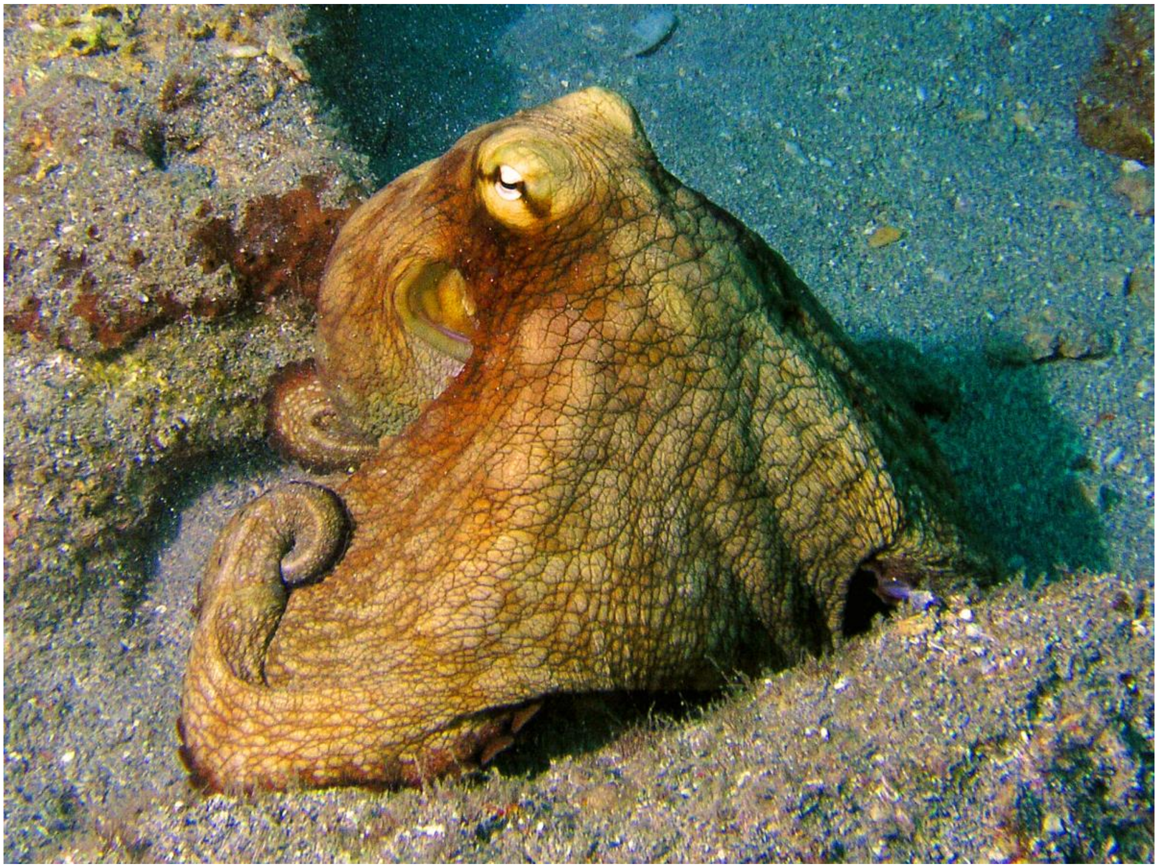
Evaluation of the South Florida Coral Reef Complex as a National Natural Landmark



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Executive Summary

The proposal includes the geographic area known as the South Florida Coral Reef Complex (SFCRC) from Cape Florida (Key Biscayne, 25° 40.0'N, 80° 09.5'W) to the St. Lucie Inlet (near Stuart, 27° 09.9'N, 80°09.7'W); linear distance is approximately 166 km. The SFCRC parallels the east coast of Florida; reefs are situated approximately from 10 ft depth to 100 ft (3 to 30m).

The reef, sea grass, and mangrove communities are important to fisheries, as coastal protection from storms, and to a thriving tourist industry dependent on these "American tropics." Florida is the only state in the continental United States to have such an ecosystem in its coastal waters. These coastal marine communities include a diverse assemblage of plants and animals. The Caribbean Sea and the Gulf of Mexico transform southeast Florida climate ranges, from subtropical in Stuart to more tropical maritime in Miami.

Coral reefs in SFCRC are based on Late Pleistocene beach ridges that parallel the shoreline ridges (perhaps ancient sand dunes). These were inundated by rising sea level and became topographical high points that attracted epibenthic marine flora and fauna colonists. Moderated offshore seawater temperatures are a factor as to why there is greater biological diversity on the outer reefs.

Coral reefs off southeast Florida are in a non-accretionary mode; however, they are rich in biological diversity. Sponges and octocorals predominate; barrel sponges (X*estospongia muta*) are the largest of the sponges and typically exceed the size of the zooxanthellate Scleractinia colonies. *Pseudopterogorgia* octocorals may attain a height of a meter. There are 24 shallow-reef stony corals in the area north of Government Cut (Miami harbor channel) in Miami-Dade County, 28 off Broward County, 25 off Palm Beach County, and 8 in Martin County on the reefs south of the St. Lucie Inlet. At least 350 fish species are reported for the coastal area of Broward and Miami-Dade counties, and 400 species are reported for Palm Beach County (Banks et al., 2008). There are 265 species of fish seen in the St. Lucie Inlet Preserve State Park. Fish species are typical of the Caribbean-Bahamian reef fish fauna.

Southeast Florida's economy is dependent on marine-oriented tourism. Fishing, boating, and diving are all closely tied to healthy and vibrant coral reefs. A comprehensive economic study of southeast Florida coral reefs was published by Johns et al. (2001). In their report, users spent, in Palm Beach County, over 2.8 million person-days on the natural reefs off the coast of the county. The market economic impact on the county totaled $357 million in sales, generated $142 million in local income, and supported 4,500 jobs (Johns et al., 2001). The reefs off Palm Beach County had a net annual user value of over $42 million. In Broward County, users spent about 5.5 million person-days on the natural reefs, with market economic impacts for the county of over $1.1 billion in sales, generating $547 million in local income, and supporting 19,000 jobs (Johns et al., 2001). The reefs off Broward County had a net annual user value of over $23 million. In Miami-Dade County, users spent almost 3 million person-days on the natural reefs, which had market economic impacts in the county of $878 million in sales, generated $419 million in income locally, and supported 13,000 jobs. The reefs off Miami-Dade had a net annual user value of almost $47 million. Residents of southeastern Florida are active users of the marine environment; in the 2004-2005 fiscal year there were 173,870 boat registrations (167,822 pleasure and 6,048 commercial) (Florida Statistical Abstract, 2006) and 74,454 saltwater fishing licenses (67,777 recreational and 6,677 commercial) (FWC license sales data, personal communication) in Martin, Palm Beach, Broward, Miami-Dade, and Monroe counties.

Introduction

Source of proposal

This proposal was compiled and prepared by Walter C. Jaap, Lithophyte Research LLC, 273 Catalan Blvd NE, St. Petersburg, FL 33704-3845.

Scope of the proposal

The proposal includes the geographic area known as the South Florida Coral Reef Complex (SFCRC) from Cape Florida (Key Biscayne, 25° 40.0'N, 80° 09.5'W) [geographic coordinates, latitudes and longitudes presented in the document are based on WGS 1984 datum; degrees, minutes, decimal minutes] to the St. Lucie Inlet (near Stuart, 27° 09.9'N, 80°09.7'W); linear distance is approximately 166 km. The SFCRC parallels the east coast of Florida with reefs situated from approximately 10 ft depth to 100 ft (3 to 30 m); this translates from very close to shore continuing seaward 2 to 3 km off Palm Beach and Broward counties, and up to 4 km off Dade County. The geological, biological, ecological, and anthropogenic information used to characterize the resources is based on personal experience and published research. The cartography that best describes the coastal features of the SFCRC and its risks to navigators is found in naval charts published by the National Oceanic and Atmospheric Administration's Office of Coast Survey; coastal charts 11428, 11451, and 11467 provide details from Miami to Stuart, Florida.

Overview

South Florida is a unique enclave of the Caribbean due to the nexus of geography and environment (Figure 1). Mangrove, sea grass, and coral reef epifaunal and infaunal sedimentary communities are common from Stuart on the east coast to Tampa Bay on the west coast. Florida is the only state in the continental United States to have such an ecosystem in its coastal waters. These coastal marine communities include a diverse assemblage of plants and animals. The reef, sea grass, and mangrove communities are important to fisheries, serve as coastal protection from storms, and promote a thriving tourist industry dependent on these "American tropics" (Odum et al., 1982; Zieman, 1982; Jaap, 1984).

"The maritime influence of the Caribbean Sea and the Gulf of Mexico transforms Florida's climate" (Chen and Gerber, 1990); southeast Florida's climate ranges from mostly subtropical in Stuart to more tropical maritime in Miami. Climate is influenced by the Bermuda high pressure system that reduces precipitation and by northern frontal systems that lower the air temperature (November to April). The "jet stream," a narrow band of strong winds in the upper atmosphere, steers cold air masses; in its wandering, it is influenced by the El Nino Southern Oscillation (ENSO) system. Florida's climate is superimposed on the ENSO cycles. An El Nino results in warmer and wetter winters, fewer hurricanes, and doldrums in late summer that often lead to coral bleaching events. Its opposite, La Nina, results in drier and cooler winters and more frequent summer hurricanes. Tropical cyclones (hurricanes) force radical changes in the coral reef, sea grass, and mangrove communities; hurricanes are most common in August and September.

Southern Florida's climate and marine systems benefit from a large western boundary current (often referred to as the Caribbean Current, Florida Current, or the Gulf Stream). The Gulf Stream is closest to the North American land mass off Palm Beach County. This current modifies the climate, is a link to the Caribbean, and, for many long-lived animals, is their means of support and transport during a portion of their life cycle. The coral reef fauna found in the Bahamas, Cuba, and southern Florida is remarkably similar. Lack of land barriers, connectivity of the water masses, and ocean currents facilitate larval transport of progeny between these areas.

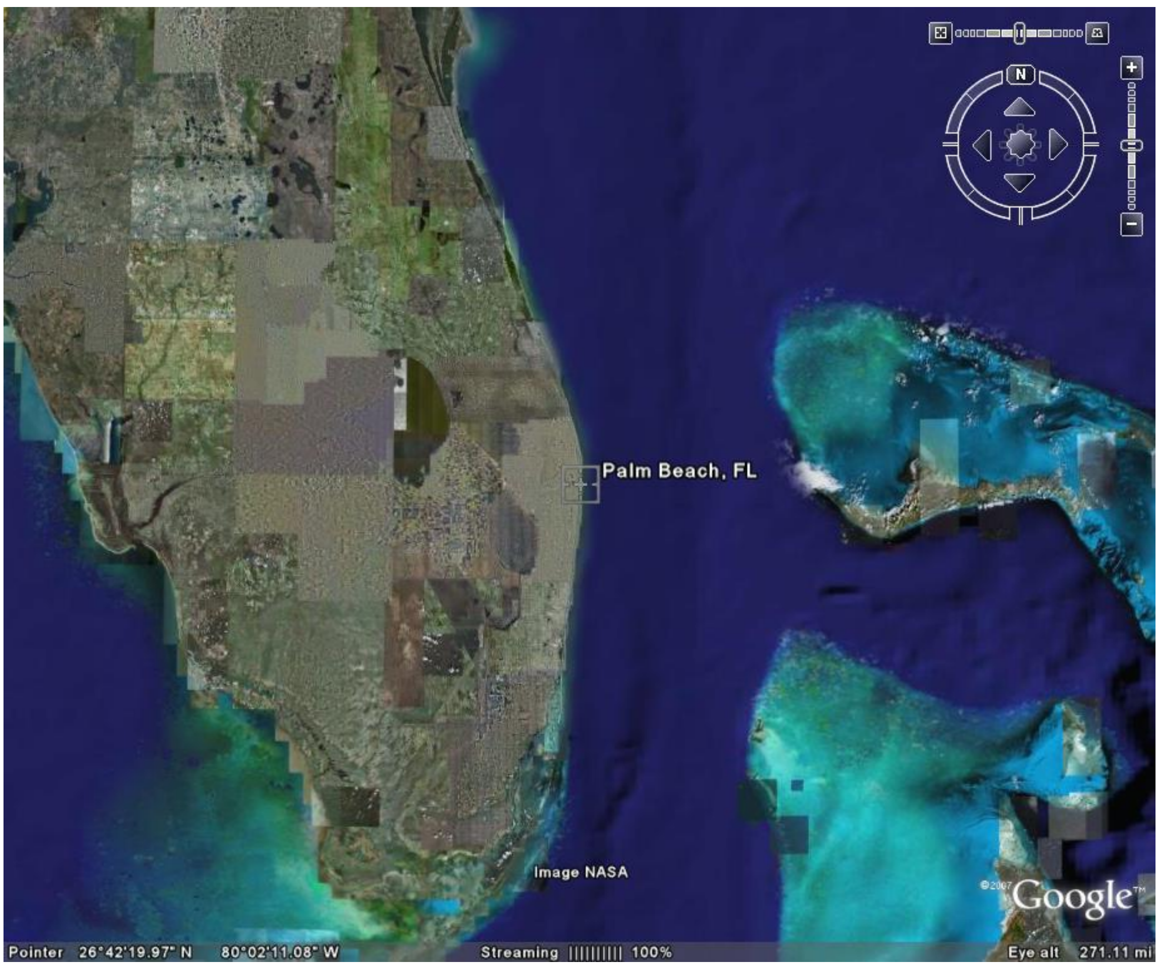

Figure 1. Southeast Florida and northern Bahamas, Google Earth image

The coral reefs in SFCRC are believed to be based on Late Pleistocene beach ridges that parallel the shoreline (Shinn et al., 1977; Banks et al., 2007). These ridges (perhaps ancient sand dunes) were inundated by rising sea level and became topographical high points that attracted epibenthic marine flora and fauna colonists. The SFCRC is nominally referred to by the local fishermen, divers, and researchers as the inshore ridge complex, comprising inner, middle, and outer reef complexes. They are separated by sandy sediments, sometimes only a thin layer, overlying limestone.

Natural History Themes

Land to sea (longitudinal) gradient

The SFCRC coastal ecosystem is a complex natural area that has experienced intensive modification as a result of human interference. A number of rivers debouch into bays and estuaries; Lake Okeechobee and the eastern Everglades provide the greatest hydrologic gradient. Rivers and canals are managed by locks and dams, and the water quality is often degraded by agricultural and urban runoff. These waters enter the Indian River, a body of water referred to by boaters as the intracoastal waterway. The Indian River is a tropical estuary; in the rainy season or when the water management district opens the floodgates, salinity in the river is lowered and, in severe situations, portions of the basin become nearly freshwater. During prolonged dry periods, evaporation results in hypersaline situations. In undeveloped areas, mangrove forests are common. Sea grasses such as turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal weed (*Halodule wrightii*) are found in both the Indian River and Biscayne Bay. Mangroves and sea grasses are unable to survive off much of the southeast Florida coast because of the high energy of the surf. However, sea grasses and mangroves do exist off Virginia Key and Key Biscayne (Miami-Dade County).

Tides and hydraulic gradients push waters from the Indian River and Biscayne Bay through a series of inlets, such as Jupiter, Hillsboro, and Baker's Haulover (Table 1). The waters then mix with the more saline Atlantic Ocean. The Indian River and Biscayne Bay are low energy, shallow, and can be hyposaline or hypersaline depending on the season. They also heat and cool quickly because of the low-volume shallow depth. Depth increases dramatically off the southeast Florida coast; 10 km beyond the coast it is hundreds of meters deep. Episodic high energy wind events are common and associated with frontal passages. Because of this, temperature and salinities in the Atlantic are more stable than in the Indian River.

The nominal tide is diurnal and the range is 80 to 100 cm (Table 1). The tide flows in and out of inlets and is very energetic; entering and exiting an inlet in a small vessel at Spring Tide is risky business. When the South Florida Water Management District is releasing large volumes of water into the estuary, the flows in the inlets are magnified and stratified with a freshwater surface lens.

Table 1. Tidal flow in southeast Florida inlets (as reported in Banks et al., 2008)

Inlet	**Latitude (dd.mm.mm)**	**Flow area (m^2)**	**Tidal prism (m^3)**	**Tide range (cm)**
Lake Worth	26°46.35	1400	$24x10^6$	100
South Lake Worth	26°32.72	100	$3x10^6$	90
Boca Raton	26°20.16	180	$4.9x10^6$	90
Hillsboro	26°15.44	300	$8.1x10^6$	90

Port Everglades	26°05.63	2,900	$18x10^6$	90
Bakers Haulover	25°54.00	520	$10.2x10^6$	80
Government Cut	25°45.63	1,400	$2.7x10^6$	80

The Gulf Stream is dynamic; it may venture close to shore and at times gyres and eddies flow into Lake Worth inlet. Average monthly low velocity of the Gulf Stream in this region is 1.0 m/s in November, and the average monthly high is 2.3 m/s in July. Approximately 2 km offshore, the current speed is 2.5 m/s (Banks et al., 2008). During periods with strong westerly winds, the Gulf Stream is pushed to the east, resulting in upwelling of cold water. Chilled water may cause fish kills and the phosphorus nutrients that are transported in the upwelled water masses result in episodic algal blooms (*Codium* and *Caulerpa*).

Latitudinal gradient

The 166 km distance from Cape Florida to the St. Lucie Inlet is a transition from subtropical to warm temperate climate, and the flora and fauna reflect the climate changes. Although the latitudinal change is subtle (1° 19’, 79 nautical miles), it is sufficient to change the community structure in remarkable ways. For example, mean low air temperature is less than 15°C in January, February, and March in Stuart but not in Miami (Figures 2 and 3). Wells (1957) reported that temperatures less than 18°C were not conducive to zooxanthellate coral reef development.

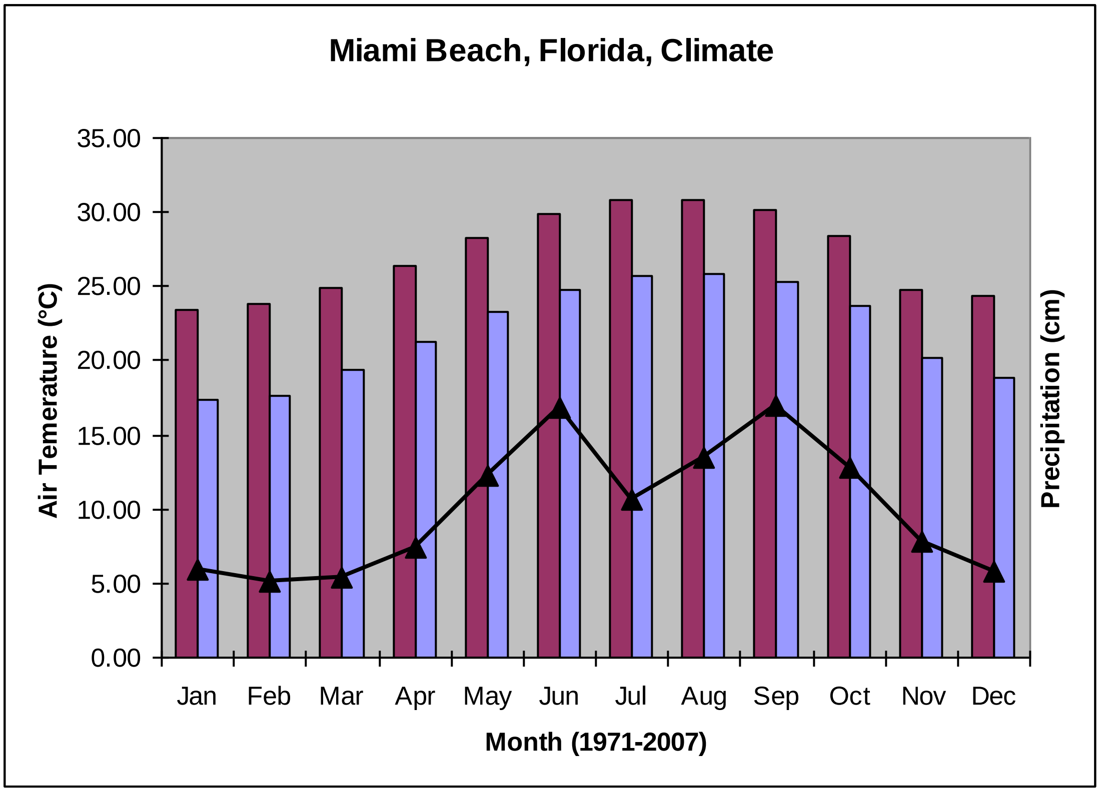

Figure 2. Minimum (blue), maximum (maroon) air temperature and precipitation (black line), Miami Beach, FL, Source: National Weather Service

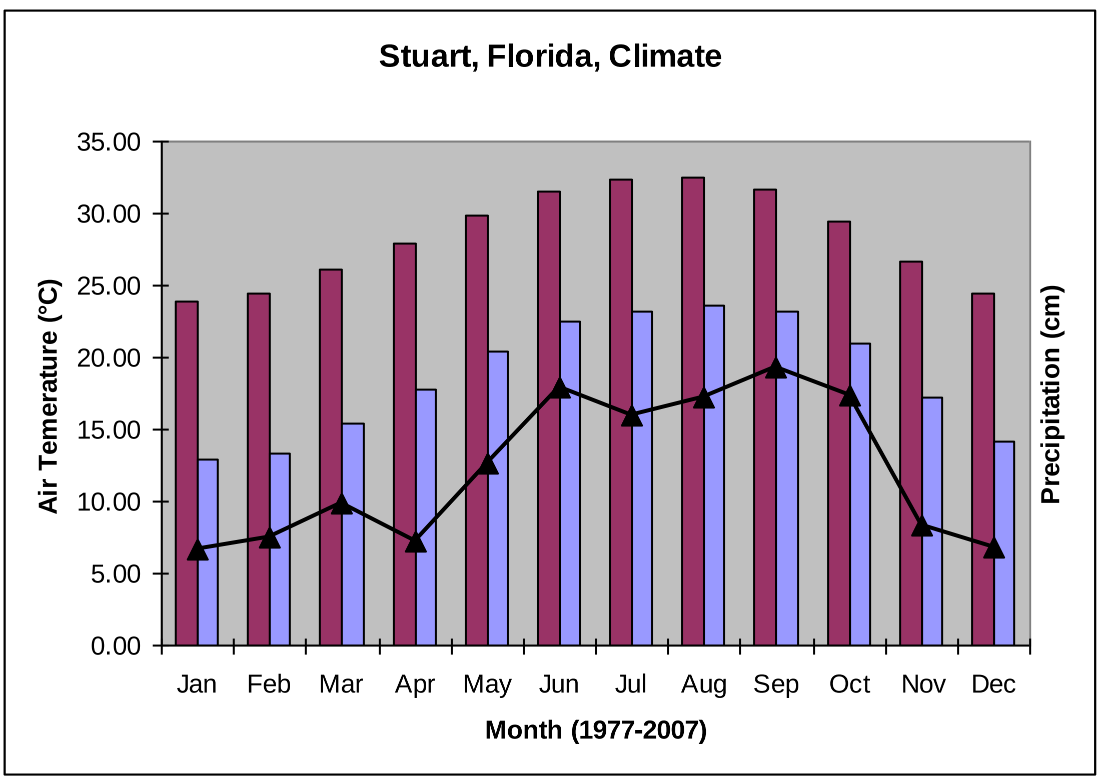

Figure 3. Minimum (blue), maximum (maroon) air temperature and precipitation (black line), Stuart, FL, Source: National Weather Service.

Seawater temperatures measured by the NOAA Ocean Buoy system show that the temperatures off Palm Beach County (Lake Worth) are18°C or less in February and March. Seawater temperatures off Broward County have a gradient that is warmer in the winter and cooler in the summer on the outer reef compared to the inner ridge; the inner ridge temperature range is 18.5° to 30.5°C and the outer reef range is 21.5° to 29.5°C (Banks et al., 2008). Moderated offshore seawater temperatures are a factor as to why there is greater biological diversity on the outer reefs. Figure 4 gives a ten-year picture of seawater temperature for Fowey Rocks Lighthouse (25°35.394'N, 80°05.790'W); the location is a bit south of the SFCRC and is the northern boundary of the Florida Keys reef system.

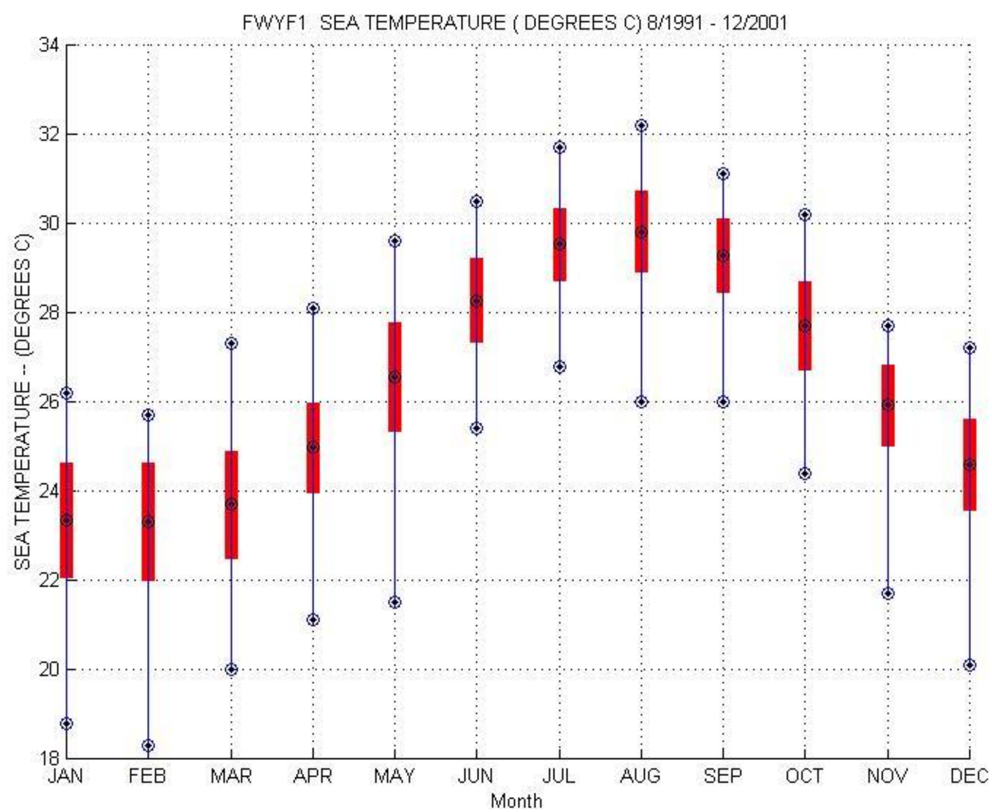

Figure 4. Seawater temperature (Mean, ± Std. dev, minimum, and maximum), Fowey Rock Lighthouse (25°35.394'N, 80°05.790'W), 1991-2001, National Ocean Buoy Program, NOAA.

The zooxanthellate Scleractinia are a reasonable proxy of latitudinal tropical species losses. Between southern Broward County and Stuart, 78 percent of all zooxanthellate Scleractinia are no longer extant (Table 2). Causative influences include the availability of epibenthic habitat, cooler temperatures, and the deflection of the Gulf Stream to the east. The Gulf Stream hugs the coast from Miami-Dade to Palm Beach; however, it veers away from the coast north of Palm Beach (26° 40'N). It is confined in the Straits of Florida between the Florida peninsular land mass and the greater and lesser Bahamas Banks (Figure 1). Once north of the Bahamas Banks, the Coriolis effect forces the Gulf Stream eastward.

Table 2. Species richness of zooxanthellate Scleractinia as a function of latitude.

Location	Latitude	Nautical Miles (km) North, measured from Biscayne National Park	Number of Zooxanthellate Scleractinian species
Biscayne National Park	25° 23'N	0 (0)	28
Miami Dade County	25° 50'N	27 (50.0)	24
Broward County	26° 06'N	43 (79.6)	28
Palm Beach County	26° 42'N	79 (146.3)	25
Martin County	27° 09'N	106 (196.3)	8
North of Martin County to Cape Hatteras, N. Carolina	27°N to 35° 13'N	N/A	4
Grand Bahama	26° 30'	67 (124.1)	31

Life cycle phenomenon

Plants and animals display varying degrees of fidelity to the coral reef communities. Some are lifelong residents and some are transients; they may be in the reef community on a seasonal basis, while others may be present during a specific portion of their life history. Some mobile residents may find shelter in the daylight hours and forage away from the reef at night. The Gulf Stream current plays a meaningful role in the transport and distribution of the eggs, sperm, and larvae of reef animals. In the case of an animal with a long life span, fertilized eggs may be transported from the Caribbean and Central America and develop into a larvae while in transit. At metamorphosis, a tidal or lunar signal beckons the larvae to ride the tide currents into a coastal bay or lagoon where they mature and become juveniles. They are driven by instinctual or lunar stimuli to move from the lagoon to the offshore reef where they find residence. This life history is characteristic of some reef fish and the spiny lobster.

Sessile or attached animals exhibit reproductive strategies that resemble flowering plants. They may spawn once per year or multiple times; gametes are released into the water column (the stimulus is lunar) and fertilized eggs develop into a mobile larva. The larvae settle locally or are transported to another reef. Upon finding suitable hard substrate, they settle and undergo a metamorphosis into the adult form. Sponges, octocorallian and scleractinian corals typically follow this pattern.

Marine turtles have a long life span and some species are found in the reef during specific time periods (Meylan, 2006; Meylan and Redlow, 2006). Sea turtles deposit fertilized eggs on a beach, seaward of the highest tide; the nest beach is typically the same beach where that turtle was born. After hatching, the young turtles scramble back to the sea. They hitchhike on the Gulf Stream and other currents from Florida, to Europe, back to the Caribbean, and finally back to Florida. They feed on the plants and animals in current drift communities, such as *Sargassum, Sargassum* resident fauna, and jellyfish. Turtles, such as the hawksbill, take up residency on a reef and find food (sponges) and places to rest. Mating occurs on or near the reefs, and then the turtle goes ashore to lay her eggs.

Integrity of the ecosystem is important in supporting the reef communities. The life cycle of many species of highly sought after reef fish are dependent on multiple habitats. The previous discussion pointed out the importance of the bays and lagoons as nursery habitat for fish and lobster. Urbanization, port development, and watershed alteration degrade the quality of the estuarine habitat.

Changes in the natural systems of South Florida

There are very old and large star coral (*Montastraea annularis* complex) colonies situated off Broward County. These colonies retain historical information about growth rates, salinity, and seawater temperature. The oldest coral sampled (cored and x-rayed) thus far dated to 1694 (Helmle et al., 2008). Coral growth rates were stable from the 1700s to about 1940 with few indications of stress (indicated by very narrow and dense calcium carbonate precipitation; nominally referred to as a stress band). From 1940 until 1970, growth was remarkably reduced compared to the previous period. This 30-year time span coincided with the draining of the Everglades and Lake Okeechobee watersheds. The US Army Corps of Engineers dredged canals and diverted the majority of the freshwater east, draining water from the Kissimmee River, Lake Okeechobee, and the Everglades from 1940 to 1960. Canals released the water into the Indian River Lagoon, and from there it was carried by the tides out into the Atlantic. Old corals have a historical record that is consistently observed (Helmle et al. 2008). The combination of reduced salinity, increased turbidity, and deleterious water quality reduced the growth of the corals during this 30 year period. Since 1970, the growth record trend in the corals is on the increase. However, there is a greater frequency of stress banding that is linked to coral bleaching through hyperthermic stress (Helmle et al., 2008).

Economic importance of the coral reefs to the region

Coral reefs are important to the economy of southeast Florida. Fishing, boating, and diving are all closely tied to healthy and vibrant coral reefs (Table 3). A comprehensive economic study of southeast Florida coral reefs was published by Johns et al. (2001). In their report, users in Palm Beach County spent over 2.8 million person-days on the natural reefs off the coast of the county. The market economic impact on the county totaled $357 million in sales, generated $142 million in local income, and supported 4,500 jobs (Johns et al., 2001). The reefs off Palm Beach County had a net annual user value of over $42 million. In Broward County, users spent about 5.5 million person-days on the natural reefs, with market economic impacts for the county of over $1.1 billion in sales, generating $547 million in local income, and supporting 19,000 jobs (Johns et al., 2001). The reefs off Broward County had a net annual user value of over $23 million. In Miami-Dade County, users spent almost 3 million person-days on the natural reefs, which had market economic impacts in the county of $878 million in sales, generated $419 million in income locally, and supported 13,000 jobs. The reefs off Miami-Dade had a net annual user value of almost $47 million. Residents of southeastern Florida are active users of the marine environment; in the 2004-2005 fiscal year there were 173,870 boat registrations (167,822 pleasure and 6,048 commercial) (Florida Statistical Abstract, 2006) and 74,454 saltwater fishing licenses (67,777 recreational and 6,677 commercial) (FWC license sales data, personal communication) in Martin, Palm Beach, Broward, Miami-Dade, and Monroe counties.

Table 3. Coral reef habitat estimates and economic value, Florida, east coast (Johns et al., 2001).

Region (county)	Habitat area (hectares)	Capitalized Value (Billions of 2001 $)	Annual usage (person days, millions)
Palm Beach	12,000	1.4	2.83
Broward	8,300	2.8	5.46
Miami-Dade	7,200	1.6	6.22
Monroe	115,290	1.8	3.64

Primary Natural Features

Coral reef systems off Martin, Palm Beach, Broward, and Miami Dade counties.

The primary natural features are coral reefs extending from Cape Florida to Riviera Beach (25°35'N to 26°46'N) and an isolated reef system south of the St Lucie Inlet (27° 06'N to 27° 08'N). The system of reefs that occupy the continental shelf between Miami and Palm Beach off southeastern Florida is documented geologically in Banks et al. (2007). A regional reef Geographic Information System (GIS) mapping effort can be found in Walker et al. (2007). In sum, they found that reefs developed in the Holocene (past 100,000 years), flourished, and then went into a non-accretion mode that left the reef edifice or structure in place. Depending upon the latitude, the geomorphology may include inner, mid, and outer reef complexes, and a near-shore ridge (Figures 5, 6, and Table 4).

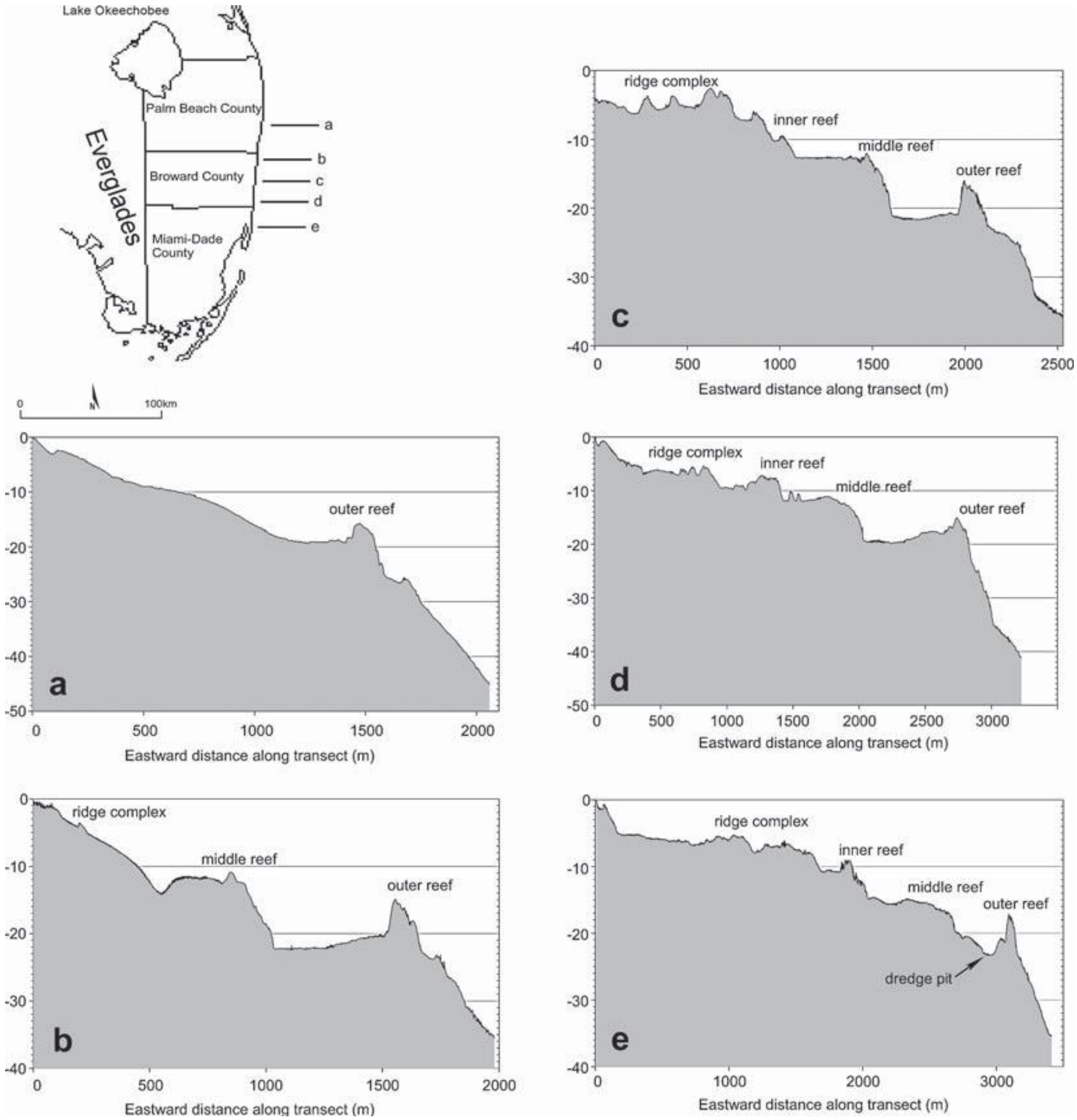

Figure 5. Reef structural profiles, Miami-Dade, Broward, and Palm Beach counties (Banks et al., 2007).

Table 4. Reef complex configuration off SE Florida after Banks et al. (2007).

Location	**Latitude (N)**	**Ridge complex**	**Inner reef complex**	**Middle reef complex**	**Outer reef complex**
Mid Palm Beach	26°46’	Not present	Not present	Not present	Present
North Broward County	26°12’	Present	Not present	Present	Present
Mid Broward County	26°09’	Present	Present	Present	Present
South Broward County	26°01’	Present	Present	Present	Present
Miami Dade	25°40	Present	Present	Present	Present

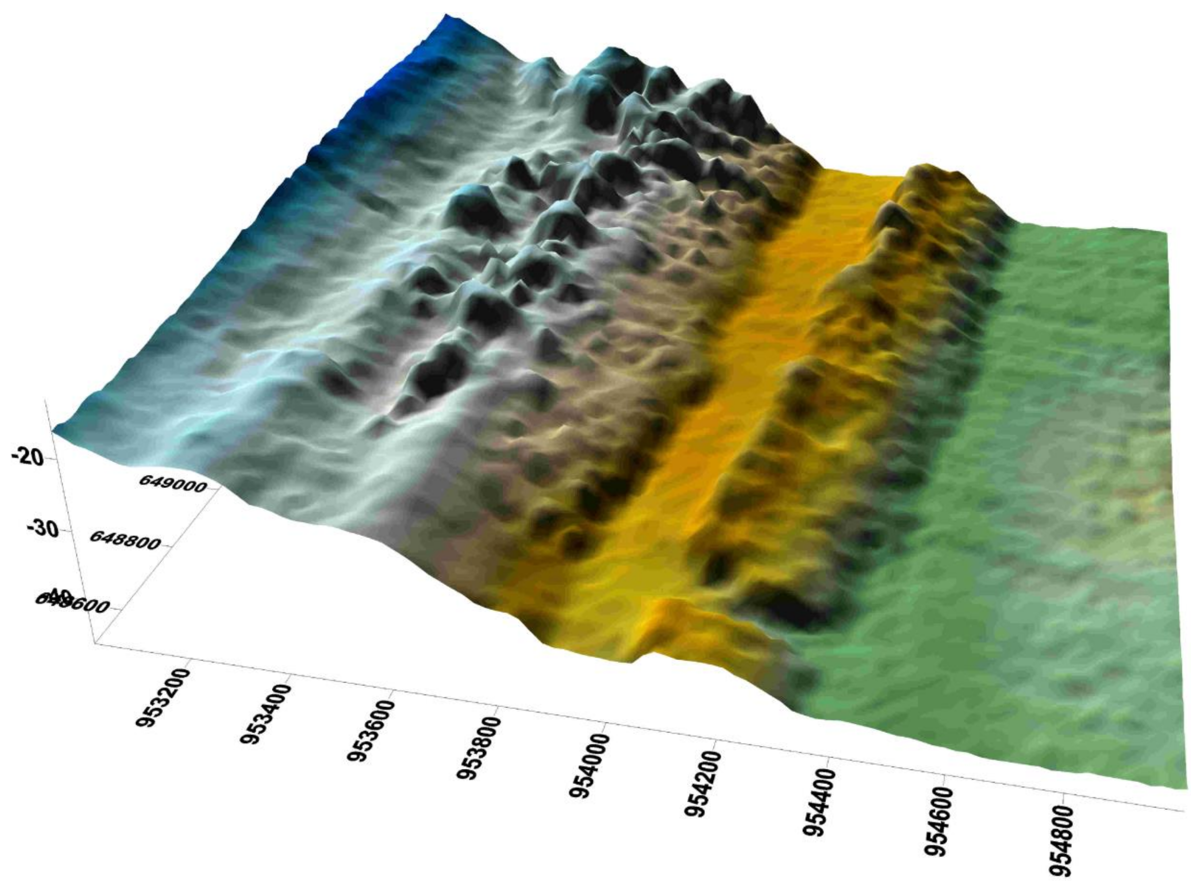

Figure 6. Laser airborne depth sounder (LADS) map of the Broward reef system, north of Port Everglades shipping channel. Outer reef, far right, inner reef far left. Figure courtesy of National Coral Reef Institute, NOVA.

The outer reef is approximately 16 m below sea level. Coring and excavation reveal that the outer reef framework is a relic *Acropora palmata* (elkhorn coral) barrier reef (Macintyre and Milliman, 1970; Lighty, 1977; Lighty et al., 1978). Structural features along the outer reef, such as spur and grooves, imply that the outer reef was a barrier reef and that *A. palmata* was the principal structural component; however, *Acropora cervicornis* (staghorn coral) debris (Figure 7) was found in some locations (Banks et al., 2007).

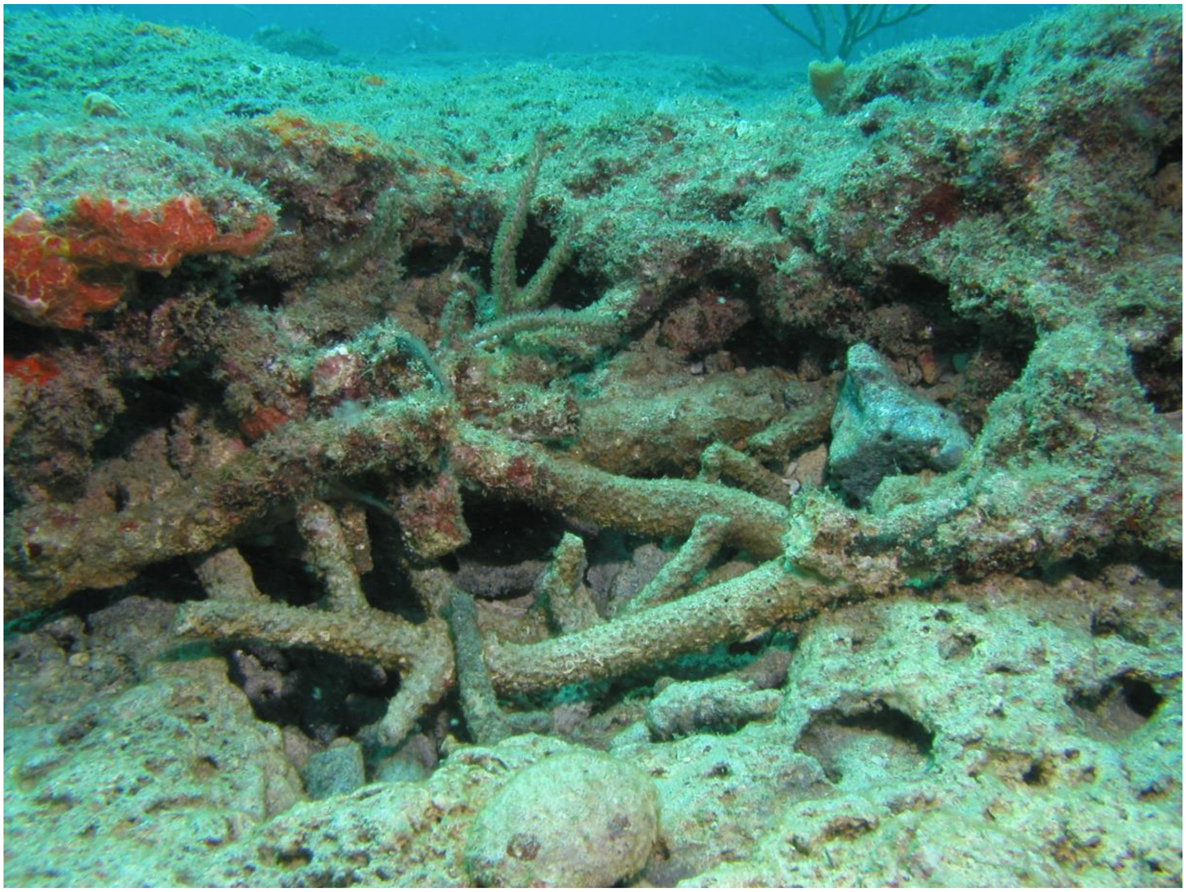

Figure 7. Middle reef, relic *Acropora cervicornis* debris, *Alam Senang* grounding site, Broward County.

Carbon dating of the *Acropora* skeletal materials is 8,000 to 7,000 YBP (Banks et al., 2007). Gaps and channels are interpreted as either collapsed reef structure or channels created by erosion processes, paleo inlets, and river channels (Banks et al., 2007). There are several man-made cuts through the reef structures, most notably Government Cut, Port of Miami shipping channel, and Port Everglades shipping channel. These were dredged to facilitate deep draft vessels' access to the port.

Banks and colleagues (2007) postulated that in the late Pleistocene to early Holocene (250, 000 to 100,000 years before the present) sea level was receding exposing the coastal sand ridges. In early Holocene times, sea level began to rise from glacial melt, and the hardened sand ridges were recruited by coral larvae forming the outer reef. At this time, the middle reef may have been the shoreline. As sea level continued to rise, the outer reef was in depths that became light starved, at which point the outer reef ceased to accrete. However, the middle reef took its place as an active site for coral growth. As more time passed and the sea level continued to rise, the inner reef became the principal area of coral reef accretion. At about 3.5 thousand years before the present, coral reef accretion ceased off the southeast Florida coast. Researchers are not sure what caused this demise. The principal coral that built the reefs (*Acropora* spp.) has a fossil record of boom and bust population dynamics (Boulon et al., 2005). It is thought that rising sea level may have flooded the inshore bays and lagoons resulting in a localized water quality (salinity, nutrients, turbidity) perturbation. These waters would have been carried by tides to the reef areas.

Seaward of the outer reef complex, seafloor depth slopes from the outer reef in a series of steps to 80 m; here the steeper gradient, or Florida Escarpment, descends to a depth of 200 to 375 m to the Miami Terrace (Banks et al., 2008).

Biological communities

The first quantitative community reef assessment in the region is Goldberg's (1973) study off Boca Raton. He described the octocoral-dominated reef and noted 24 Scleractinian coral species. Courtney et al. (1974) also provided some insights to coral reef communities off Broward County and their susceptibility to beach renourishment projects. The most comprehensive ecological survey on southeast Florida coral reefs is the Moyer et al. (2003) study of four areas (termed "corridors"); each separated by about 8 km distance (Table 5) covering Broward County (25°58'N to 26°18'N). Each corridor was approximately 3.1 km^2; the study included Laser Airborne Directed Sonar (LADS), bathymetric mapping, and diver line point intercept transect surveys. Transects were 50 m long and paralleled the depth contour, N-S.

Table 5. Comparison of biological characteristics, Broward County reefs (Moyer et al., 2003)

Corridor	No. of Species/transect	Ridge complex	Inner Reef	Middle Reef	Outer Reef
1: North	19-36 (total 57)	Octocorals 5%	N/A	Octocorals 21%	Benthic algae (20%) Octocorals (32%)
2	12-33 (69)	Octocorals 11 to 29%	Sponges (10%)	Macro algae (24%)	Benthic algae (16%)
3	22-34 (74)	Octocorals (17%), Scleractinia (13%)	Benthic algae (25%)	Benthic algae (33%)	Benthic algae (33%)
4 South	20-36 (79)	Octocorals (15%)	Benthic algae (16%),	Benthic algae (29%)	Octocorals (20%), Sponges

			Zoanthids (13%), Octocorals (12%)		(14%)

Moyer's group (2003) basically concluded that

- The percentage cover of the dominating benthic organisms is spatially variable,
- Percentages of live coral increase seaward,
- In the north, sponges are the dominant organisms on the ridge complex,
- Octocorals and Scleractinian corals dominate the ridge complex in the south,
- Benthic algae, massive sponges, and octocorals are the most common animals in the outer reef communities, and
- Mixtures of faunal groups with inconsistent fidelity occupy the inner and middle reef communities.

These reefs are in a non-accretionary mode; however, they are rich in biological diversity (Figure 8). The abundance of sponges and octocorals is a prominent feature. Barrel sponges (X*estospongia muta*) are the largest of the sponges and typically exceed the size of the zooxanthellate Scleractinia colonies. *Pseudopterogorgia* octocorals may attain a height of a meter. The ZS are common on the middle and outer reefs.

A faunal survey in a ship grounding reported that sponges constitute 52.83%, octocorals 35.22%, and stony corals 11.95% of the epibenthic community (Jaap, 2006). Proportions are based on the density (m^2) reported for these groups. Density data from 64 m^2 of reef habitat in and around the *Federales Pescadores* grounding site showed sponge colony density was 4.20 colonies m^2, octocoral colony density was 2.80 m^2, and stony coral colony density was 0.95 m^2. The most common of the ZS on these reefs are *Siderastrea siderea* (starlet coral), *Colpophyllia natans* (boulder brain coral) (Figure 9), *Dichocoenia stokesi* (eyelet coral), *Solenastrea bournoni* (smooth star coral) (Figure 10), *Diploria clivosa* (knobby brain coral), and *Montastraea cavernosa* (giant star coral) (Figure 11).

Acropora palmata (elkhorn coral) the major reef building species in times past, is very rare in the SFCRC. A few colonies are known from Broward County (Figure 19); however, they do not seem to be forming a reef. *Acropora cervicornis* (staghorn coral) is more common and is known to exist off Palm Beach as well as Broward County. These species are at the northern limit of their comfort zone; an extremely cold winter or hurricane could extirpate them. However, their existence in this area is not an example of global warming facilitating latitudinal expansion; they are known from previous studies to have existed in the area for decades.

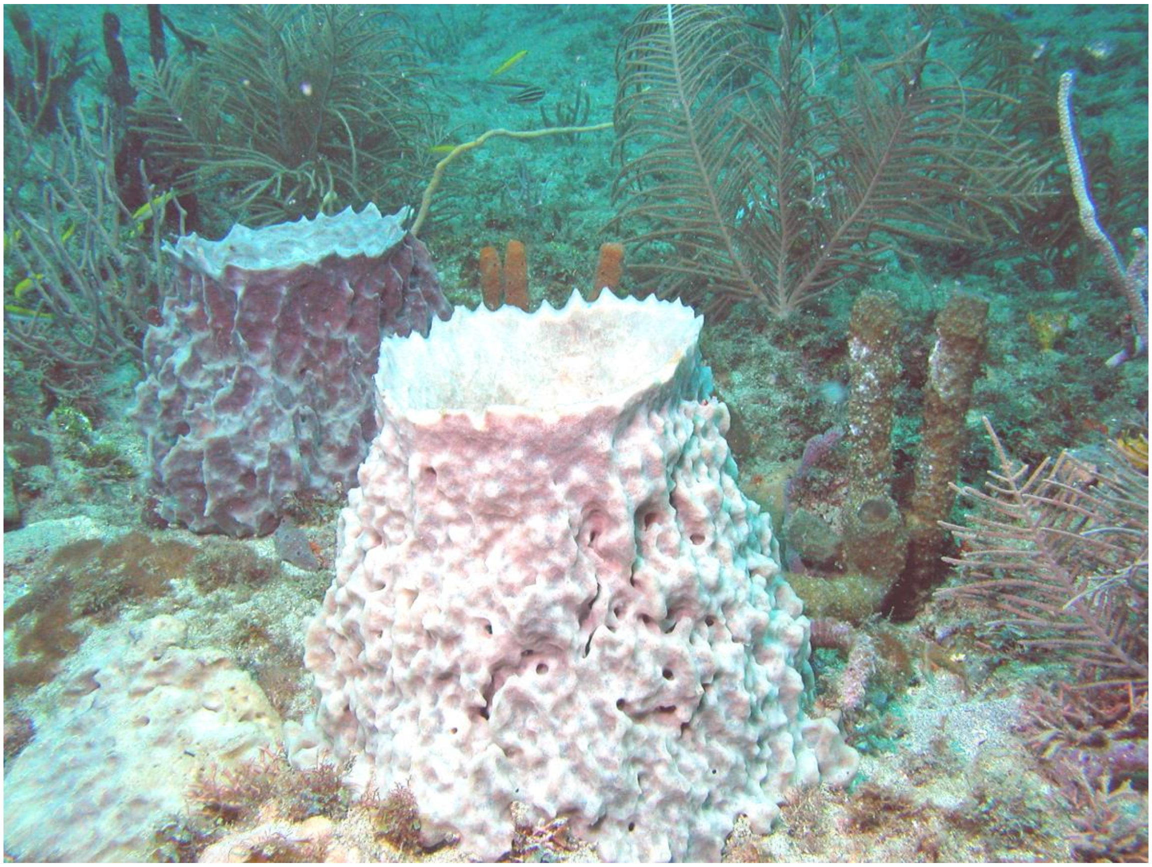

Figure 8. Middle reef area, Broward County; X*estospongia muta* (barrel sponge) in foreground; *Pseudopterogorgia* octocorals (sea plumes) in the background.

Benthic cover for the un-colonized rock, benthic algae, Porifera, Octocorallia, and Scleractinia document the nature of the reefs. The pattern is relatively consistent; most of the bottom is not occupied by corals (Figure 12). Since the substratum is typically limestone with a veneer of turf algae, sponges, octocorals, and Scleractinian corals are not major components. The exceptions are a staghorn coral patch with 40% coral cover and another site on the ridge complex with 12% coral cover of massive *Montastraea* and *Diploria* colonies (Banks et al., 2008).

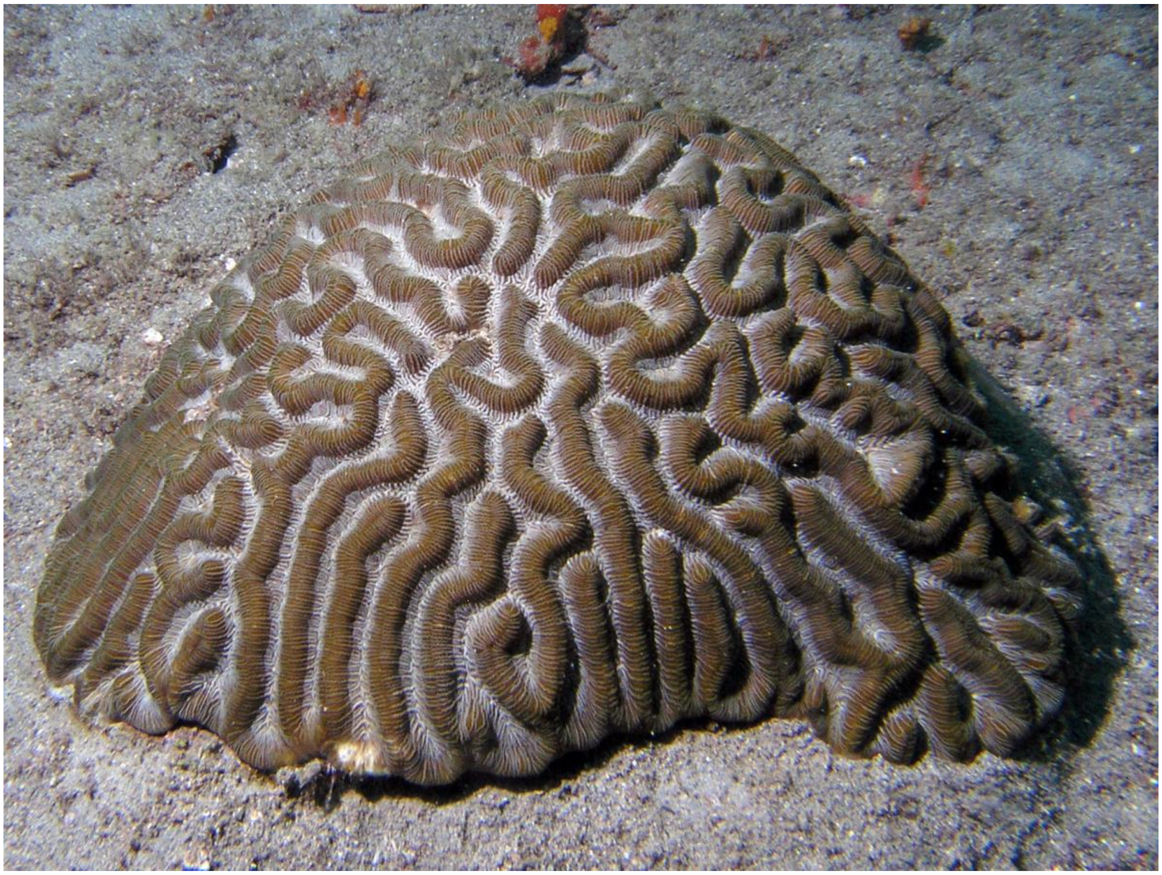

Figure 9. Boulder brain coral, *Colpophyllia natans*, middle reef, Broward County.

Figure 10. *Solenastrea bournoni*, smooth star coral, middle reef, Broward County.

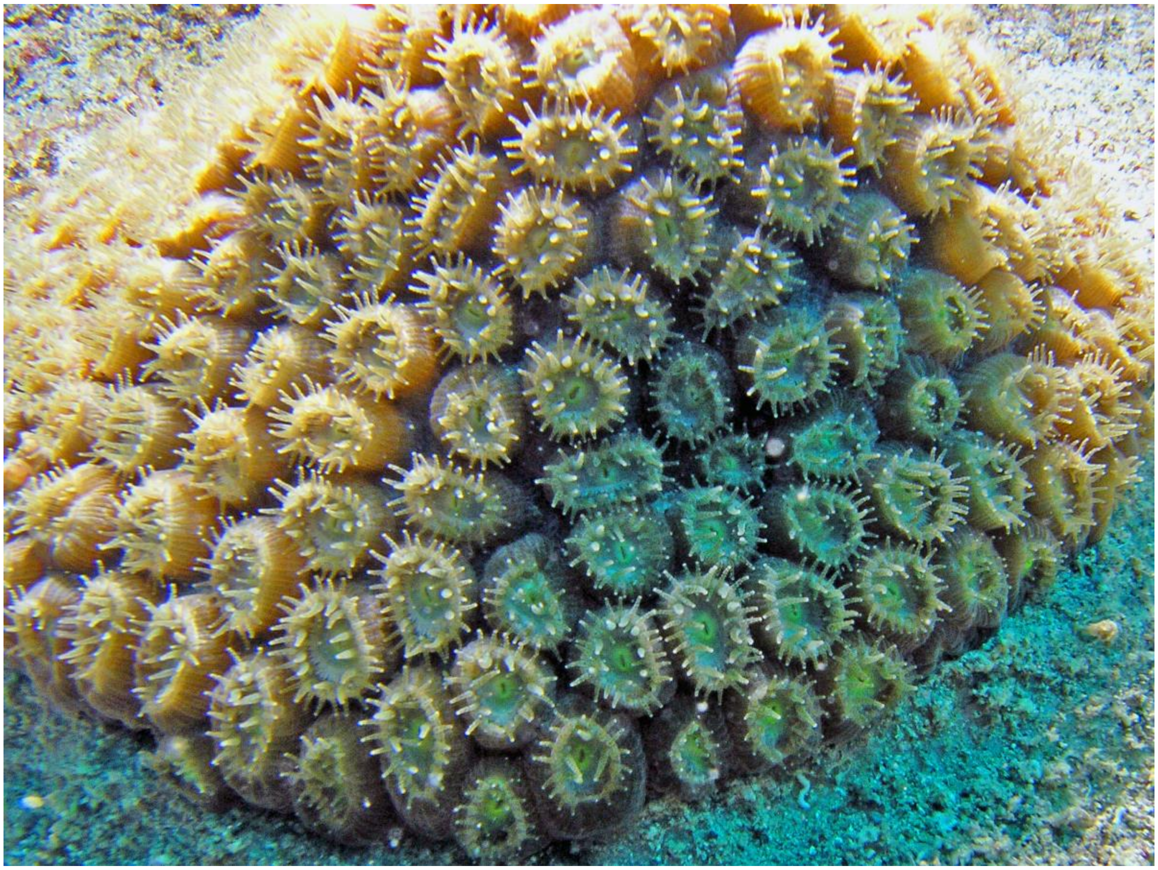

Figure 11. Giant star coral, *Montastraea cavernosa*, middle reef, Broward County. Note the polyps are open and tentacles extended.

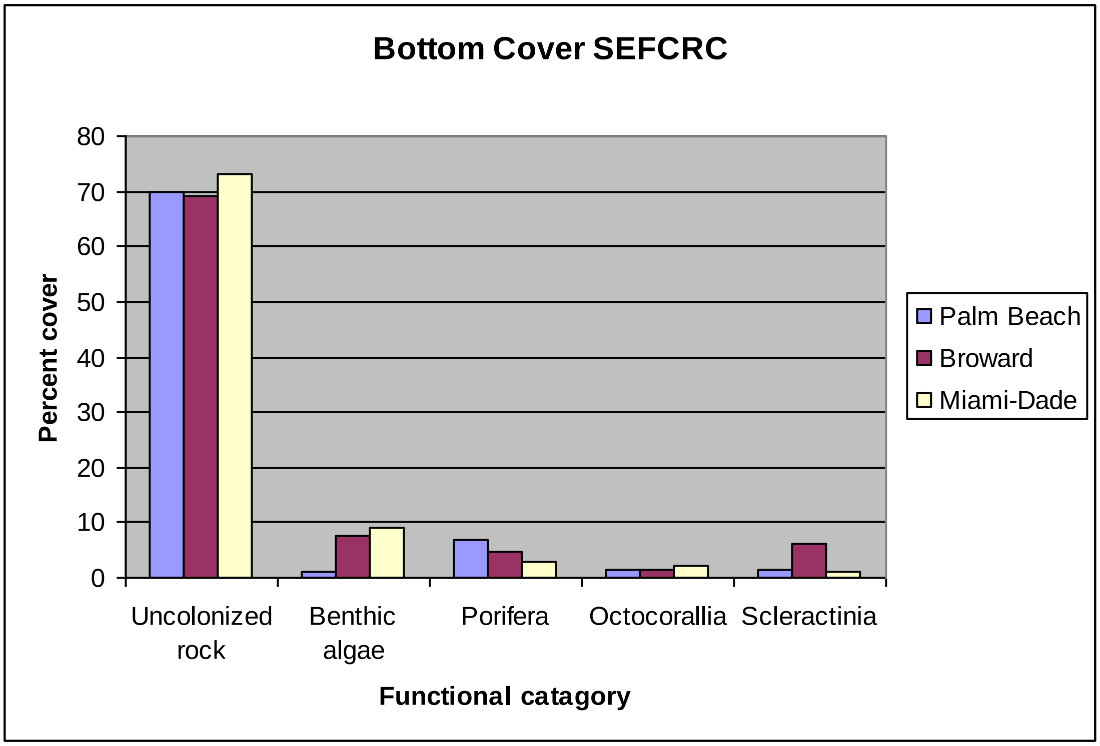

Figure 12. Benthic cover, SFCRC, data from: Moyer et al., 2003; FWCC, 2006; Foster et al., 2006.

Currently, there are 47 zoozanthellate (ZS) species at Dry Tortugas, 38 at Looe Key, 28 in Biscayne National Park, 24 in the area north of Government Cut (Miami harbor channel) in Miami-Dade County, 28 off Broward County, 25 off Palm Beach County, and 8 in Martin County on the reefs south of the St. Lucie Inlet (Table 6). North of the St. Lucie Inlet to Cape Hatteras, the ZS fauna is sparse: *Stephanocenia intersepta* (blushing coral), *Leptoseris cucullata* (delicate lettuce coral), *Solenastrea Hyades* (knobby star coral), and *Cladocora arbuscula* (tube coral) are reported.

Table 6. List of zooxanthellate Scleractinia, Miami-Dade (MD, north of Government Cut), Broward (B), Palm Beach (PB), and Martin counties (M). Multiple sources include Banks, 2008; Monte, 2008; Jaap, unpublished.

Species	**MD**	**B**	**PB**	**M**
Stephanocenia intersepta	xx	xx	xx	xx
Madracis decactis	xx	xx	xx	xx
Madracis mirabilis		xx	xx	
Madracis pharensis		xx		
Acropora cervicornis		xx	xx	
Acropora palmata		xx		
Agaricia agaricites	xx	xx	xx	
Agaricia fragilis	xx	xx		
Agaricia lamarcki	xx	xx		

Leptoseris cuculata		xx		
Siderastrea radians	xx	xx	xx	xx
Siderastrea siderea	xx	xx	xx	xx
Porites astreoides	xx	xx	xx	xx
Porites porites	xx	xx		xx
Favia fragum				??
Cladocora arbuscula	xx	xx		
Colpophyllia natans	xx	xx	xx	
Diploria clivosa	xx	xx	xx	xx
Diploria labyrinthiformis	xx	xx	xx	
Diploria strigosa	xx	xx	xx	xx
Manicina areolata		xx		
Montastraea annularis	xx	xx	xx	xx
Montastraea cavernosa	xx	xx	xx	xx
Solenastrea bournoni	xx	xx	xx	xx
Oculina diffusa	xx	xx	xx	xx
Oculina varicosa				xx
Dendrogyra cylindrus		xx		
Dichocoenia stokesi	xx	xx	xx	xx
Meandrina meandrites	xx	xx	xx	xx
Isophyllia sinuosa				xx
Mussa angulosa		xx	xx	
Mycetophyllia aliciae			xx	xx
Mycetophyllia lamarckiana	xx			
Scolymia cubensis	xx	xx	xx	xx
Scolymia lacera	xx		xx	
Cladocora arbuscula	xx		xx	
Eusmilia fastigiata	xx	xx	xx	
Astrangia pulchellus		xx	xx	
Phyllangia americana				xx
Tubastrea coccinea		xx		
Millepora alcicornis	xx	xx	xx	xx
Stylaster rosea	xx	xx		
Totals	**27**	**34**	**26**	**20**

Multivariate, MDS ordination (Figure 13) and cluster analysis (Figure 14) document that the geographic areas Miami-Dade, Broward, and Palm Beach are relatively similar (75% or>) whereas Martin County is distinctly different, based on the presence or absence of ZS species (Figures 12 and 13).

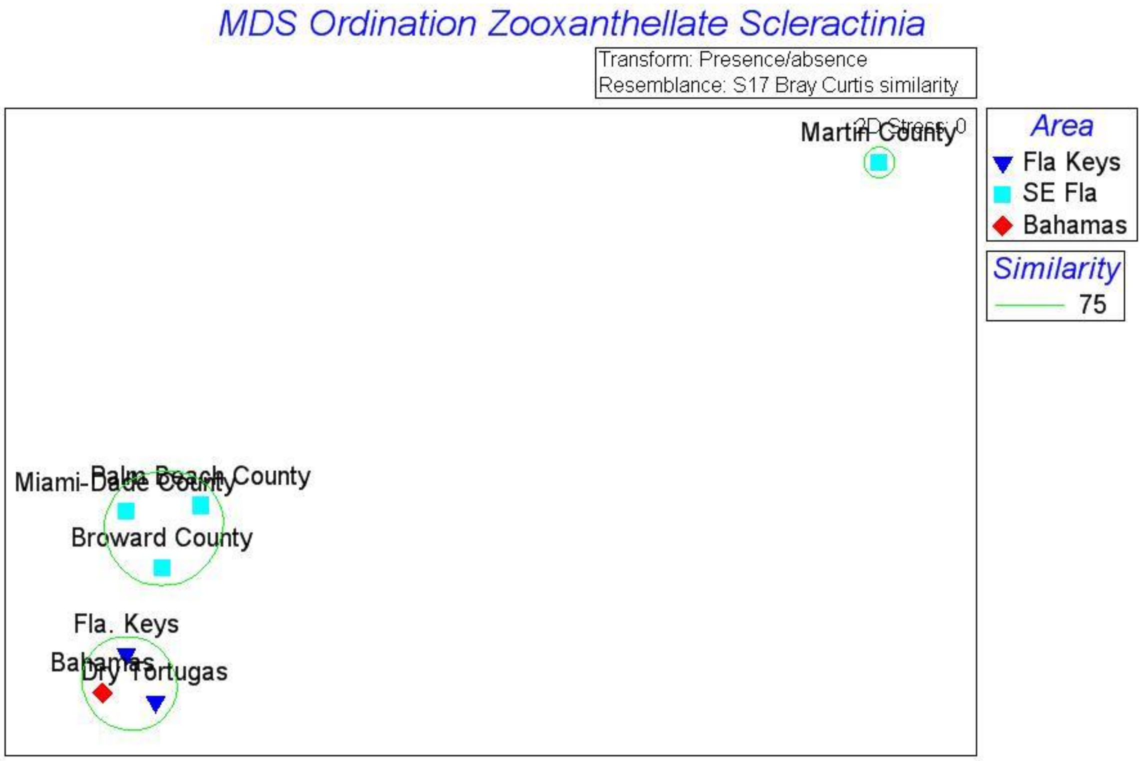

Figure 13. Ordination by non-metric multidimensional scaling (MDS) of Bray-Curtis similarities presence/absence of Zooxanthellate Scleractinia, SE Florida, Dry Tortugas, Florida Keys, and Bahamas.

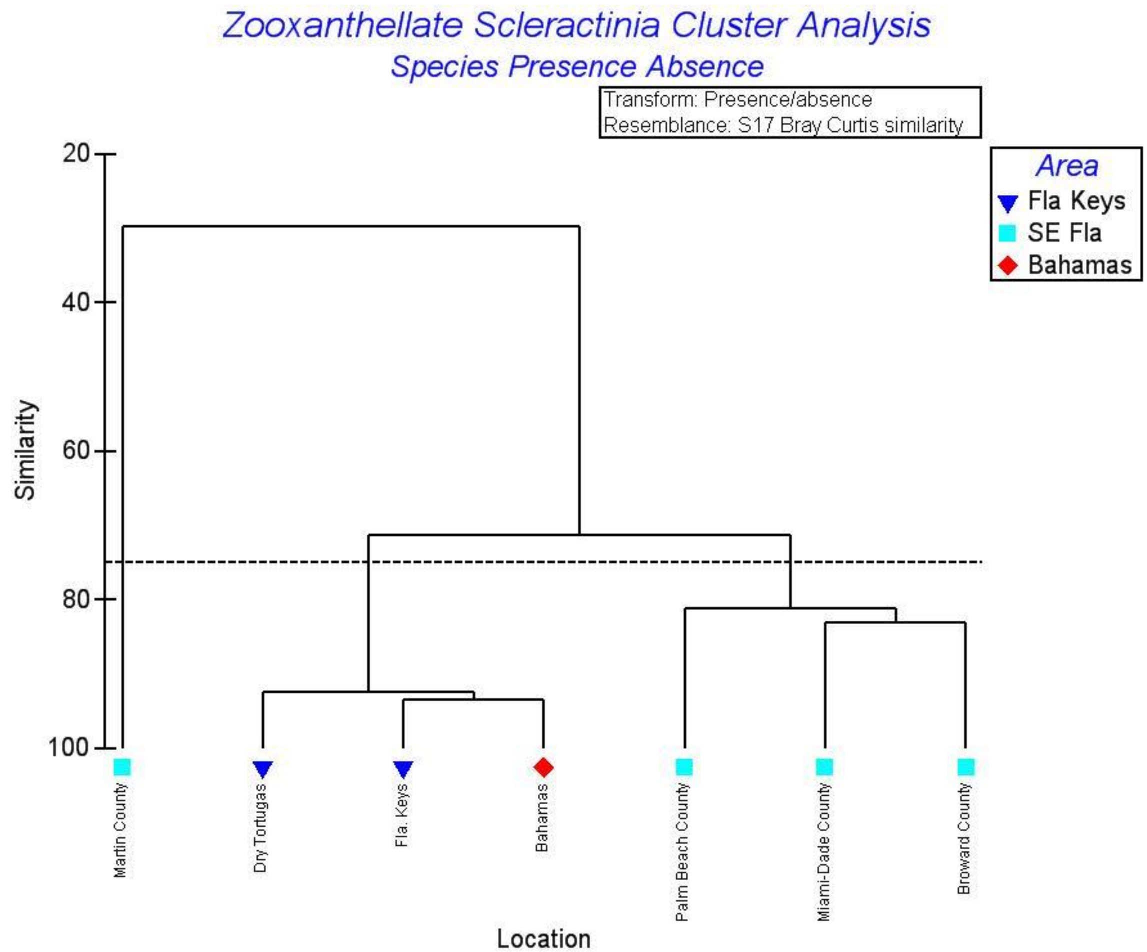

Figure 14. Clustering using group average sorting of Bray-Curtis similarities presence/absence of Zooxanthellate Scleractinia, SE Florida, Dry Tortugas, Florida Keys, and Bahamas. Dashed line is an arbitrary 75 % similarity slice.

In 2003, a long-term coral reef monitoring program was established in Martin, Palm Beach, Broward, and Miami-Dade counties (FWC and NCRI, 2007). Three sampling sites were established each in Martin, Palm Beach, and Miami-Dade counties and four in Broward County (Figure 15, Table 7). Sites are monitored annually with replicate sampling stations at each site. Sampling was initiated in 2003 for all sites with the exception of Martin County; sampling was initiated there in 2006. Data collected includes stony coral species richness and benthic cover of functional groups (substrate, benthic algae, sponges, octocorals, zooanthids, and stony corals). Other information is collected but will not be discussed here. Sites were selected at inshore, middle, and offshore reefs; however, in Martin County, all sites are along the St. Lucie Reef in equivalent depths (4.6m).

Site	Latitude (N)	Longitude (W)	Depth (m)
Martin 1	27°07.900’	80°08.042’	4.6
Martin 2	27°06.722’	80°07.525’	4.6
Martin 3	27°07.236’	80°07.633’	4.6
Palm Beach 1	26°42.583’	80°01.714’	7.6
Palm Beach 2	26°40.710’	80°01.095’	16.8
Palm Beach 3	26°42.626’	80°00.949’	16.8
Broward A	26°08.985’	80°05.810’	7.6
Broward 1	26°08.872’	80°05.758’	7.6
Broward 2	27°09.597’	80°04.950’	12.2
Broward 3	26°09.518’	80°04.641’	16.8
Miami-Dade 1	25°50.530’	80°06.242’	7.6
Miami-Dade 2	25°50.520’	80°05.704’	13.7
Miami-Dade 3	25°50.526’	80°05.286’	16.8

Table 7. Geographic coordinates and depths of coral reef monitoring sites, SFCRC (FWCC and NCRI, 2007)

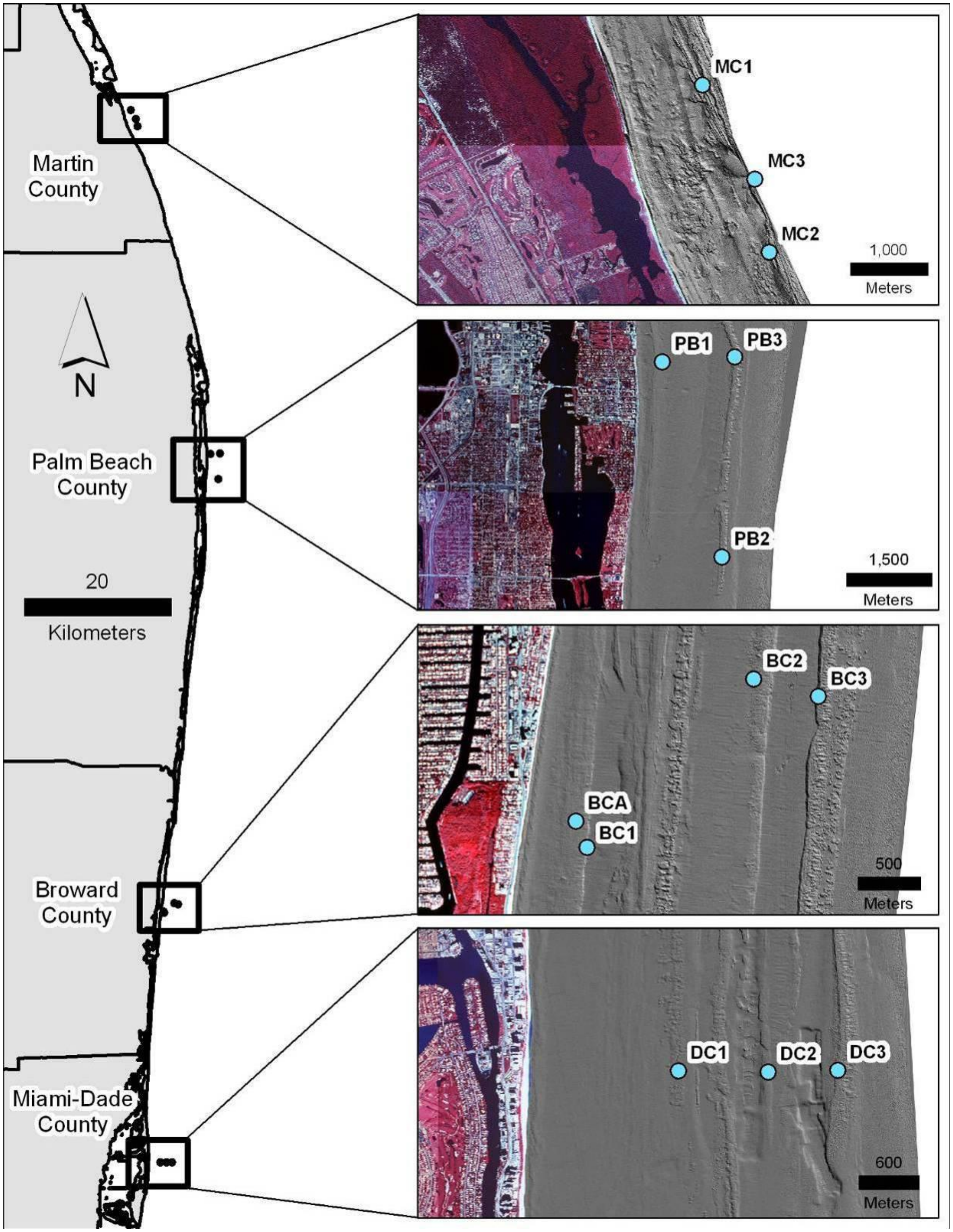

Figure 15. Coral reef monitoring sites, SFCRC (FWCC and NCRI, 2007)

Coral cover for most sites has remained stable and is in the range of 0.5 to 13.0% (mean values); the *Acropora cervicornis* (staghorn coral) site (BC-A) is an exception. In 2003, the cover was 31.7%; in 2004, 39.6%; in 2005, 39.8%; but in 2006, it decreased to 25.4% (FWCC and NCRI, 2007). The 2006 coral cover loss at BC-A was attributed to a decrease of unknown causes in the *A. cervicornis* population. Overall, the functional group status and trends document that substrate category ranks highest in cover, followed by benthic algae and octocorallia.

St Lucie Reef

The reef south of Stuart (St. Lucie Inlet Preserve State Park) is a narrow structure that is situated approximately 1.5 km east of the beach. The foundation of the reef is formed by multiple ridges of Anastasia limestone and isolated rock outcroppings inshore of the ridges. A cliff or escarpment is typically found at the seaward face of the reef, including irregular channels and depressions. The park encompasses 3,900 acres of seafloor including the reef system (Monte, 2008). The St. Lucie Inlet reef system is the northernmost shallow water reef system on the continental shelf of North America with reasonable numbers of zooxanthellate Scleractinia (Table 6) and associated Caribbean coral reef flora and fauna. Another interesting aspect of the St. Lucie reef is the presence of organisms that are unusual or rare on Caribbean coral reefs: the reef building polycheate, *Phragmatopoma caudate,* and the ascidians *Ascidea niger* and *Eudistoma obscuratum*. Macro algae of a tropical nature are common: *Dictyota* spp., *Halimeda discoidea*, and *Padina sanctaecruis* (Monte, 2008). There is also a persistent population of the long, black-spine sea urchin, *Diadema antillarum*. St. Lucie Inlet reef Scleractinian coral cover is around 1.5%; the majority is provided by the brain coral *Diploria clivosa* (FWC & NCRI, 2007). This reef system is being intensely studied with multiple monitoring programs: SECREMP, Resilient Reef Program, benthic species monitoring program, and REEF protocol fish surveys. Benthic surveys documented 160 species of algae and invertebrates (Monte, 2008). The park has an active marine management program fostering education, vessel mooring systems, and a marine debris removal program (Monte, 2008).

North of the St. Lucie inlet, hard bottom is far less prominent (Perkins et al., 1997). In shallow water, worm reefs (*Phragmatotoma*) become a prominent biological feature (Jaap and Hallock, 1990). In deeper areas off the east coast, *Oculina varicosa* (fused ivory tree coral) builds reefs that are as deep as 70 m (Jaap and Hallock, 1990; Reed, 2000; Reed et al., 2003). This species is zooxanthellate in shallow depth and azooxanthellate in deeper waters. Because these systems are more temperate, they will not be evaluated further in this report.

Reef fish communities

At least 350 fish species are reported for the coastal area of Broward and Miami-Dade counties, and 400 species are reported for Palm Beach County (Banks et al., 2008). There are 265 species of fish seen in the St. Lucie Inlet Preserve State Park; this is a cumulative number based on multiple surveys (Monte, 2008). Fish species are typical of Caribbean-Bahamian reef fish fauna. In the Broward County reefs, abundance and diversity is greater on the offshore reef complex. Juvenile grunts (Haemulidae) favor the inshore ridge and reef complexes; in the middle and outer reefs, the most common groups are wrasses (Labridae) and damselfish (Pomacentridae) (Jordan et al., 2004; Banks et al., 2008). The more abundant species differ between the northern and southern reefs in Palm Beach County (Table 8).

Table 8**.** Fish census data, REEF protocol of frequency (% of samples) that fish species were observed off north and south Palm Beach County reefs (Banks et al., 2008). The data set included 2,440 fish surveys at 109 sites.

Scientific name	Common name	North	South
Acanthurus bahianus	Ocean Surgeonfish	33.2	70.8
Acanthurus chirurgus	Doctorfish	87.5	59.2
Acanthurus coeruleus	Blue Tang	47.3	86.7
Caranx ruber	Bar jack	50.2	73.6
Centropomus undecimalis	Snook	95	5.2
Chaetodon capistratus	Foureye Butterflyfish	19.5	69.7
Chaetodon ocellatus	Spotfin Butterflyfish	24.5	70.2
Chaetodon sedentarius	Reef Butterflyfish	32.5	70.6
Ansiotremus surinamensis	Black Margate	61.7	62.5
Anisotremus virginicus	Porkfish	91.6	89
Haemulon aurollneatum	Tomtate	54.2	66.1
Haemulon flavolineatum	French Grunt	78.3	77.8
Haemulon parra	Sailor's Choice	66.8	48.9
Haemulon sciurus	Bluestriped Grunt	66.4	77.6
Chaetodipterus faber	Atlantic Spadefish	73.3	36.5
Gerres cinerus	Yellowfin Mojarra	76.7	57.8
Kyphosus spp	Bermuda & Yellow Chub	69.5	36.5
Bodianus rufus	Spanish Hogfish	38	75
Halichoeres bivittatus	Slippery Dick	67.5	33.3
Halichoeres garnoti	Yellowhead Wrasse	30	67.3
Thalassoma bifasciatum	Bluehead Wrasse	79.6	58
Lutjanus apodus	Schoolmaster Snapper	68.5	31.6
Lutjanus griseus	Gray Snapper	66.8	50.7
Lutjanus synagris	Lane Snapper	63.3	23.6
Cantherhines pullus	Orangespotted Filefish	10	55.2
Pseudupeneus maculatus	Spotted Goatfish	33.6	78.9
Holocanthus ciliaris	Queen Angelfish	64.6	48.7
Holocanthus tricolor	Rock Beauty	25.8	74.5
Pomacanthus paru	French Angelfish	85	88.1
Abudefduf saxatilis	Sergant Major	85.9	86.2
Pomacentrus leucostricus	Beaugregory	73.9	32.4
Pomacentrus partitus	Bicolor Damselfish	52.4	82.3

Pomacentrus variabilis	Cocoa Damselfish	50.9	68.4
Sparisoma aurofrenatum	Redband Parrotfish	29.5	67.7
Sparisoma rubripinne	Yellowfin Parrotfish	64.2	21.7
Sparisoma viride	Stoplight Parrotfish	28.5	79.3
Equetus acuminatus	High-hat	71	63.4
Diplodus argenteus	Silver Porgy	95.3	65.7
Sphyraena barracuda	Great Barracuda	73.8	26

Dry Tortugas has 442 species of fish, 300 of which are reef fish (Longley and Hildebrant, 1941); Stark reported 517 species of fish for Alligator Reef, 389 were reef fish (Stark, 1968); Bohlke and Chaplin (1968) reported 496 species of fish for the Bahamas, 450 were reef fish. The fish reported for SFCRC are similar numbers of species (Banks et al., 2008).

A comparison of the abundances of species within families along the Florida coast from Dry Tortugas through Palm Beach County (Table 9) shows that families shift in rank with no latitudinal pattern; note, however, that Hamulidae species (grunts) are ranked number one at three of six locations.

Table 9. Comparison of the most abundant reef fish based on their family: John Pennekamp Coral Reef State Park (Jones and Thompson, 1978), Dry Tortugas National Park (Jones and Thompson, 1978), Biscayne National Park (Tilmant et al., 1979), Bal Harbor (Thanner et al., 2006), and Palm Beach Reefs (Banks et al., 2008).

Rank:	First	Second	Third	Forth	Fifth	Sixth
Dry Tortugas	Pomacentridae	Serranidae	Haemulidae	Scaridae	Chaetodontidae	Labridae
John Pennekamp State Park	Haemulidae	Scaridae	Pomacentridae	Labridae	Serranidae	Chaetodontidae
Biscayne National Park	Scaridae	Pomacentridae	Haemulidae	Labridae	Chaetodontidae	Serranidae
Bal Harbor, Boulder Mitigation Reef	Gobiidae	Haemulidae	Labridae	Scaridae	Lutjanidae	Serranidae
Palm Beach North Reefs	Haemulidae	Pomacentridae	Labridae	Lutjanidae	Pomacanthidae	Acanthuridae
Palm Beach South Reefs	Haemulidae	Pomacentridae	Labridae	Acanthuridae	Chaetodontidae	Pomacanthidae

The Bray-Curtis similarity level between the north and south Palm Beach reefs is 74.361 based on frequency of occurrence data in Table 8. This implies moderately equivalent faunal characteristics from north to south.

Secondary Natural Features

Supporting (secondary) natural features include the terrestrial watershed, mangrove, and sea grass communities. Offshore, deeper areas have connection with the coral reefs, and there are no barriers that restrict pelagic animals and propagules from moving from one area to another.

Mangrove forests are common in natural estuarine areas in South Florida. There are three primary species: red, black, and white (*Rhizophora mangle, Avicennia germinans, Laguncularia racemosa*). This summary is extracted from Odum et al. (1982). Mangroves require temperatures >19°C; they do best in low salinity situations; they do not require tidal fluctuations but have a competitive advantage in forests and swamps that alternate between flooding and drying. Mangroves will not tolerate high and consistent wave energy; they favor silt and mud soils. They are important in shoreline protection, the creation of new intertidal lands, and as habitat for plants and animals (algae, invertebrates, fish, reptiles, birds, and mammals). Mangroves sustain a complex food web, including some popular commercial and recreational species: oysters, crabs, lobsters, shrimp, and fish. Mangrove forests produce carbon through photosynthesis, and their leaf litter is important to the detritus food web, supporting fungi, bacteria, and microscopic fauna. The leaf litter epifauna are prey for small fish and invertebrates, some of which move on to become reef dwellers as adults. The root structure is important refuge habitat; juvenile invertebrates and fish avoid predators by slipping into the maze of the red mangrove prop roots or pneumatophores of the black mangrove. Mangroves also indirectly add nutrients into the estuary. Roosting birds and bird rookeries produce nitrogen feces that enter the water and may stimulate local phytoplankton blooms. This produces another small, but important food web in the mangrove system.

Sea grasses are the only obligated, totally submerged angiosperms that are found in salt water. In south Florida they are common in estuaries and coastal lagoons. This summary is extracted from Zieman (1982). There are three principal species of sea grass in southeast Florida: turtle grass, manatee grass, and shoal weed (*Thalasia testudinum, Syringodium filiforme, Halodule wrightii*). There are several other species that exist in this area, but they are uncommon. Sea grasses grow in sediments, ranging from mud to coarse sand; they do not occur in the open Atlantic due to the high wave energy and shifting sands north of Key Biscayne. In Biscayne Bay, turtle grass can have a daily growth rate of 2.5 mm., and it photosynthesizes best at 28° to 30° C. Shoal weed is more tolerant of cooler temperatures. The sea grasses favor salinities ranging from 20 to 36 parts per thousand; freshwater is stressful and prolonged exposure to it will kill turtle grass and manatee grass. Shoal weed, however, is more tolerant of low salinities. Light controls sea grass depth; in clear water, sea grasses can grow in depths up to 14 to 16 m.; however, because bays and estuaries tend to be turbid, sea grass species may only be found up to 3 or 4 m. Like mangroves, sea grasses are primary carbon producers; their output is consumed directly by grazing organisms while the leaf litter detritus is consumed by fungi, bacteria, and micro fauna. Important sea grass ecological functions include stabilizing sediments (rhizomes form a root mass that hold the sediments in place), high growth rates and productivity (5 to 10 mm/day), and shelter for juvenile and small invertebrates and fish. There are three groups of organisms that make use of the sea grass structure. The first type is epiphytic algae (diatoms & crustose corallines) that grow on the leaves of the grass and constitute an additional photosynthetic component. The second are epifaunal organisms that are of two forms: those that attach to the leaves (bryozoa), and large and mobile fauna, such as sea urchins and gastropods, that feed on the sea grass and the epiphytes. Finally, infaunal organisms include shrimp, polycheates, and amphipods found within the sediment interstitial area around the rhizomes. Plankton and neckton hover in the water column in the sea grass canopy. These organisms are further categorized as: permanent resident, seasonal, temporal migrant, transient, casual visitor. Migrants include fish that move daily from the reef to the sea grass and back. Birds are the most conspicuous of the transient and casual visitors: Great Blue Heron, Great Egret, Tri-color Heron, Snowy Egret, Little Blue Heron, Little Green Heron, Brown Pelican, and Osprey feed on prey found in sea grass beds.

Physical setting

The South Florida Coral Reef Complex (SFCRC) parallels the east coast of Florida from Cape Florida (Key Biscayne, 25° 40.0’N, 80° 09.5’W) to the St. Lucie Inlet (near Stuart, 27° 09.9’N, 80°09.7’W); linear distance is approximately 166 km. Reefs are situated from approximately 10 ft depth to 100 ft (3 to 30 m); this translates from very close to shore continuing seaward 2 to 3 km off Palm Beach and Broward counties and up to 4 km off Dade County; estimated coral reef area is 19,653 km^2 (Rohmann et al., 2005). This area is on the continental shelf of North America; the geological features are Pleistocene and Holocene marine limestones.

Land Use and Condition

The Florida peninsula (151, 670 km^2) is a large carbonate plateau and projects south from the continental land mass of North America into the Atlantic Ocean and Gulf of Mexico. In southeast Florida, reefs are arranged linearly and parallel the trend of the shoreline. They are separated by sandy sedimentary deposits. Epifaunal (sponges, hydrocorals, octocorals, scleractinian corals, zooanthids) communities develop on the geologic structures. The southeast Florida reef system is totally submerged under the Atlantic Ocean.   In the area seaward of Broward County, there are several 1960 era artificial reefs. These were built with stacks of automotive tires tied together with metal bands. Over time, the metal bands corroded, and the loose tires have been carried away by storms and are in contact with natural reef resources. Currently, there are efforts to remove the tires, a daunting task since they number in the millions.

Beach renourishment off southeast Florida has resulted in several problems ranging from reef injuries to excavated sand mines. Sand was mined from deposits that lay between the middle and outer reef structures.   Mining sand, transporting, and depositing it on barrier island beaches has a history of problems in the context of severe insults to marine benthic communities (Courtenay et al., 1974; Salvat, 1987; Kuehlmann, 1988; Blair et al., 1990). The dredges used to mine the sand often stray into hardbottom and coral reef habitat resulting in physical damage, including losses in coral abundance, coral cover, structural rugosity, and taxonomic diversity (Brown et al., 1990; Rogers, 1990). Additionally, silt and sediments created by the dredging are detrimental to light quality and quantity at depth. Corals tolerate short-term exposure to high turbidity; however, when the water is filled with sediment for long periods of time, the corals loose the ability to clear sediment from their tissues because of energy losses. Most shallow-water coral species gain the majority of their energy via a symbiotic linkage to autotrophic zooxanthelllae. Nominal sedimentation on a coral reef is 1 to 10 mg/cm^2/day (Rogers, 1990). When the water column is chronically turbid and sediment is raining on the coral tissues, they are at a distinct disadvantage (losing their photosynthetically derived energy). Additionally, sponges, algae, and other benthic sessile organisms are buried by the suspended sediments associated with the dredging.

Piping sediment material up on the beach results in a chronic runoff of silt-laden water. This contributes to degrading the near-shore hardbottom habitats including corals, sponges, *Phragmatopoma* worm reefs, and mobile organisms.

Studies of corals exposed to elevated sedimentation have shown that the most hardy of the species (*Siderastrea radians* [lesser starlet coral] and *Stephanocenia intersepta* [blushing star coral]) tolerate 15 days of chronic sedimentation burial (Rice and Hunter, 1992). Chronic sedimentation weakens community composition/structure; stability became unraveled because of dredge-induced sedimentation (Clarke et al., 1993).

There are several anchorages for large ships off Miami-Dade, Port Everglades, and Palm Beach. The anchorage seafloor is charted by the US Coast Guard. In spite of that, the Coast Guard recently was forced to close the anchorage off Port Everglades after multiple groundings on reefs from ships that had anchored or attempted to anchor.

Multiple ship groundings (Figure 16) on inshore and adjacent coral reefs have occurred in the past few years; many have resulted because a designated anchorage is too close to the reefs. The following incidents document this growing problem: *Firat* 1994, , *Hind* 1998, *Pacific Mako* 1998, *Alam Senang* 2003, *Eastwind* 2004, *Puritan* 2004, *Federales Pescadores* 2004, *Cosette* 2004. Lost and injured reef habitat includes 21,008 m^2 (2.1 hectares, 5.19 acres). These groundings caused considerable loss of productive coral reef habitat. Reattachment of dislodged corals or removal of rubble generated by the groundings can help recovery of the reefs; however, a return to baseline status for these injured reefs can take from decades to centuries. The net effect of these groundings has been significant habitat destruction.

Figure 16. *Eastwind* reef grounding off Broward County, March 26, 2004.

Sewage discharges into the Atlantic are located at Delray Beach (Figure 17) and Boca Raton in Palm Beach County; Pompano Beach and Hollywood in Broward County; and North Miami Beach and Virginia Key in Miami-Dade County. They are scheduled to be phased out of operation by 2013.

Proliferation of algae on SFCRC is episodic; several species are involved and they have the potential effect of smothering epibenthic sessile organisms. The green algae *Caulerpa brachypus* creates an algal biomass that at times forms thick layers and can persist for months before dissipating.. It is most common in Palm Beach and north Broward County reefs. It also is a potential threat to sea grass beds in the Indian River Lagoon.

The Cyanobacteria (blue-green algae) *Lyngbya* spp. is a pest that smothers corals on the reefs. There was a bloom in 2003 that coincided with sponge and octocoral declines in abundance (Banks, 2008). This alga appears as a cobweb mat that covers the surface of octocorals, sponges and the seafloor. Regional experts have put forward several hypotheses that attempt to explain the algal blooms. One is nutrient enrichment from sewage outfalls that stimulate algal production. There is circumstantial evidence that sewage nutrients are linked to chronic *Lyngbya confervoides* blooms on a reef near the Delray Beach outfall. Some believe that upwelling of cool, nutrient-rich water associated with Gulf Stream current dynamics contributes to the proliferation of algae. Others point to the release of large volumes of water from the Lake Okeechobee-Everglades watershed that provides the nutrients necessary for algal proliferation. Finally, there is the African dust argument; in this scenario, iron in the dust is the fertilizing agent that brings about the algal blooms.

Figure 17. Sewage outfall discharge, Delray Beach. Photo provided by M. Risk.

Communication (fiber-optic) cable installation has resulted in a number of reef injuries, especially to sponges (Figure 18), octocorals, and stony corals (scaring, dislodging, and cables lying on top of organisms).

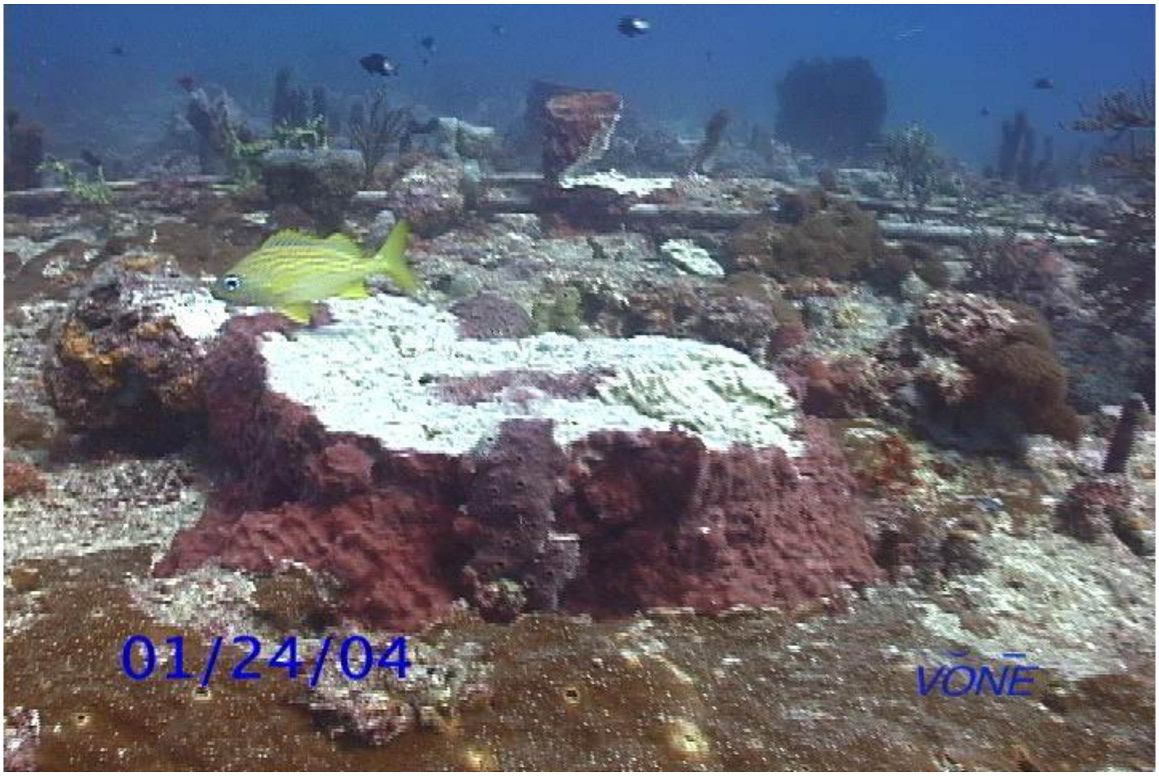

Figure 18. Fiber-optic cable injuries to barrel sponges (*Xestosponia muta*) off Broward County, 24 January 2004.

Sensitive Resources

The two *Acropora* species, *Acropora cervicornis* (staghorn coral) and *Acropora palmata* (elkhorn coral), have been designated as threatened species (Boulon et al., 2005), Both have made limited appearances on SFCRC reefs. A*cropora cervicornis* is a recent immigrant to many Broward County reefs, and it is known as far north as Boca Raton. *Acropora palmata* was always rare in southeast Florida reefs; recent surveys report a few colonies off Pompano Beach, Broward County (Figure 19).

Figure 19. *Acropora palmata* off Pompano Beach, Broward County in 2003;
status of these few northernmost colonies presently is unknown. Photo credit J. Sprung.

Although NOAA designated the two *Acropora* species as threatened (Federal Register / Vol. 71, No. 89 / Tuesday, May 9, 2006 / Rules and Regulations), Boulon et al. (2005) concluded that neither *A. palmata* nor *A. cervicornis* are in danger of extinction at the current time. However, both formerly prolific species are at extremely low levels of abundance; for the past 20 years, there is little evidence of recovery, and, in many areas, there is a declining status. Appendices include a biological review of *Acropora* spp.

Dendrogyra cylindrus (pillar coral) is another species that is rare in these reefs. There are several colonies off Broward County; one was injured during the salvage of the *Pacific Mako* in 1998. These colonies do not develop as normal *D. cylindrus* colonies; they are encrusting and the pillars are simple protuberances. *Drendrogyra cylindrus* is not a common ZS in the Florida Keys and Dry Tortugas. It is found in a few locations; the colonies in southeast Florida are the northernmost to be found on the continental shelf of North America.

Hazardous Resources

The US Navy maintains a submarine acoustical research center south of the Port Everglades Channel. Since the Second World War, the testing facility has installed multiple hydrophones and other instruments on the seabed. They are connected to the laboratory on land with cables strewn haphazardly across the reefs and seafloor. They do not pose a risk other than that they are a visual insult in a natural area. It would be impossible to remove the cables since they are imbedded in the reef and encrusting entities (sponges, octocorals, and stony corals) are attached and growing on the cables.

The red lionfish (*Pterois volitans*), an introduced species (accidentally released into Biscayne Bay in 1992), is reported in SFCRC. Populations are self-sustained by reproduction. Their poison can be lethal; the fish typically stalks its prey: smaller crustaceans and fish. It is well camouflaged and blends in nicely with the environment. The venomous nature of this species is substantial, and a sting from the red lionfish constitutes a serious health emergency. Localized symptoms of evenomation include, but are not limited to, persistent sharp pain at the sting site, tingling sensations, sweatiness, and blistering. The worst cases may cause systemic repercussions from headache and nausea to paralysis or heart complications including congestive heart failure. Basic treatment includes immersing the afflicted area in hot water (to 45° C); past case histories informally indicate that certain components of red lionfish venom may be inactivated by heat. Obviously, professional medical attention should be sought quickly.

Several species of scorpion fish are also reef residents and contain poisons similar to those of the red lionfish. Scorpion fish are camouflaged and nominally sit motionless waiting for the prey to come to them. Sharks, barracuda, and stingrays are also a risk to swimmers and divers. The black spiny sea urchin (*Diadema antillarum*) is moderately rare in most of the SFCRC; however, it is increasing in abundance in some areas. The spines can result in painful puncture wounds.

Although there are a multitude of potentially dangerous marine organisms in the SFCRC, the greatest risk for a swimmer or diver in southeast Florida comes from fellow human beings. Boating accidents are very prevalent. Most boating accidents occur on weekends in the spring through the fall; alcohol is often involved.

Comparative Assessment

Three reefs in SFCRC represent interesting coral reef features in this system: the Juno Ledges, Palm Beach County; the staghorn reef (*Acropora cervicornis*) patch off Broward County; and an mitigation reef that was constructed off Bal Harbor, Miami-Dade County. The system general characteristics were described in the section dealing with Primary Natural Features. Here we go into some detail.

Juno Ledges, Palm Beach County

Juno Ledges (26°52.312’, 80°00.789) is an outer reef complex in northern Palm Beach County; the area is a popular dive site. The seaward escarpment is an interesting structure. The seafloor is 100 to 110 ft deep at the base of this escarpment; in some areas there is a moderate slope to the upper reef platform at approximately 80 ft. In other areas the transition is a sheer vertical wall. It is very irregular with canyons and isolated structures (Figure 20) separated from the reef face. The collapse of some portions of the escarpment is evident from talus deposit at the base. The Gulf Stream current bathes this area, and it is best to drift dive with the current. Conspicuous epifauna include the large barrel sponge (*Xestospongia muta*), deep-water sea fan (*Iciligorgia schrammi*), the golden seamat (*Palythoa mammillosa*), giant star coral (*Montastraea cavernosa*), maze coral (*Meandrina meandrites*), pineapple coral (*Dichocoenia stokesi*), and knobby cactus coral (*Mycetophyllia aliciae*). The density and the cover of organisms along the escarpment is sparse. The less conspicuous but omnipresent epibenthic organisms include hydroids, small sponges, and octocorals, particularly *Pseudopterogorgia* spp. The mobile megafauna include sharks, rays, and turtles. Smaller mobile fauna include grunts, cottonwicks, butterfly fish, snapper, and grouper.


Figure 20. Hawksbill turtle (*Eretmochelys imbricata*) feeding on sponges, Juno Ledge, Spanish Hogfish (*Bodianus pulchellus*) accompanying the turtle forages on prey that the turtle exposes.

The upper reef surface is typically horizontal with some irregular topography, including depressions filled with sediment. The surface is often densely covered with octocorals (seawhips and sea plumes) and the occasional large barrel sponge and giant star coral. An interesting feature is the patchy distribution of the organisms. For example, two to three square meter areas may be covered with a single species, such as yellow pencil coral (*Madracis mirabilis*); however, it will not be seen in any other location during a dive.

Staghorn reef, Broward County

The staghorn reef (*Acropora cervicornis*) off Broward County (26°08.985'N, 80°05.810'W) is 7.6 m. (20 ft.) deep and has been extant for less than a decade (Vargas-

Angel et al., 2003). Speculation is that a swarm of larvae in the Gulf Stream hitched a ride on an eddy or gyre and ended up on the middle reef complex off Broward County. The colonies are, in some cases, isolated branches, but in at least one case there is a densely populated thicket (Figures 21, 22).

Figure 21. *Acropora cervicornis*, a dense thicket off Broward County. Stark white on branches is evidence of disease or predation by the polychaete *Hermodice carunculata* or the gastropod *Coralliophyllia abvreviata*. Terminal branch tips typically are white as the new tissue growth is not populated by zooxanthellae.

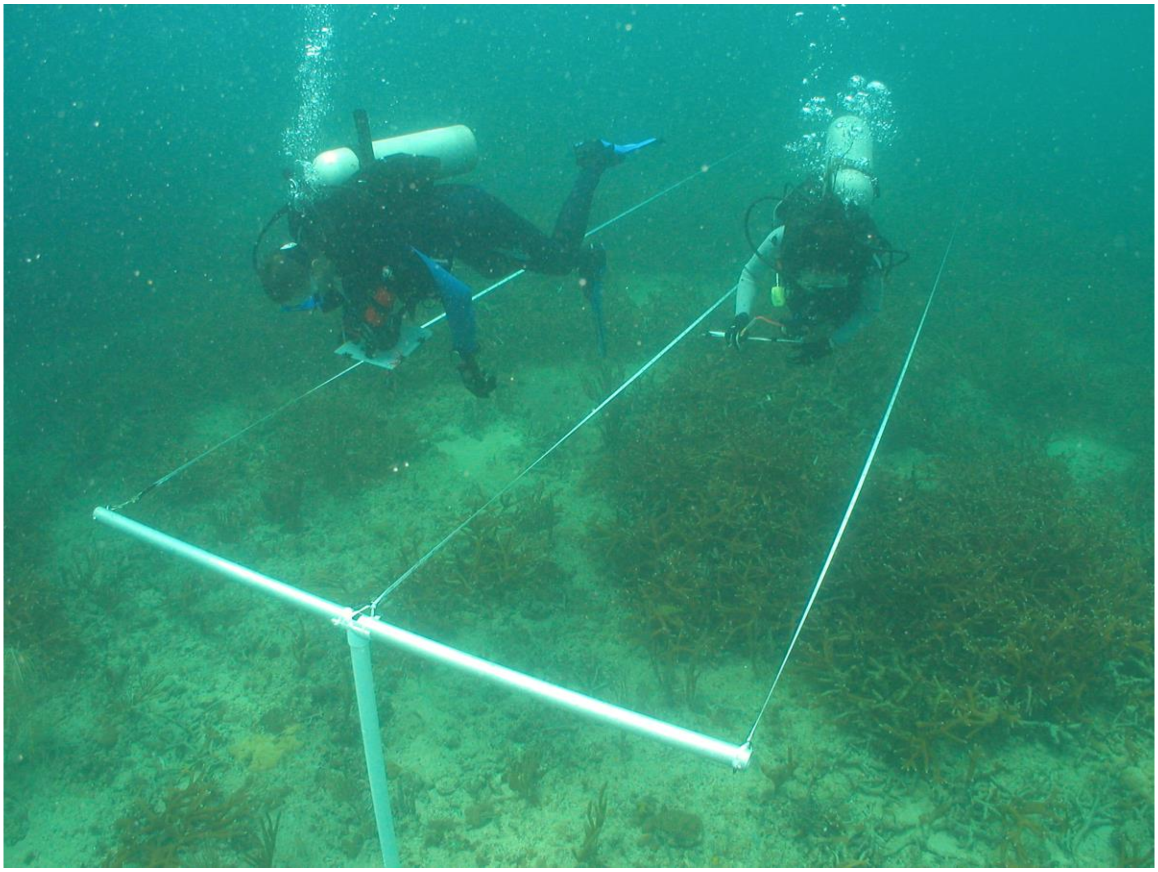

Figure 22. Monitoring station, staghorn reef, and large thicket of *Acropora cervicornis* in the background.

The seafloor around the staghorn thicket is low relief limestone with pockets of gravel and sand-sized sediments. Although *Acropora cervicornis* is the most abundant benthic organism, sponges, *Muricea*, and *Pseudopterogorgia* octocorals are common. The branches of *A.cervicornis* form a complex maze structure providing refuge for fish and invertebrates. The branches extend upward a meter or so from the substrate. The species is capable of great spatial expansion from fragments. Asexual reproduction involves fragmentation; branches and pieces of branches are dislodged from larger colonies to form new colonies (Tunnicliffe, 1981; Highsmith, 1982; Porter et al., 1982; Jaap, 1984).

Bal Harbor Mitigation Reef

This reef was constructed following burial of a natural reef from dredging. The incident occurred in 1990 during a beach renourishment project (Blair et al., 2004). The Florida Department of Environmental Protection conducted an impact assessment including a 'lost service' evaluation of the impacted reef (Thanner et al., 2006) and determined that 2,938 m^2 of artificial reef material would be required as mitigation. The mitigation reef site is approximately 3.1 km offshore from Baker's Haulover Inlet, Miami-Dade County, at a depth of 20 m; the site is located between the mid- and offshore reef lines (Thanner et al., 2006). Two different styles of reef structures were constructed for mitigation: a multilayer aggregation of natural limestone boulders and 176 prefabricated concrete modules. The boulder reef was constructed with approximately 8,000 tons of 0.9 m – 1.5 m diameter boulders arranged in a north/south (N/S) rectangular configuration (approximately 46 by 23 m); vertical relief ranged from 2.5 m – 3.5 m. The reef units were arranged in nine columns (N/S) and 22 rows (E/W). Modules surrounded the rectangular boulder reef (Thanner et al., 2006). Construction was completed in May 1999. Mitigation reefs and reference sites (benthic and fish communities) have been monitored semi-annually (1999-2004) and annually after 2004. The rock pile relief is about three times the height of the modules and provides greater complexity and rugosity. The pattern of benthic community utilization of the mitigation began with the algae, with sponges following in the second wave. The most abundant species were *Holopsamma helwigi*, *Diplastrella megastellata* , *Ulosa ruetzleri*, *Monanchora barbadensis*, *Iotrochota birotulata*, and *Strongylacidon* sp. Density of *H. helwigi*, a 'pioneering' or opportunistic species, has decreased from a maximum of 17.8 individuals m^2 in April 2003 to an average (on the modules and boulders combined) of 12.3 m^2 by July 2004. In 2004, *D. megastellata* density surpassed that of *H. helwigi* (Blair et al., 2004). Two years after deployment, Scleractinian corals began colonizing the boulders and modules. *Siderastrea siderea* (massive starlet coral) is the most common species on the mitigation reefs. Abundance and densities of benthic invertebrate species exceeded the reference areas after year four. "Benthic assemblages on artificial reef materials developed and changed throughout the first five years after placement. Their moderately high level of similarity to the natural reefs in species composition and relative species representation may indicate that the artificial reef materials are developing communities that are comparable to the natural reef areas" (Thanner et al., 2006).

Comparative Assessment

Differences and similarities in the reefs are the result of a number of variables such as topography, structural complexity, distance from shore, and intrusion from inlets that may bring degraded water into the area. In the previous three examples, we gave a snapshot of several sites that are typical of the region. There are a variety of reefs; each provides habitat for a multitude of plants and animals. The unique nature of the system—a Caribbean-like enclave along the southeast Florida coast—makes it an important natural landmark attribute.

Evaluation Recommendations

We recommend that the SFCRC be designated as a National Natural Landmark: a marine system that should be recognized as an important asset to the nation and the Caribbean region. Landmark status would give greater recognition and awareness of the reefs and other natural resources that provide food, recreation, coastal protection, education, research opportunities, and aesthetic values to southeast Florida's coastal region.

Summary Significance Statement

Proposed Landmark Boundary and Ownership Maps

We recommend that the southern boundaries should be coordinated with Biscayne National Park and Florida Keys National Marine Sanctuary to avoid conflicts on jurisdiction and responsibility. The northern boundary should be the Saint Lucie Inlet (27° 10'N, 80°09'W). The eastern boundary should be the 100 ft depth contour. Coastal charts 11428, 11451, and 11467 provide coverage of this region.

The seafloor out to three nautical miles is owned by the state of Florida. The Florida Department of Environmental Protection (FDEP), Division of State Lands, is the trustee delegated to manage, protect, and regulate sovereign submerged state lands. Beyond three miles, the federal government is the trustee. Currently, the area has been declared an area of special interest. The FDEP, Office of Coastal and Managed Areas, Coral Reef Conservation Program, based in Miami, has developed the Southeast Florida Coral Reef Initiative (SEFCRI). The SEFCRI has broad goals that are conservation based and focus on pollution, coastal engineering, unintentional human impacts, fishing, and education-outreach. Any new program should cordinate with SEFCRI to avoid duplicating efforts and jurisdictional conflicts. Chantal Collier is the program manger:

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Natural Landmark Brief

Name: the South Florida Coral Reef Complex

Location: offshore of Miami-Dade, Broward, Palm Beach, and Martin Counties, Florida

Description:

The South Florida Coral Reef Complex (SFCRC) parallels the east coast of Florida from Cape Florida (Key Biscayne, 25° 40.0'N, 80° 09.5'W) to the St. Lucie Inlet (near Stuart, 27° 09.9'N, 80°09.7'W); linear distance is approximately 166 km. Reefs are situated from approximately 10 ft depth to 100 ft (3 to 30 m); this translates from very close to shore continuing seaward 2 to 3 km off Palm Beach and Broward counties and up to 4 km off Dade County; estimated coral reef area is 19,653 km^2 (Rohmann et al., 2005). This area is on the continental shelf of North America; the geological features are Pleistocene and Holocene marine limestones.

Coral reefs off southeast Florida are in a non-accretionary mode; however, they are rich in biological diversity. Sponges and octocorals predominate; barrel sponges (X*estospongia muta*) are the largest of the sponges and typically exceed the size of the zooxanthellate Scleractinia colonies. *Pseudopterogorgia* octocorals may attain a height of a meter. There are 24 shallow-reef stony corals in the area north of Government Cut (Miami harbor channel) in Miami-Dade County, 28 off Broward County, 25 off Palm Beach County, and 8 in Martin County on the reefs south of the St. Lucie Inlet. At least 350 fish species are reported for the coastal area of Broward and Miami-Dade counties, and 400 species are reported for Palm Beach County (Banks et al., 2008). There are 265 species of fish seen in the St. Lucie Inlet Preserve State Park.

Significance: This reef complex is important to coastal marine conservation, fisheries, recreation, and the economic tourist engine of South Florida. These reefs are latitudinally, the northern most Caribbean-like reefs on the continental shelf of North America.

Ownership: State of Florida is the trustee

Designation: Proposed in 2008

Evaluation: Walter C. Jaap, Independent Contractor, September 2008.

Supporting Documentation

The documentation includes the literature we cited in this report. The appendices also provide a wealth of information on the Southeast Florida Coral Reef Complex.

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