Benthic Habitat: Coral and Hardbottom

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In a nutshell

- Coral reefs and hardbottom communities provide a vital habitat to numerous species of fish and invertebrates.
- People value coral reefs and hardbottom communities as a place to find large numbers and varieties of fish, for protecting coastlines, a critical habitat for protected species, an ecosystem with a high biodiversity of species, and for their aesthetic beauty.
- Coral reefs and hardbottom communities are vulnerable to direct physical damage from recreational and commercial activities and from the impacts of human development, e.g., beach renourishment, dredging, port development and, potentially, eutrophication of coastal waters.
- In contrast to the Florida Keys, no wildlife preserves and/or marine protected areas presently exist along the southeast Florida reef tract, which poses a challenge to proactive management.

Overview

The SEFC marine ecosystem consists of a series of offshore reefs and hardground ridges that harbor a rich and diverse marine flora and fauna similar to that found in the Florida Keys (Figure 1). Reefs are separated by sandy plains that are themselves home to infauna and a typical fish and epibenthic invertebrate community. The nearshore and seaward-facing shoreline are sandy and characterized by longshore drift of predominantly carbonate sands in a southerly direction. This longshore drift has generated a series of barrier islands that enclose a lagoon of variable width. Most space on the barrier islands is occupied by urban development, and virtually the entire shoreline (both seaward and lagoon facing) has been more or less severely altered by coastal construction activities. The lagoon behind the barrier islands has been severely modified by dredging of the Intracoastal Waterway, artificial inlets to the sea, and drainage canals from the Everglades. The lagoon is characterized by seagrasses and seasonally-variable cover by macroalgae. Mangroves are a common feature on unaltered lagoonal shorelines and constitute an important nursery habitat for fishes. The mainland adjacent to the lagoon is characterized by dense urban development throughout the SEFC region. Salinity in the lagoon is highly variable and, at times, large plumes of lagoonal waters emanate through the inlets.

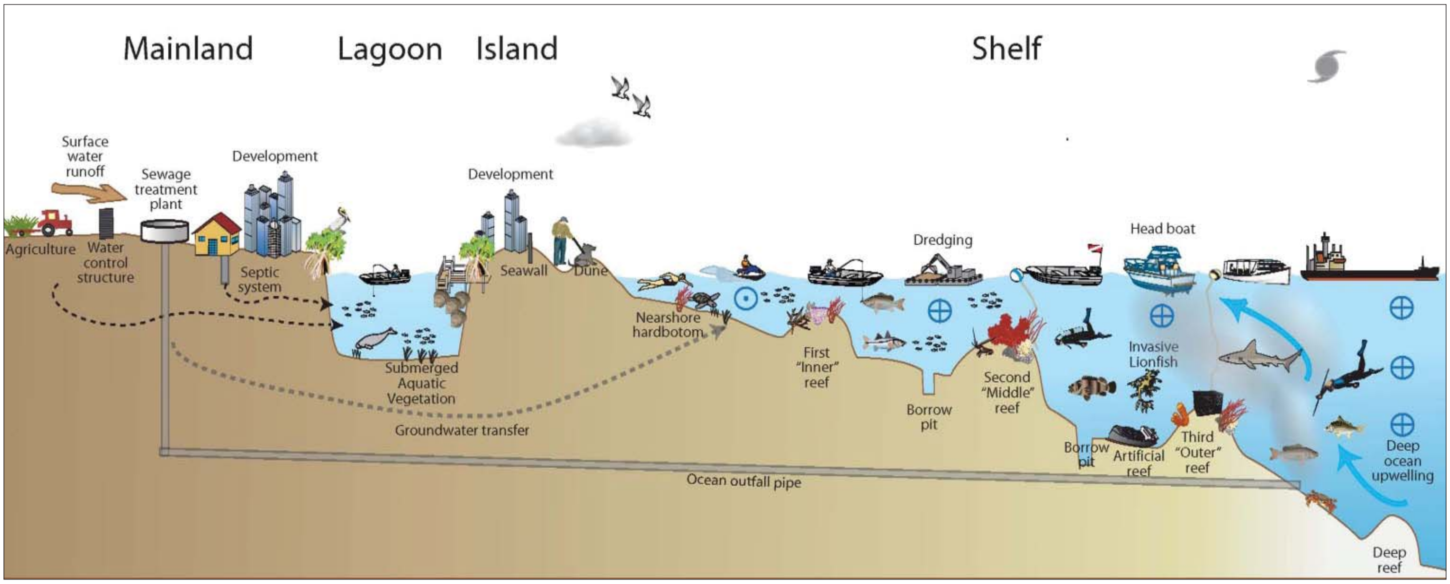

Figure 1. Diagrammatic representation of the *Drivers* and *Pressures* that shape and alter the coral reef and hardbottom habitats of the southeast Florida coast.

Define Resource

Geographic Extent

The coral reefs and hardbottom communities of the SEFC are comprised of a complex of relict Holocene shelf-edge, mid-shelf reefs, and limestone ridges (Lighty, 1977; Banks *et al.,* 2007, 2008). The linear, mostly continuous reef/ridge structures span the continental coast of southeast Florida from offshore West Palm Beach (26°43´N) southward to offshore South Miami (25°34´N), a distance of ~125 km (Banks *et al.,* 2007, 2008; Finkl and Andrews, 2008). These pre-existing structures, along with the present-day biological/physical conditions of the SEFC, allow formation of hardbottom areas, patch reefs, and worm reefs that support rich and diverse biological communities of octocoral, stony coral, macroalgae, and sponge assemblages (Moyer *et al.,* 2003; Banks *et al.,* 2007, 2008). An estimated 19,653 km^2 of inshore area (<18.3 m water depth) exists in southeast Florida that could potentially support shallow-water coral reef ecosystems and represents one of the largest such areas in the U.S. (Figure 2; Rohmann et al., 2005; Banks et al., 2008).

The reefs are positioned <3 km from the highly urbanized centers and rapidly developing coastal areas of southeast Florida where nearly a third of Florida's total population of 16 million resides. Despite their vulnerable location, these reefs possess high economic value by supporting local/regional tourism, fishing, and diving industries and providing natural *Ecosystem Services* such as coastal protection from severe storms. Only recently have the reefs of the SEFC received significant scientific research and resource management attention, yet are likely to become increasingly stressed from continued population growth, coastal development, and climate change (Dodge and Helmle, 2003; Moyer *et al.,* 2003; Collier *et al.,* 2007).

The reefs of southeast Florida are comprised of three shore-parallel, sequentially deeper terraces named the "inner," "middle," and "outer" reefs and also a shallower, "nearshore

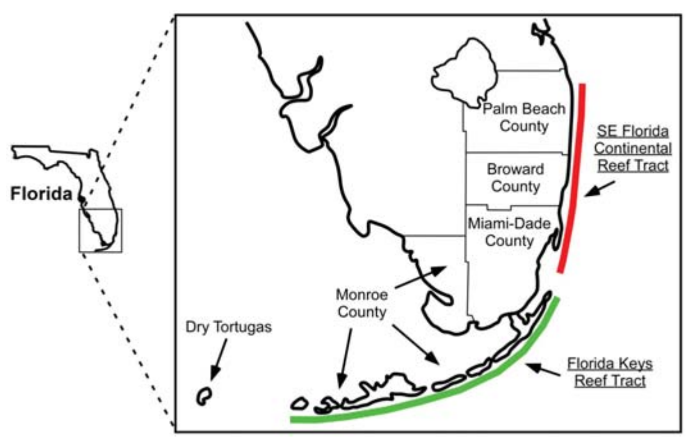

Figure 2. Geographic extent of the southeast Florida reef tract.

ridge complex" (Moyer *et al.,* 2003; Banks *et al.,* 2007). In some instances linear, yet discontinuous "intermediate ridges" exist in the sandy plains between the major reef lines and often form topographic highs of a few meters (Duane and Meisburger, 1969a, 1969b; Raymond, 1972; Shinn *et al.,* 1977; Banks *et al.,* 2007, 2008). Collectively, these structures have been termed the "southeast Florida reef tract" by Banks *et al.* (2007) and are currently distinguished from the better known Florida Keys reef tract located farther south. Despite the geomorphological distinctions between the two reef tracts, they are linked by the northward-flowing Gulf Stream and its dynamic eddies, shingles, and countercurrents.

The SEFC reefs are above 25°N and, therefore, considered a high-latitude system. As a result, cold weather fronts, occasional upwelling, and severe wave action and turbidity (Goldberg, 1973; Jaap and Adams, 1984) in the region lead to low cover of reef builders and reduced reef accretion (Moyer *et al.,* 2003). Presently, the reefs are colonized by a tropical fauna characteristic of west Atlantic/Caribbean reef systems. Stony coral cover is low (~3-6 percent among all reefs), except for a few higher density areas and patches of *Acropora cervicornis*; however, rich communities including mixtures of algae, soft corals, zoanthids, and sponges are more common and thrive in the region.

Low-relief hardbottom communities are a key component of SEFC coastal habitats, in addition to coral reefs. Hardbottom habitats in the southeast Florida reef tract can be found adjacent to the mainland at depths from <1 m to >20 m. Nearshore hardbottom communities are characterized by limestone platform with locally strong, undulating morphology consisting of lithified Pleistocene Anastasia Formation (shelly sands) or early Holocene beachrock ridges. This hardground can be covered by a thin layer of sediments and harbors a similar fauna to the shallow reefs: a sparse mixture of stony corals, soft corals, macroalgae, and sponges. As in the Florida Keys, any of these communities are found on remnant, low-profile habitats lacking significant zonation and topographical development (<1 m of vertical relief) in areas where sediment accumulation is <5 cm (Lirman *et al.,* 2003). These habitats, which can be important nursery habitats for lobsters, are characterized by low coral cover and small coral colony size (Blair and Flynn, 1999; Chiappone and Sullivan, 1994; Butler *et al.,* 1995).

Role in Ecosystem

The coral reef and hardbottom submodel of the SEFC is linked to several other *State* submodels, mainly by:

- Beaches and natural shorelines
- Inland waterways
- Offshore marine waters adjacent to the SEFC

In this section, the interactions of this submodel with the other submodels will be explained.

Beaches and Natural Shorelines

Due to their three-dimensional structure, coral reefs provide protection for beaches and natural shorelines. Although the reefs in southeast Florida do not break the water surface in most areas, the nearshore ridges and inner reef cause sands to pond behind them and, therefore, provide an efficient barrier to offshore sand migration, directly contributing to beach preservation. The shallow, nearshore hardground ridges and reefs serve as wave-breaks in stormy and high-swell conditions. Without reefs, beaches and shorelines would experience more direct physical damage from tropical storm waves and surge. Increased beach erosion by sediment loss and redistribution would also likely occur.

Inland Waterways

The coastal waters of the SEFC interact with upland water through nine tidal inlets plus the wide and shallow "safety valve" opening to Biscayne Bay (Figure 3; Lee, 2012). The two systems exchange water through ebb and flow that can be altered by processes such as increased water runoff due to greater precipitation or swells formed by low-pressure systems (Banks *et al.,* 2008). Fresh water discharge into the coastal waters results in a loss of fresh water supplies on land and ecosystem damage to the marine water bodies that receive the water (Lee, 2012). South of Palm Beach, ocean outfalls discharge secondary treated sewage effluent. This leads to a loss of hundreds of millions of gallons of fresh water supply daily and injects large quantities of nutrients and organic matter into the coastal waters. Algae blooms can occur as a result and threaten the health of coral reefs and the ecosystem (Lee, 2012). Thus, the coastal water's

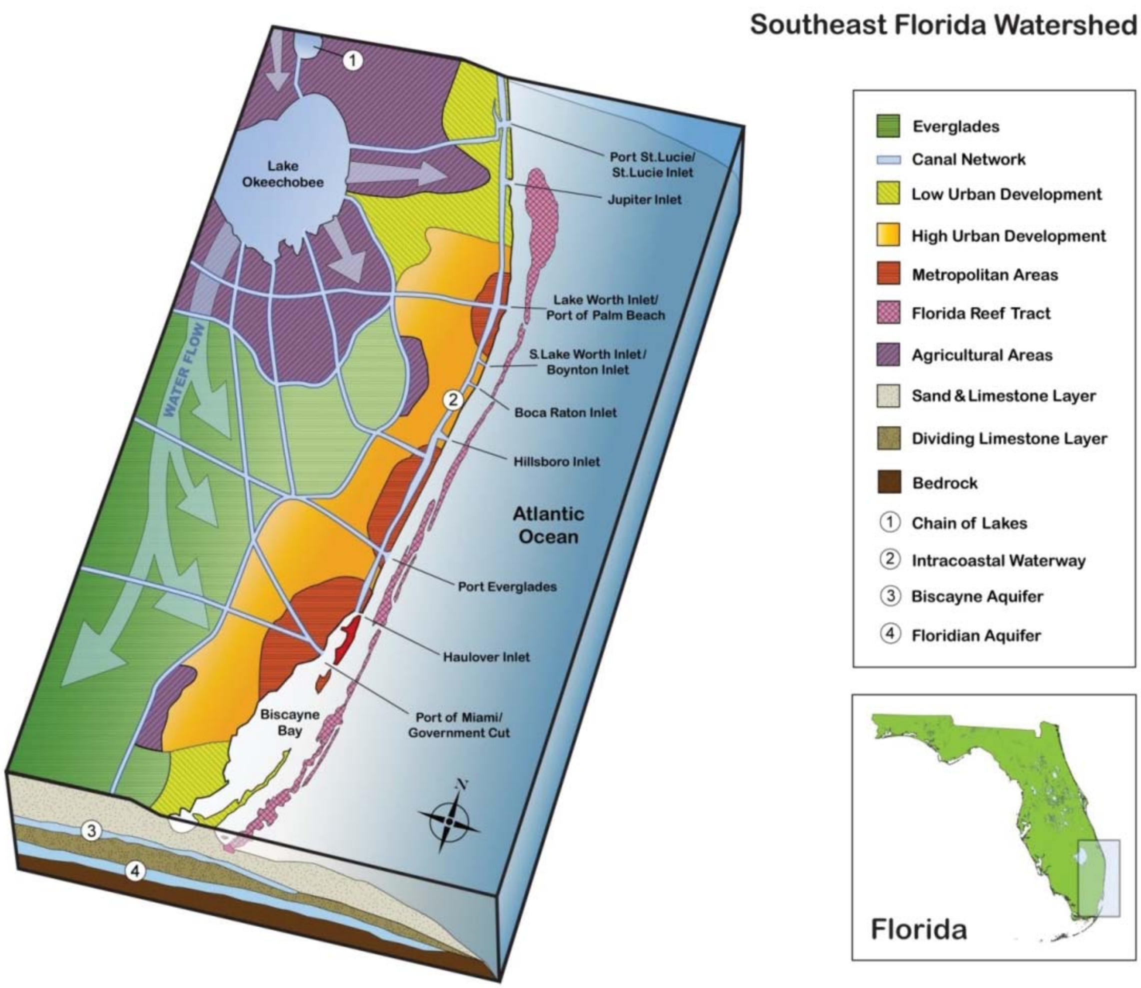

Figure 3. Inland waterways of the southeast Florida coast.

influence on the inland waterways is mainly the loss of fresh water, while the inland waterways bring nutrients and organic matter into the coastal waters.

Offshore Marine Waters

The waters of the SEFC are connected with the Gulf of Mexico and the Gulf Stream in the Atlantic through the Florida Current. This current plays an important part in the North Atlantic Sverdrup circulation (Leetmaa *et al.,* 1977) and global thermohaline circulation (Gordon, 1986). The Loop Current in the Gulf of Mexico brings water from the Florida Keys, West Florida Shelf (Hitchcock *et al.,* 2005; Sponaugle *et al.,* 2005), and upstream river sources such as the Mississippi River to the SEFC (Ortner *et al.,* 1995). Frontal eddies in the Straits of Florida can originate from the Gulf Stream, particularly in the Florida Keys region. Eddies that leave the SEFC region grow rapidly to dimensions of 100-200 km in just a few days (Lee, 2012). Those eddies bring nutrients to the outer shelf and, therefore, enrich marine ecosystem development from Florida to Cape Hatteras (Lee *et al.,* 1991).

The SEFC region is connected to the other Florida model subregions primarily as a downstream recipient. However, larval connectivity from the SEFC region towards the Florida Keys has been demonstrated by DeBiasse *et al.* (2010) and, therefore, all ecosystems along the entire SEFC should be considered intricately connected by a web of oceanographic and genetic connections. The currents will mainly influence the water quality of the other submodels but could also facilitate recruitment of organisms from one submodel to the other.

Key Attributes

People value coral reef and hardbottom ecosystems for the following services and source materials they provide:

- Productivity
- Recreation and aesthetics
- Research and education
- Structure and protection
- Resilience

Productivity

Fishing is an important recreational activity in southeast Florida with significant financial impact on the marine industries. The International Game Fish Association's Fishing Hall of Fame in Dania Beach indicates very well how important this sport is to the local community. Fish and seafood make up an important part of the diet of people living in the region, leading to significant extractive use of the local marine resources. Trophy fisheries, as well as diving and sightseeing activities, also use local fish and other marine life stocks. People tend to have an interest in healthy, growing reefs with high topographical complexity since they provide high levels of productivity that translates into abundant fish and shellfish stocks.

Recreation and Aesthetics

Diverse, productive, and healthy coral and hardbottom habitats also provide maximum enjoyment for snorkelers and divers. The recreational value of coral and hardbottom habitats will increase if a wide variety of different habitat types is widely distributed. This will provide a large number of diverse enjoyment opportunities for repeat visitors, as well as spread the impacts of excessive use over a wider area. Recreational users of the reefs contributed $2.3 billion in sales and $1.1 billion in income from June 2000 to May 2001 and created 36,500 full- and part-time jobs in South Florida (Johns *et al.,* 2001).

Research and Education

The research and education sectors benefit from healthy coral and hardbottom habitats since they can serve as living laboratories for scientists, teachers, and students of all levels of education. Several universities in southeast Florida have marine-based curricula and laboratories situated adjacent to and using the southeast Florida reef tract (e.g., Florida International University's Biscayne campus, Florida Atlantic University's Ocean Engineering Campus, the University of Miami's Rosenstiel School of Marine and Atmospheric Science Virginia Key campus, and Nova Southestern University's Dania Beach campus). Marine high school magnet programs are also maintained by the county school boards. Thus, well functioning coral and hardbottom communities support research and education.

Structure and Protection

The three-dimensional structure of coral reefs provides protection from the impacts of storm waves, surge, and tides, protecting both natural shorelines and property from physical damage. Coral reefs also provide much needed protection for beaches and natural shorelines from erosion. In South Florida, many beachfront hotels and other real estate interests benefit from the indirect protection of coral reefs to their beaches and buildings by providing a barrier to offshore migration of sand.

Resilience

Intact habitat with an intact trophic structure: (1) maximizes the long-term sustainability of the system; (2) increases the likelihood of recovery of threatened species like acroporid corals (the staghorn coral, *Acropora cervicornis,* in particular, has important populations along the southeast Florida reef tract); and (3) increases the resilience potential of the system so that the unique South Florida experience can be enjoyed by both present and future generations.

State: Measurable Ecosystem Attributes

The *Drivers* and *Pressures* characterized by this conceptual model directly impact essential life processes including survival/mortality, growth, reproduction, recruitment, and calcification of various organisms within coral and hardbottom habitats. The end result of these processes determine the *State* of the ecosystem, often characterized and measured in terms of abundance, spatial distribution and extent, diversity and resilience of its fauna and flora, and geomorphic reef structure.

Coral reefs are among the most biologically-diverse ecosystems in the world, and their diversity has long been regarded as a measurable indicator of status and condition (Connell, 1978). Diverse communities (at both the species/taxa and genetic level) are thought to be more resistant and resilient to disturbances and are desired management goals for coral and hardbottom habitats. Whatever the ecological benefits of biological diversity, a more diverse reef system tends to be more visually appealing and provides a higher recreational value to a variety of users. Thus, diversity of reef organisms can be a highly desirable attitude from both a biological and social perspective.

Stony coral abundance (usually estimated as percent cover of substratum) is the most commonly used metric of coral reef status. Coral cover has been observed to decline throughout the Caribbean over the last 30 years and has been used to draw attention to the status and trends of reef systems (Gardner *et al.,* 2003) (refer to Table 1 for a recently estimated relative bottom cover of coral and hardbottom habitats of the SEFC). An abundance of keystone species such as urchins or other bioeroding organisms like boring sponges can also be measured and may provide further insight into coral reef status.

Remotely-sensed data from satellites and aerial photography allow large-scale measurement of the spatial distribution and extent of coral and hardbottom habitats. Data gleaned from these analyses can provide detailed habitat, as well as bathymetric and geomorphological maps, that can be used by resource managers to identify vulnerable areas or temporal changes in habitat extent.

Table 1. Average relative bottom cover for coral reef and hardbottom habitats of the southeast Florida coast (from Banks *et al.,* 2008).

	Palm Beach County		Broward County		Miami-Dade County
	(3)	(1)	(3)	(2)	(3)
Bare substrate	70%	10%	73% (80%)	54%	73%
Macroalgae	1%	66%	4% (4%)	15%	9%
Octocoral	20%	12%	8% (12%)	16%	12%
Porifera	7%	8%	2% (4%)	8%	3%
Scleractinia	1%	2%	13% (0%)	5%	1%
Other	1%	2%	1% (0%)	3%	2%

(1) Foster *et al.* (2006); (2) Moyer *et al.* (2003); (3) FWCC (2006).

The structure and function of coral and hardbottom habitats are closely linked since reef-building corals contribute to the geomorphic structure that is tantamount to healthy and functional coral reefs. This structure serves as the vital habitat for a multitude of reef-associated species (Bell and Galzin, 1984), and reductions in coral cover can cause bioerosional forces to exceed reef accretion. As a result, reduced topographic complexity can decrease a reef's value as a functional habitat (Alvarez-Filip *et al.,* 2009) and affect its ability to keep pace with sea-level rise.

Resilience, or the ability of a system to absorb, resist, or recover from disturbances or to adapt to change while continuing to maintain essential functions and processes, is increasingly recognized as a desirable ecosystem attribute in scenarios where multiple acute and chronic disturbances are common occurrences (Holling, 1973; Nystrom and Folke, 2001), such as is the case in the southeast Florida reef system. Disturbances to this system are both natural (unusual cold or hot events, exacerbated by the high-latitude position of these reefs) and man-made (stresses caused by dredging, coastal construction, runoff, etc.). The Nature Conservancy's Reef Resilience Program (http://www.reefresilience.org/index.html) developed for the Florida Keys also bears relevance to the southeast Florida reef system. It has identified four main components or elements of reef resilience to be considered: (1) representation and replication (and risk spreading) to help increase the likelihood of habitat survival; (2) designation and protection of critical areas vital to survival and sustainability of marine habitats that constitute high priority conservation targets, such as fish spawning aggregations and nursery habitats; (3) preservation of the connectivity among reefs and associated habitats to ensure replenishment of coral communities and fish stocks; and (4) effective management to meet conservation and restoration goals and objectives and, ultimately, keep reefs vibrant and healthy.

Drivers of Change

Changes in the SEFC marine environment share very similar underlying causes as environmental changes in the Everglades and the Florida Keys. The *Drivers* of change act at three scales. Globally, changes arise from the effects of climate change, rising sea levels, and economic and demographic factors that drive changes in land use and exploitation of the region's natural resources. At the scale of the South Florida region, agricultural, municipal, and regional water management practices affect water quality and other characteristics of nearshore coastal water. Locally, human activities along the SEFC impose their own set of *Pressures* on the surrounding marine environment. These can be extractive activities that trigger ecological cascades, cause physical disturbance to reef habitats by careless use, and introduce pollutants and toxins into the water column that eventually impact reef organisms, as well as a myriad of other damaging but usually small additive activities.

Global Scale

Climate change and rising sea levels are important global *Drivers* for the SEFC. Climate and sea level have shaped the ecology and geology of southeast Florida in a comparable, but subtly different way than the Florida Keys (Banks *et al.,* 2007, 2008). Rising sea levels in the early Holocene determined the position of reefs on the SEFC and can be expected to do so in the future. A main determinant in reef health during the Holocene has been the amount of hinterland flooding (Florida Bay, Biscayne Bay) that, as it increased, decreased the vigor of reef growth in the Florida Keys (Lidz *et al.,* 2008). This is likely to have had a cascading effect on the ecosystems of the southeast Florida reef tract, causing a steep decline in coral populations about 4,000 years ago when Biscayne Bay fully flooded. In combination with altered drainage patterns from the Everglades, this interruption of unhindered larval exchange with coral populations in the Florida Keys may have been the reason for the decline of active reef growth that resulted in a depauperate reef-building coral fauna on the southeast Florida reef tract.

Ogden *et al.* (2005) described the effects of climate change on South Florida as follows:

> *"Over the next century, global climate change will interact with and magnify other stresses on South Florida ecosystems (Twilley et al., 2001). Global climate models suggest significant temperature increases and an amplified rate of sea-level rise over the next 100 years with summer highs increasing between 2 degrees and 4 degrees Celsius and winter low temperatures increasing 3 degrees Celsius in South Florida (Twilley et al., 2001). These warmer temperatures will result in fewer freezes, changes in rainfall and storm frequency, and possible shifts in ranges of plant and animal species and alterations in the composition of biological communities."*

Climate change and the stressors associated with this phenomenon are a major source of concern for coral and hardbottom habitats in southeast Florida that commonly live near thresholds for environmental factors predicted to be affected by global climate change. However, it is debatable whether sea level is rising as quickly as feared. Information from U.S. tide gauges suggests that sea-level rise cannot be proven, but that a possible deceleration was observed over the last century (Houston and Dean, 2011). It is, therefore, unclear whether sea-level rise will pose a problem for reefs in the near future.

Worldwide temperatures have increased over the past century by 0.74°C. Strong thermal anomalies leading to bleaching events have been observed with increasing frequency since the 1980s (Baker *et al.,* 2008). It has also been demonstrated that disease outbreaks are favored by unusually warm temperatures (Bruno *et al.,* 2007). In the Florida Keys, a series of repeated bleaching and disease outbreaks have served to reduce the average coral cover from near 15 percent to less than 5 percent, and losses in the dominant reef builders *Acropora palmata*, *A. cervicornis,* and the *Montastraea annularis* complex have been particularly striking (Jaap *et al.,* 2008). Many Florida Keys reefs are presently comparable in coral cover and diversity to those on the higher latitude southeast Florida reef tract. The latter has so far escaped similar depredation of its coral populations due to weather and disease and may, therefore, constitute an important refuge for the Florida Keys reef tract populations.

South Florida experienced a rapid change in economic and demographic factors during the 20th century. Florida was the only state in the U.S. to grow from a population of less than 1 million at the start of the 20th century to a population of over 10 million by the century's end (Hobbs and Stoops, 2002). Most of this population growth occurred in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe, and Collier). In 2030, southeast Florida will have a population of 8.5 million, 2.9 million more than in 2010 (Bureau of Census, 2010). The population size of South Florida influences many regional- and local-*scale D*rivers like coastal development, agriculture, wastewater, fishing, and boating.

Regional Scale

Regional-*scale D*rivers include human activities such as agriculture, wastewater disposal, and coastal development, as well as climate-in*duced D*rivers consisting of storms and low-pressure systems.

Human activities on the South Florida mainland influence conditions on the SEFC through their effect on the discharge of freshwater, nutrients, and contaminants into coastal waters of the southeast and southwest Florida shelves. The inputs into the coastal waters of the Southwest Florida Shelf become regional-*scale D*rivers to the SEFC through currents. Effects on the coastal water of the SEFC, on the other hand, are considered *local D*rivers.

Occurring mostly during the 20th century, vast areas of freshwater wetlands were converted to urban and agricultural uses, drastically altering the regional hydrology. To accommodate these changes, a water management system was created to provide flood control and water supply needs to the burgeoning human population. As a consequence, water management, agricultural, and urban land-use practices altered the timing, distribution, quantity, and quality of freshwater discharge into coastal waters. Further changes in inputs from the South Florida region can be anticipated into the foreseeable future.

SEFC marine waters are vulnerable to impacts from human activities outside the South Florida region. Within the Gulf of Mexico, the Loop Current drives a clockwise circulation ending just west of the Dry Tortugas. The Florida Current flows east from this point, then northeast along the Florida Keys and the SEFC before joining the Gulf Stream in the Atlantic Ocean. Via these currents, the SEFC marine waters are vulnerable to impacts from extensive oil and gas exploration and production activities in the Gulf, as demonstrated by the Deepwater Horizon spill of 2010.

Tropical storms regularly strike South Florida, causing direct physical damage in the form of coral fragmentation, dislodgement and overturning, burial, and sediment scouring, as well as secondary damage through light reduction, impairment of filter-feeding activities, and a reduction in salinity due to rainfall and increased runoff (Goreau, 1964). The beneficial impacts of storms include removal of macroalgae and a reduction in seawater temperature that may mitigate bleaching (Man*zello e*t al., 2007). Low-pressure systems, which occur in winter, lead to swells which increase sedimentation and the ebb flow coming from the Intracoastal Waterway through the inlets (*Banks e*t al., 2008). Associated with these low-pressure systems are frequent, unusually cold temperatures that have led to the death of reef organisms in the Florida Keys, but much less so on the southeast Florida reef tract.

Local Scale

Local-*scale D*rivers along the SEFC include water management and agricultural and urban land use practices, as well as boating and fishing. Water management, agricultural, and urban land-use practices have altered the timing, distribution, quantity, and quality of freshwater discharge into the coastal waters. Due to the population boom of the 20th ce**n**tury, f**i**shing and b**o**ating have also increased in southeast Florida.

Coastal construction is an impo*rtant* Driver of urban land use. It includes the dredging of harbors, laying of pipes and cables on the seafloor, and restoration of eroded beaches. These activities lead to direct physical damage to coral and hardbottom habitats, as well as to increased sedimentation. Since virtually the entire SEFC is developed and artificially hardened in many places, movements of sediment have been significantly altered. This has caused problems to nearshore hardgrounds by both smothering due to altered sedimentary movements and the requirement for beach renourishment that tends to lead to significant impacts by turbidity and smothering by newly-introduced sediments.

Fishing is a very popular recreational and important commercial activity in southeast Florida. Fishing and harvesting activities, both recreational and commercial, are key components of the economy (Johns *et al.,* 2001). The removal and collection of marine organisms have both direct and indirect impacts on coral and hardbottom habitats. Direct impacts include the targeted removal of organisms such as fish, sponges, lobsters, shrimp, anemones, live rock, etc. Indirect impacts include physical disturbance associated with harvesting activities, fishing and collecting gear, boating, pollution and modifications to the trophic structure, and removal of key organisms that can have cascading impacts on benthic communities. Fishing gear impacts have been documented for both coral reefs and hardbottom communities. These impacts include the removal of sponges and soft corals by drag nets (Ault *et al.,* 1997), as well as trap and line impacts on reef organisms (Chiappone *et al.,* 2005).

Boating in southeast Florida includes commercial ships, cruises, and recreational boating. It causes physical damage to the coral and hardbottom via anchoring and ship grounding, polluting coastal waters and introducing new diseases and invasive species to the region through ballast water release by commercial ships, and fouling organisms travelling on hulls. The physical damage caused by vessel groundings is a major source of disturbance to shallow habitats found within and adjacent to busy shipping lanes. In Florida, impacts by large and small vessels to coral reefs are a significant source of coral mortality and reef-framework modification (Lutz, 2006; *Lirman* et al., 2010).

Southeast Florida is home to three major ports: Port Everglades, the Port of Miami, and the Port of Palm Beach. In 1927, Port Everglades was officially established as a deep-water harbor. It is one of the most active cargo ports in the U.S. and South Florida's main seaport for petroleum products like gasoline and jet fuel. In 2009, Port Everglades opened the world's largest cruise terminal, overtaking the Port of Miami as the most important cruise passenger port in the world (Broward County, 2011). The Port of Miami is planning to dredge its harbor deeper to minus 50 feet until 2014. This will introduce trade with east Asia, resulting in a doubling of the cargo output of this port (Johnson, 2010). This change will not only increase the physical damage to the coral and hardbottom but also introduce new diseases and invasive species from Asia to the SEFC. The Port of Palm Beach is an export port and the fourth busiest container port in Florida. It also has a cruise ship based at the port, the B*ahamas Celeb*ration cruise (Port of Palm Beach District, 2011).

Mechanisms of Change

Of all marine habitats in Florida, the SEFC marine ecosystem is the most severely impacted by urban development and human activities. Stressors are primarily related to construction activities (coastal construction, beach renourishment, dredging for sand-mining and construction purposes, runoff, etc.) and commercial activity related to ports (ship anchoring, ship groundings, ballast water, and pollutants emanating from ships). Recreational activities feature strongly in the perception of the value of the SEFC marine ecosystem, and marine-based tourism accounts from ~$4 billion income per annum in the tri-county area (Miami-Dade, Broward, and Palm Beach counties). Recreational impacts are both direct (fishing, removal of ornamental organisms, breakage of reef organisms, pollution emanating from recreational vessels, etc.) and indirect (construction activities to harbor recreational vessels, ecological cascades triggered by the removal of keystone fish or invertebrate species, etc.).

Natural *Drivers* of ecosystem quality are related to high latitude setting, global change, and introduced species (Figure 4).

Sea-Level Rise

As predicted by many scenarios of future global change, sea-level rise can modify the depth distribution of organisms based on their light requirements. Sea-level rise in South Florida is predicted to be amplified by climate change (Twilley *et al.,* 2001), but evidence to date is elusive (Houston and Dean, 2011). Indirect impacts of sea-level rise, due to impingement of the sea on the developed coastline, would be much greater than direct impacts. Since much of southeast Florida is low-lying, a rise in sea level and the likelihood of flooding in residential and commercial areas would lead to increased shoreline protection activities. The associated construction would likely lead to even more significant environmental alterations in the nearshore environment that would likely have cascading effects on the further offshore ecosystems.

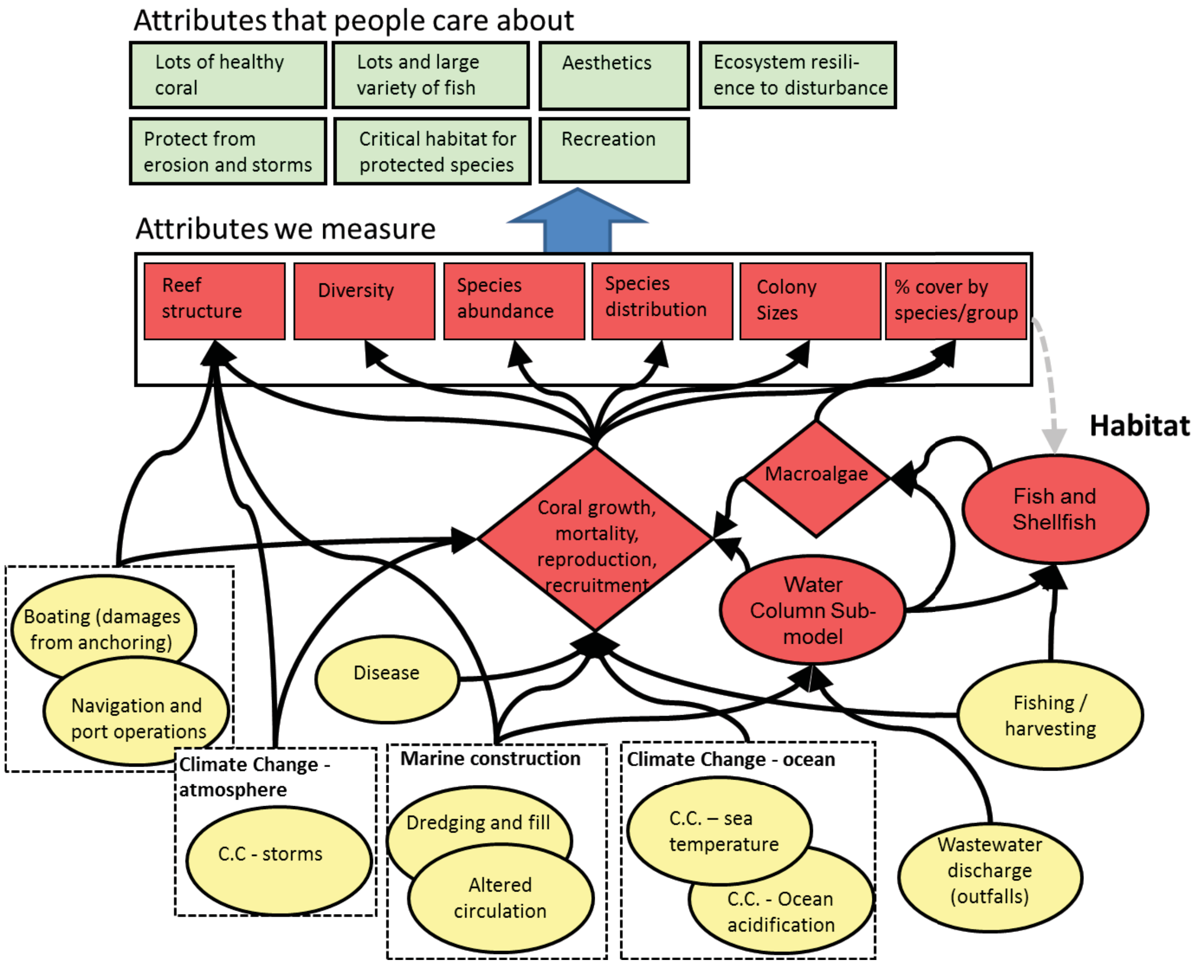

Figure 4. The coral and hardbottom conceptual ecological submodel for the southeast Florida coast.

Temperature Extremes

Both high (>30°C) and low (<15°C) temperatures have been shown to cause coral bleaching (i.e., expulsion of symbiotic dinoflagellates) and, if prolonged, significant mortality to corals and other benthic organisms (Van Oppen and Lough, 2009). Coral bleaching and mortality on the Florida reef tract have been recorded during the 1998 and 2005 bleaching events. Cold-water mortality of corals and other organisms was observed historically (Davis, 1982; Jaap and Sargent, 1994) and, more recently, in the winter of 2010 (Lirman, personal observation). The two *Drivers* which influence seawater temperature are climate change and storms. Seawater temperatures are predicted to rise due to climate change (Twilley *et al.,* 2001). Storms, on the other hand, can lower seawater temperature (Manzello *et al.,* 2007).

Water Quality

Water quality includes acidity, nutrients, salinity, turbidity, light, and aragonite saturation. Decreased water quality can lead to lower growth rates, coral mortality, and a reduction in reproduction, recruitment, and calcification. Land-based sources of pollution are the most immediate mechanism of change that is of concern.

Increases in atmospheric CO_2, as predicted in global change scenarios, will increase the acidity of the seawater. This will result in reduced calcification and potentially even skeletal dissolution (Kleypas *et al.,* 1999; Andersson *et al.,* 2005; Cohen and Holcomb, 2009). Effects would be similar in western Florida, the Florida Keys, and southeast Florida ecosystems. Aragonite saturation (Ωarag) decreases when the pH of the water decreased, as predicted by climate change. Hall-Spencer *et al.* (2008) showed that organisms with aragonite skeletons are absent at a mean Ωarag ≤2.5. This leads to the prediction that these organisms are not able to form their skeletons at these concentrations.

Nutrients

Increased nutrients can have both direct and indirect impacts on benthic organisms (Szmant, 2002). Direct impacts include the impairment of calcification and growth in stony corals under high nutrient conditions (Koop *et al.,* 2001). Indirect effects include the disruption of the coral-zooxanthellae symbiosis and a reduction in the translocation of carbon to the host (Fabricius, 2005), increased phytoplankton in the water column leading to reduced light penetration, and even toxicity (Brand and Compton, 2007; Butler *et al.,* 2005; Boyer *et al.,* 2009) and enhanced growth of macroalgae, a key space competitor in coral reefs and hardbottom habitats (Lapointe and Clark, 1992; Lapointe *et al.,* 2002, 2004). Wastewater discharge and agriculture are the two anthropogenic *Drivers* which can add additional nutrients to the natural nutrient load of the ocean.

Salinity

Changes in salinity in either direction can lead to increased or decreased respiration, depending on the coral species (Vernberg and Vernberg, 1972). Reduced salinity can also lead to local coral bleaching (Brown, 1997). It is generally agreed that most scleractinian corals can survive only small variations in salinity, with death resulting when salinity drops below 25 percent (Edmondson, 1928) or increases above 40 percent (Jokiel *et al.,* 1974). The SEFC has nine tidal inlets which connect the ocean to the inner coastal waters. Heavy rainfall can lead to the increased outflow of freshwater, reducing the salinity around the inlets. Changes in atmospheric heat content are predicted to change global rainfall patterns, leading potentially to increased dryness in Florida. This would, however, be counteracted by the increased moisture content of the tropical atmosphere delivering more severe precipitation associated with cyclonic disturbances. Hence, while mean terrestrial runoff may decline in the future, stormwater delivery and pulsed runoffs that tend to bring pollutants and nutrient pulses to reefs may indeed increase.

Turbidity

Turbidity is caused by storms and sedimentation and influences the amount of light that corals receive. Aller and Dodge (1974) and Dodge *et al.* (1974) discovered that coral growth slows down when the water becomes more turbid. However, other scientists have concluded that turbidity does not prohibit coral growth and may even increase coral growth (Roy and Smith, 1971; Maragos, 1974a, 1974b). A study conducted in the Florida Keys found that coral cover is less in more turbid water (Yentsch *et al.,* 2002).

Toxicity

Toxification can result from wastewater or from phytoplankton blooms. The following chemicals commonly found in wastewater induce toxic effects on corals and other reef organisms: polychlorinated biphenyls, metals, chlorine, phosphate, pesticides, and petroleum hydrocarbons (Pastorok and Bilyard, 1985). Cyanobacteria blooms can be directly toxic to corals and indirectly affect them by stimulating the growth of bacteria. This can lead to corals suffering from black band disease (Gantar *et al.,* 2009). In southeast Florida, a bloom by the cyanobacteria *Lyngbia* spp. caused significant coral mortality. Toxins from phytoplankton can be carried up the food web by zooplankton and even lead to the death of fish, whales, dolphins, and sea birds (Steidinger, 1983; Burkholder and Glasgow, 1995; Anderson and White, 1992; Gerachi *et al.,* 1989; Work *et al.,* 1993), changing the community that surrounds coral reefs.

Sedimentation

Sedimentation is recognized as an increasing source of disturbance to coral and hardbottom habitats around the globe experiencing rapid population expansion, watershed modification, and coastal construction (Wilkinson, 2002, 2008). All of these *Drivers* are present in southeast Florida. Sedimentation can impact coral reef and hardbottom organisms through light reduction, smothering and burial, and toxicity (Bastidas *et al.,* 1999; Fabricius, 2005). Reductions in coral growth, photosynthesis, reproductive output, lesion regeneration, feeding activities, and recruitment have all been documented for corals under high sediment loading (Rogers, 1983, 1990; Riegl, 1995; Babcock and Smith, 2000; Lirman *et al.,* 2003; Philipp and

Fabricius, 2003). Sedimentation tends to be increased by the artificial alteration of shorelines and coastal construction activities.Pollution

Pollution impacts caused by human activities on coral and hardbottom habitats have been associated with oil spills (Jackson *et al.,* 1989), urban and agricultural stormwater and overland runoff (Glynn *et al.,* 1989; Jones, 2005; Fauth *et al.,* 2006), as well as physical impacts caused by solid waste disposal and others (Peters *et al.,* 1997). Coastal development, boating, and fishing are also anthropogenic *Drivers* that cause pollution. The impacts of oil spills may include tissue and larval mortality, as well as sublethal impacts on photosynthesis and reproduction (Haapkylä *et al.,* 2007).

Disease

Diseases have been implicated as one of the main causal factors in the drastic decline in the abundance and distribution of corals recorded over the past three decades in Florida and elsewhere (Aronson and Precht, 2001; Kim and Harvell, 2002; Richardson and Voss, 2005). Many (if not most) of the epizootic agents and transmission pathways that affect soft and hard corals and sponges have not been fully described. Nevertheless, studies have found that increased temperatures are related to disease prevalence, especially after bleaching events (Brandt and McManus, 2009), that human pathogens may cause disease in nearshore corals (Sutherland and Ritchie, 2004), and that the predatory and territorial activities of snails, polychaete worms, and fish may be a mechanism for the inter-colony transmission of disease vectors (Williams and Miller, 2005).

Physical Damage

Physical damage can result from storms, fish, boats, or fishing. Hurricanes can cause anything from minor colony fragmentation and scouring to severe fragmentation of reef framework (Lirman and Fong, 1997; Gardner *et al.,* 2005; Gleason *et al.,* 2007). Fish prey on corals or damage them through other means like territorial activities. Boating activities, both recreation and commercial, are a major source of physical impacts to coral and hardbottom habitats (Precht, 2006 and references therein). Physical damage to benthic organisms and habitats can be caused directly by the impact of vessels' hulls, keels, propellers, and anchors, or indirectly through the movement of dislodged coral colonies and the shifting of sediments and rubble created during the initial impact. Damage to coral reefs can range from superficial, where only the living surfaces of corals are damaged, to structural where the geomorphologic reef matrix is fractured and exposed (Lirman *et al.,* 2010). Fishing gear impacts have been documented for both coral reefs and hardbottom communities. These impacts include the removal of sponges and soft corals by drag nets (Ault *et al.,* 1997), as well as trap and line impacts on reef organisms (Chiappone *et al.,* 2005).

Macroalgae and Phytoplankton

Macroalgae and phytoplankton interact with coral and hardbottom habitats as *Drivers* and *Pressures*. Macroalgae overgrowth of corals under high nutrient and low grazing conditions has been implicated in the phase shift from coral-dominated to algal-dominated communities throughout the world (Hughes, 1994; McCook, 1999; Hughes *et al.,* 2007). Human activities can result in the release of: (1) top-down control of macroalgae by modifying the trophic structure of coral and hardbottom habitats which reduces the abundance of key herbivores (e.g., parrotfish); and (2) bottom-up control of macroalgae by increasing nutrient availability. The rapid growth of macroalgae under these scenarios can result in coral mortality through shading, sediment accumulation, smothering, and allelopathy, as well as reduced recruitment and survivorship of coral larvae (Lirman, 2001; McCook *et al.,* 2001; Nugues and Roberts, 2003). Elevated phytoplankton populations may stress hermatypic corals in two ways. First, reduced light penetration affects coral nutrition growth and survival through negative impacts on the zooxanthellae (Smith *et al.,* 1981). Second, increased water-column production often favors the growth of benthic filter-feeders such as sponges, bryozoans, and tunicates, which outcompete corals for space (Maragos, 1972; Maragos and Chave, 1973; Birkeland, 1977). Hardbottom cryptofauna may also increase in biomass (Brock and Smith, 1983).

Fish

Herbivores, predators, shellfish, and invasive species like algae and phytoplankton interact with the coral and hardbottom as *Drivers,* as well as *Pressures*. While the removal of herbivores (e.g., parrotfish, surgeonfish, and sea urchins) is not a problem in South Florida where fishing activities are highly regulated, overfishing of herbivores has resulted in increases in macroalgae in other areas of the Caribbean (Hughes, 1994). The removal of predators may result in an increase in the abundance of damselfish that can result in increased coral mortality. This is due to their territorial activities that include killing coral tissue to grow macroalgae (Kaufman, 1977). Another cascading effect of predator removal, in this case lobsters, may be the increase in the abundance of corallivorous gastropods (*Coralliophila abbreviata*) that cause significant tissue mortality on colonies of reef-building corals and are known prey items for this once abundant taxon (Johnston and Miller, 2007).

Invasive Species

Invasive species can alter the ecosystem balance of a region. In South Florida, the lionfish is a major threat to coral reef communities. Many adults and juveniles have been found, which indicates that they are established and reproducing in the region (Hare and Whitfield, 2003). Lionfish could impact the native SEFC ecosystem through predatory interactions. Lionfish feed on a wide variety of smaller fish, shrimp, and crabs which are abundant in southeast Florida (Fishelson, 1975, 1997; Sano *et al.,* 1984; Wenner *et al.,* 1983). Predation on lionfish is thought to be limited because there are only a few predators within the native range (Bernadsky and Goulet, 1991). Moreover, predators along the southeast U.S. have no experience with the venomous spines of the lionfish (Ray and Coates, 1958; Halstead, 1965).

In response to the lionfish invasion, NOAA made a flyer informing divers about the threat lionfish posed and asked them to report their sightings of lionfish (Hare and Whitfield, 2003). Morris *et al.* (2010) made a population model of the lionfish that suggested the lionfish population could be controlled if 27 percent of the adult population was fished every month. As a way to implement this scenario, Morris *et al.* (2010) further suggested the use of lionfish as food for humans. NOAA responded by publishing an "Eat Lionfish" pull card informing the public and restaurants of the advantages of including lionfish in their diet: Eat sustainable, eat lionfish!

Water Management

In southeast Florida, water quality monitoring is limited to inland waters (Trnka *et al.,* 2006; Caccia and Boyer, 2005; Torres *et al.,* 2003; Carter, 2001). There are no long-term data available for ocean waters, but the Broward County Environmental Protection Department began a coastal water quality monitoring program in 2005 (Craig, 2004). Around Port Everglades, nutrients, chlorophyll, salinity, dissolved oxygen, and pH are measured monthly at three different sites (Banks *et al.,* 2008).

Different agencies work together to implement sustainable water management in southeast Florida. These agencies include the South Florida Water Management District (SFWMD) and its Water Resources Advisory Commission (WRAC). The SFWMD is a regional governmental agency in charge of the water resource. Created in 1949, the agency is responsible for managing and protecting the water resources of South Florida by balancing and improving water quality, flood control, natural systems, and water supply. Its goal is to manage stormwater flows to rivers and freshwater discharge to South Florida's estuaries in a way that preserves, protects, and, where possible, restores these essential resources (SFWMD, 2011a).

All of the SFWMD's coastal projects focus on wetlands; nevertheless, some of the measurements they implement also benefit coral and hardbottom habitats. The wetlands in South Florida have a severe problem with extreme salinity fluctuation, pollution, nutrients, wastewater, and stormwater runoff. The SFWMD wants to improve their state by dredging new channels, building reservoirs and stormwater treatment areas, and through education (SFWMD, 2011b; Dupes, 2004). For the Lake Worth Lagoon, they've even gone a step further by implementing and enforcing regulations to eliminate sewage discharges and the building of artificial reefs (Palm Beach County Department of Environmental Resources Management, 2008). All of these measures help the coral and hardbottom communities by lowering their nutrient load and the amount of wastewater and stormwater they receive.

The WRAC is an advisory body to the South Florida Water Management Governing Board and the South Florida Ecosystem Restoration Task Force. Its main purpose is to improve public participation and decision-making in water resource-related topics. For this reason, the members of the Commission come from the following backgrounds: business, agriculture, environment, tribal, government, and public interest (SFWMD, 2011c).

Climate Change

Climate change threatens millions of people and businesses along the SEFC by shifting weather patterns, increased hurricane intensity, and rising seas (South Florida Regional Planning Council, 2008). For these reasons, the South Florida Regional Planning Council wants to take action against climate change. Between 1990 and 2005, green house gas (GHG) emissions increased in Florida by about 35 percent, and a business-as-usual projection to 2025 showed an increase in GHG emissions of 86 percent compared to the 1990 level (Strait *et al.,* 2008). On July 13, 2007, Governor Charlie Crist signed executive orders (07-126, 07-127, 07-128) which required South Florida to reduce its GHG emissions to 80 percent below the level of 1990 by 2050 (South Florida Regional Planning Council, 2008). Recent actions that Florida has undertaken, like the electric utility cap and the adoption of California Clean Car Standards, will lower the increase of GHG emissions to 55 percent of the 1990 level by 2025 (Strait *et al.,* 2008).

Ship Groundings and Anchor Damage

Due to the proximity of reefs to navigational inlets, southeast Florida has a high risk of reef damage due to ship groundings and anchor damage. Fortunately, vessel owners respond well to the damages they cause and carry out reef restoration (Banks *et al.,* 2008). Moffatt and Nichol (2006) completed a study about alternative anchorages at Port Everglades. This study should help federal, state, and local government agencies eliminate shallow anchorages, thereby reducing impacts. Recreational boats anchoring outside of designated areas also cause reef damage. For this reason, over 100 moorings were installed in Broward County. Vessel-related impacts can also be minimized by the availability of high-resolution bathymetry and advances in positioning technology and remote, real-time monitoring of a vessel's position. These techniques allow the establishment of transit corridors for vessels (Banks *et al.,* 2008).

Coastal Construction

Due to a greater conservation ethic by the public and increased awareness of the resources present, coastal construction projects have increased their environmental protection measures in recent years. Broward County, for example, spent about 20 percent of the total construction cost of a recent beach restoration project for environmental protection and monitoring. For the proposed construction of three natural gas pipelines, the reef friendlier technology of tunneling under the coastal shelf was favored over horizontal directional drilling (Banks *et al.,* 2008).

Fishery Regulations

The Florida Fish and Wildlife Conservation Commission (FWC) is authorized by the Florida Constitution to enact rules and regulations regarding the state's fish and wildlife resources. Created in 1999, its goals are to manage fish and wildlife resources for their long term well-being and the benefit of people (FWC, 2012a). Fishing regulations set in place by the FWC include size limits, the amount of fish one is allowed to catch (bag limits), closed seasons, and species which are prohibited to fish. With these measures, the FWC tries to manage the different fish species depending on their conservation needs (FWC, 2012b). Next to the harvest of fish, fishing gear can also have a negative impact on coral and hardbottom habitats. To diminish the physical damage done to coral and hardbottom by lost traps, the FWC has two programs dedicated to removing lost and abandoned traps from state waters (FWC, 2012a).

Status and Trends

Despite having a similar fauna to the Florida Keys, Bahamas, and Caribbean, the community structure of the southeast Florida reef tract is different (Moyer *et al.,* 2003). The major reef builders of the Florida Keys, *Acropora palmata* and the *Montastraea annularis* complex, are both exceedingly rare in southeast Florida; however, living isolated colonies have been reported (Banks, personal observation; Banks *et al.,* 2008). On the southeast Florida reef tract, the majority of colonizable substrate is bare (roughly 70 percent), but relative cover is dominated by macroalgae or octocorals, while stony coral cover is low (<6 percent) as indicated in

Table 1. Isolated patches with higher coral cover exist on the ridge complex offshore central Broward County where a site that is dominated by massive corals has approximately 16 percent cover, and another site with large colonies of *Acropora cervicornis* has ~34 percent cover (Banks *et al.,* 2008).

Significant mortality of corals and other reefal organisms in the Florida Keys over the past few decades have led to an increasing homogenization of the faunas and community structures of reefal organisms in the Florida Keys and the southeast Florida reef tract (Jaap *et al.,* 2008). Today, *Acropora palmata* is rare in the Keys and *Montastraea annularis* complex is also much reduced in frequency and ecological importance. The newly-dominant species in the Florida Keys reef tract, mainly in the genus *Porites* and *Montastrea cavernosa*, also dominate in the southeast Florida reefs (Moyer *et al.,* 2003). Richards *et al.* (2009) have shown genetic connectivity in reef organisms between the Florida Keys and southeast Florida in both directions, indicating that the southeast Florida reef tract is not only a recipient of genetic material and populations, but also a potential source. That, and the lower rate of decline in populations of especially corals, raises the importance of the southeast Florida reef tract as a potential refuge habitat.

Given the unique accretion history and present day environmental conditions of reefs from the SEFC, comparisons to extant *Acroporid*-dominated reefs in other areas of the Caribbean and western Atlantic are difficult. The geologic and stratigraphic records of reefs from the SEFC indicate that *Acroporids* ceased dominating cover 5-7 cal BP (Lighty *et al.,* 1978; Banks *et al.,* 2007). Significant declines and large-scale loss of *Acroporids* have occurred over the past decades in the Caribbean and western Atlantic, largely as result of white band disease (Gardner *et al.,* 2003). In stark contrast, only 1.8 percent of the cover of the *Acropora cervicornis* thickets offshore of Broward County was afflicted with white band disease (Vargas-Angel *et al.,* 2003), and the populations remain vigorous to this day.

The incidence of coral bleaching and disease has been relatively low in southeast Florida since 2004, when data were first collected. That year, 19 diseased coral colonies were identified in the 10 study sites and, in 2005, 21 diseased colonies were identified, 10 of which had apparently been infected in 2004. Nine of those were *Siderastrea siderea* with dark spot syndrome and had recovered by 2005. White complex disease was more prevalent in 2005 (FWCC, 2006). No completely bleached coral colonies were reported, yet partial bleaching was more common than disease (Banks *et al.,* 2008).

Southeast Florida also experienced the Caribbean-wide decrease of the sea urchin, *Diadema antillarum*, which was once reported as being abundant offshore Boca Raton by Goldberg (1973). Recent reports indicate that recovery of this keystone species appears to be lagging in southeast Florida, as well as in the Florida Keys (FWCC, 2006; Banks *et al.,* 2008).

The relationship between sewage contamination and the increased occurrence of bioeroding clionid sponges has been reported on the Florida Keys reef tract (Ward-Paige *et al.,* 2005). Reports (FWCC, 2006) and diver observations indicate that clionids are abundant throughout Broward County, particularly on the ridge complex and inner and middle reefs (Banks *et al.,* 2008). No trends have been reported for Palm Beach and Miami-Dade counties, and thus a lack of understanding regional distributions exists. It is uncertain whether clionids pose a significant threat to southeast Florida coral populations, and investigations are underway (Chaves-Fonnegra, personal communication).

Harmful algal blooms by *Caulerpa* spp. have widely occurred offshore Palm Beach County during the past decade (Lapointe *et al.,* 2006) and, in 2007, spread into northern Broward County. Extensive cyanobacterial blooms of *Lyngbya* spp. have been reported on reefs offshore of Broward County (Paul *et al.,* 2005) and have had a significant impact on reef-associated organisms by smothering and outcompeting recruits of sessile benthos (Lapointe, 1997). Observations by Gilliam *et al.* (2007) revealed that decreased density of sponges and octocorals was caused by significant coverage of *Lyngbya* spp.; however, stony corals did not seem to be affected.

References

Aller, R., and R. Dodge. 1974. Animal-sediment relations in a tropical lagoon, Discovery Bay, Jamaica. Journal of Marine Research, 32(2):209-232.

Alvarez-Filip, L., N.K. Dulvy, J.A. Gill, I.M. Côté, and A.R. Watkinson. 2009. Flattening of Caribbean coral reefs: Region-wide declines in architectural complexity. Proceedings of the Royal Society B: Biological Sciences, 276:3019-3025.

Anderson, D.M., and A.W. White. 1992. Marine biotoxins at the top of the food chain. Oceanus, 35(3):55-61.

Andersson, A.J., F.T. Mackenzie, and A. Lerman. 2005. Coastal ocean and carbonate systems in the high CO_2 world of the Anthropocene. American Journal of Science, 305(9):875-918.

Aronson, R.B., and W.F. Precht. 2001. White-band disease and the changing face of Caribbean coral reefs. Hydrobiologia, 460(1):25-38.

Ault, J.S., J.E. Serafy, D. Diresta, and J. Dandelski. 1997. Impacts of commercial fishing on key habitats within Biscayne National Park, Homestead, Florida. Biscayne National Park Report, 80 pp.

Babcock, R., and L. Smith. 2000. Effects of sedimentation on coral settlement and survivorship. Proceedings, Ninth International Coral Reef Symposium, 1:245-248.

Baker, A.C., P.W. Glynn, and B. Riegl. 2008. Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends, and future outlook. Estuarine, Coastal and Shelf Science, 80(4):435-471.

Banks, K.W., B.M. Riegl, E.A. Shinn, W.E. Piller, and R.E. Dodge. 2007. Geomorphology of the southeast Florida continental reef tract (Dade, Broward, and Palm Beach counties, USA). Coral Reefs, 26(3):617-633.

Banks, K.W., B.M. Riegl, V.P. Richards, B.K. Walker, K.P. Helmle, L.K.B. Jordan, J. Phipps, M.S. Shivji, R.E. Spieler, and R.E. Dodge. 2008. The reef tract of continental southeast Florida (Miami-Dade, Broward, and Palm Beach counties, USA). In *Coral Reefs of the USA,* B.M. Riegl and R.E. Dodge (eds). Springer, 175-220.

Bastidas, C., D. Bone, and E.M. García. 1999. Sedimentation rates and metal content of sediments in a Venezuelan coral reef. Marine Pollution Bulletin, 38(1):16-24.

Bell, J.D., and R. Galzin. 1984. Influence of live coral cover on coral reef fish communities. Marine Ecology Progress Series, 15:265-274.

Bernadsky, G., and D. Goulet. 1991. A natural predator of the lionfish, *Pterois-miles*. Copeia, 1:230-231.

Birkeland, C. 1977. The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. Proceedings, Third International Coral Reef Symposium, 1:15-21.

Blair, S.M., and B.S. Flynn. 1999. Miami-Dade County's Sunny Isles reef restoration: Habitat restoration on intermittently impacted hardground reef. Proceedings, International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Fort Lauderdale, FL, April 14-16, 1999. National Coral Reef Institute, Nova Southeastern University, 56 pp.

Boyer, J.N., C.R. Kelble, P.B. Ortner, and D.T. Rudnick. 2009. Phytoplankton bloom status: Chlorophyll-a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA. Ecological Indicators, 9(6):S56-S67.

Brand, L.E., and A. Compton. 2007. Long-term increase in *Karenia brevis* abundance along the southwest Florida coast. Harmful Algae, 6(2):232-252.

Brandt, M.E., and J.W. McManus. 2009. Disease incidence is related to bleaching extent in reef-building corals. Ecology, 90(10):2859-2867.

Brock, R.E., and S.V. Smith. 1983. Response of coral reef cryptofaunal communities to food and space. Coral Reefs, 1(3):179-183.

Broward County. 2011. Fort Lauderdale Port—Official Port Everglades site, Fort Lauderdale, Florida (available at http://www.porteverglades.net/about-us/).

Brown, B.E. 1997. Coral bleaching: Causes and consequences. Coral Reefs, 16(5):129-138.

Bruno, J.F., E.R. Selig, K.S. Casey, C.A. Page, B.L. Willis, C.D. Harvell, H. Sweatman, and A.M. Melandy. 2007. Thermal stress and coral cover as drivers of coral disease outbreaks. PLoS Biology, 5(6):e124 (doi:10.1371/journal.pbio.0050124).

Bureau of Census. 2010. Available at http://www.bebr.ufl.edu/content/census-population-counts-county-and-city-florida-2000-2010-new.

Burkholder, J.M., and H.B. Glasgow. 1995. Interactions of a toxic estuarine dinoflagellate with microbial predators and prey. Archiv Fuer Protistenkunde 145(3-4):177-188.

Butler, M.J., J.H. Hunt, W.F. Herrnkind, M.J. Childress, R. Bertelsen, W.C. Sharp, T.R. Matthews, J.M. Field, and H.G. Marshall. 1995. Cascading disturbances in Florida Bay, USA: Cyanobacteria blooms, sponge mortality, and implications for juvenile spiny lobsters, *Panulirus argus.* Marine Ecology Progress Series, 129:119-125.

Butler, M.J., T.W. Dolan, J.H. Hunt, K.A. Rose, and W.F. Herrnkind. 2005. Recruitment in degraded marine habitats: A spatially explicit, individual-based model for spiny lobster. Ecological Applications, 15(3)902-918.

Caccia, V.G., and J.N. Boyer. 2005. Spatial patterning of water quality in Biscayne Bay, Florida as a function of land use and water management. Marine Pollution Bulletin, 50(11):1416-1429.

Carter, K. 2001. Broward County, Florida historical water quality atlas: 1972-1997. Department of Planning and Environmental Protection, 64 pp. (available at http://www.broward.org/EnvironmentAndGrowth/EnvironmentalProgramsResources/Publications/Documents/HistWaterQualAtlas72-97.pdf).

Chiappone, M., and K.M. Sullivan. 1994. Patterns of coral abundance defining nearshore hardbottom communities of the Florida Keys. Florida Science, 57:108-125.

Chiappone, M., H. Dienes, D.W. Swanson, and S.L. Miller. 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary. Biological Conservation, 121(2):221-230.

Cohen, A.L, and M. Holcomb. 2009. Why corals care about ocean acidification: Uncovering the mechanism. Oceanography, 22(4):118-127.

Collier, C., R. Dodge, D. Gilliam, K. Gracie, L. Gregg, W. Jaap, M. Mastry, and N. Poulos. 2007. Rapid response and restoration for coral reef injuries in southeast Florida: Guidelines and recommendations. The Southeast Florida Coral Reef Initiative (SEFCRI), Florida Department of Environmental Protection, 61 pp.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science, 199:1302-1310.

Craig, N. 2004. A long term vision for Broward County's coastal monitoring plan with a proposed pilot study. Broward County Environmental Protection Department, Environmental Monitoring Division, 20 pp.

Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976. Bulletin of Marine Science, 32(2):608-623.

DeBiasse, M.B., V.P. Richards, and M.S. Shivji. 2010. Genetic assessment of connectivity in the common reef sponge, *Callyspongia vaginalis* (Demospongiae: Haplosclerida), reveals high population structure along the Florida reef tract. Coral Reefs, 29:47-55.

Dodge, R.E., and K.P. Helmle. 2003. Past stony coral growth (extension) rates on reefs of Broward County, Florida: Possible relationships with Everglades drainage. Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem, Palm Harbor, FL, April 13-18, 2003.

Dodge, R.E., R.C. Aller, and J. Thomson. 1974. Coral growth related to resuspension of bottom sediments. Nature, 247(5442):574-577.

Duane, D.B., and E.P. Meisburger. 1969a. Geomorphology and sediments of the inner continental shelf, Palm Beach to Cape Kennedy, Florida. USACE Coastal Engineering Research Center, Technical Memorandum 34, 82 pp.

Duane, D.B., and E.P. Meisburger. 1969b. Geomorphology and sediments of the inner continental shelf, Miami to Palm Beach. USACE Coastal Engineering Research Center, Technical Memorandum 29, 47 pp.

Dupes, M. 2004. Central and southern Florida project Indian River Lagoon-South. Final Integrated Project Implementation Report and Environmental Impact Statement. U.S. Army Corps of Engineers, Jacksonville District.

Edmonton, C.H. 1928. The ecology of an Hawaiian coral reef. Bernice P. Bishop Museum, Bulletin 45, 61 pp.

Fabricius, K.E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. Marine Pollution Bulletin, 50(2):125-146.

Fauth, J.E., P. Dustin, E. Ponte, K. Banks, B. Vargas-Angel, and C.A. Downs. 2006. Southeast Florida coral biomarker local action study. Final Report, Southeast Florida Coral Reef Initiative, 69 pp.

Fishelson, L. 1975. Ethology and reproduction of pteroid fishes found in the Gulf of Aqaba (Red Sea), especially *Dendrochirus bracypterus* (Cuvier), (Pteroidae, Teleostei). PSZN 39 (Suppl. 1):635-656.

Fishelson, L. 1997. Experiments and observations on food consumption, growth, and starvation in *Dendrochirus brachypterus* and *Pterois volitans* (Pteroinae, Scorpaenidae). Environmental Biology of Fishes, 50(4):391-403.

Finkl, C.W., and J.L. Andrews. 2008. Shelf geomorphology along the southeast Florida Atlantic continental platform: Barrier coral reefs, nearshore bedrock, and morphosedimentary features. Journal of Coastal Research, 24(4):821-845.

FWC (Florida Fish and Wildlife Conservation Commission). 2012a. Basic recreational saltwater fishing regulations for state waters of Florida (available at http://www.eregulations.com/florida/fishing/saltwater).

FWC (Florida Fish and Wildlife Conservation Commission). 2012b. Commercial saltwater regulations, July 2012 (available at http://www.myfwc.com/fishing/saltwater/commercial/).

FWCC. 2006. Southeast Florida coral reef evaluation and monitoring project: 2005 Year 3 Final Report. Florida Department of Environmental Protection/Office of Coastal and Aquatic Managed Areas, 25 pp. (available at http://www.dep.state.fl.us/coastal/programs/coral/reports/LBSP/SECREMP_Final_Report_Year3.pdf).

Gantar, M., R. Sekar, and L.L. Richardson. 2009. Cyanotoxins from black band disease of corals and from other coral reef environments. Microbial Ecology, 58(4):856-864.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science, 301(5635):958-960.

Gardner, T.A., J.A. Gill, A. Grant, A.R. Watkinson, and I.M. Côté. 2005. Hurricanes and Caribbean coral reefs: Immediate impacts, recovery trajectories, and contribution to long-term decline. Ecology, 86:174-184.

Geraci, J.R., D.M. Anderson, R.J. Timperi, D.J. St. Aubin, G.A. Early, J.H. Prescott, and C.A. Mayo. 1989. Humpback whales (*Megaptera novaeangliae*) fatally poisoned by dinoflagellate toxin. Canadian Journal of Fisheries and Aquatic Sciences, 46(11):1895-1898.

Gilliam, D.S., R.E. Dodge, R.E. Spieler, L.K.B. Jordan, and J.C. Walczak. 2007. Marine biological monitoring in Broward County, Florida: Year 6 Annual Report. Prepared for the Broward County Environmental Protection Department, Biological Resources Division, 93 pp.

Gleason, A.C.R., D. Lirman, D. Williams, N.R. Gracias, B.E. Gintert, H. Madjidi, R.P Reid, G.C. Boynton, S. Negahdaripou, M. Miller, and P. Kramer. 2007. Documenting hurricane impacts on coral reefs using two-dimensional video-mosaic technology. Marine Ecology, 28(2):254-258.

Glynn, P.W., A.M. Szmant, E.F. Corcoran, and S.V. Cofer-Shabica. 1989. Condition of coral reef cnidarians from the northern Florida reef tract: Pesticides, heavy metals, and histopathological examination. Marine Pollution Bulletin, 20(11):568-576.

Goldberg, W.M. 1973. The ecology of the coral-octocoral communities off the southeast Florida coast: Geomorphology, species composition, and zonation. Bulletin of Marine Science, 23:465-488.

Gordon, A.L. 1986. Interocean exchange of thermocline water. Journal of Geophysical Research, 91(C4):5037-5046.

Goreau, T.F. 1964. Mass expulsion of zooxanthellae from Jamaican Reef communities after Hurricane Flora. Science, 145(3630):383-386.

Haapkylä, J., F. Ramade, and B. Salvat. 2007. Oil pollution on coral reefs: A review of the state of knowledge and management needs. Vie et Milieu, 57(1-2):95-111.

Hall-Spencer, J.M., R. Rodolfo-Metalpa, S. Martin, E. Ransome, M. Fine, S.M. Turner, S.J. Rowley, D. Tedesco, and M.-C. Buia. 2008. Volcanic carbon dioxide vents reveal ecosystem effects of ocean acidification. Nature, 454(7200):96-99.

Halstead, B.W. 1965. Poisonous and venomous marine animals of the world, Volume 1–Invertebrates. U.S. Government Printing Office, 994 pp.

Hare, J.A., and P.E. Whitfield. 2003. An integrated assessment of the introduction of lionfish (*Pterois volitans/miles* complex) to the western Atlantic Ocean. NOAA Technical Memorandum, NOS-NCCOS-2, 21 pp.

Hitchcock, G.L., T.N. Lee, P.B. Ortner, S. Cummings, C. Kelble, and E. Williams. 2005. Property fields in a Tortugas eddy in the southern Straits of Florida. Deep-Sea Research, Part I, 52(12):2195-2213.

Hobbs, F., and N. Stoops. 2002. Demographic trends in the 20th century. U.S. Census Bureau, Census 2000 Special Reports, Series CENSR-4, U.S. Government Printing Office, Washington, DC (available at www.census.gov/prod/2002pubs/CENSR-4.pdf).

Houston, J.R., and R.G. Dean. 2011. Sea-level acceleration based on U.S. tide gauges and extension of previous global-gauge analysis. Journal of Coastal Research, 27(3):409-417.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science, 265(5178):1547-1551.

Hughes, T.P., M.J. Rodrigues, D.R. Bellwood, D. Ceccarelli, O. Hoegh-Guldberg, L. McCook, N. Moltschaniwskyj, M.S. Pratchett, R.S. Steneck, and B. Willis. 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Current Biology, 17(4):360-365.

Jaap, W.C., and J.K. Adams. 1984. The ecology of the South Florida coral reefs: A community profile. U.S. Fish and Wildlife Service, FWS/OBS-82/08, 138 pp.

Jaap, W. C., and F. J. Sargent. 1994. The status of the remnant population of *Acropora palmata* (Lamarck, 1816) at Dry Tortugas National Park, Florida, with a discussion of possible causes of changes since 1881. Proceedings, Colloquium on Global Aspects of Coral Reefs: Hazards and History. University of Miami, 101-105.

Jaap, W.C., A. Szmant, K. Jaap, J. Dupont, R. Clarke, P. Somerfield, J. Ault, J.A. Bohnsack, S.G. Kellison, and G.T. Kellison. 2008. A perspective on the biology of Florida Keys coral reefs. In *Coral Reefs of the USA*, B.M. Riegl and R.E. Dodge (eds). Springer Dordrecht, 75-126.

Jackson, J.B.C, J.D Cubit, B.D. Keller, V. Batista, K. Burns, H.M. Caffey, R.L. Caldwell, S.D Garrity, C.D Getter, C. Gonzalez, H.M. Guzman, K.W. Kaufmann, A.H. Knap, S.C. Levings, M.J. Marshall, R. Steger, R.C. Thompson, and E. Weil. 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. Science, 243(4887):37-44.

Johns, G.M., V.R. Leeworthy, F.W. Bell, and M.A. Bonn. 2001. Socioeconomic study of reefs in southeast Florida. Final Report to the Broward County Department of Planning and Environmental Protection (available at http://www.dep.state.fl.us/coastal/programs/coral/pub/Reef_Valuation_DadeBrowardPBMonroe2001.pdf).

Johnson, B. 2010. Port of Miami—Up to the Challenge in 2014. (available at http://www.dredgingtoday.com/2010/10/05usa-port-of-miami-up-to-the-challenge-in-2014/).

Johnston, L., and M.W. Miller. 2007. Variation in life-history traits of the corallivorous gastropod *Coralliophila abbreviata* on three coral hosts. Marine Biology, 150(6):1215-1225.

Jokiel, P.L., S.L. Coles, E.B. Guinther, G.S. Key, S.V. Smith, and S.J. Townsley. 1974. Effects of thermal loading on the Hawaiian nearshore marine biota. U.S. Environmental Protection Agency, Final Report, Project 1805 DDN. Office of Research and Monitoring, Washington, DC, 285 pp.

Jones, R. 2005. The ecotoxicological effects of photosystem II herbicides on corals. Marine Pollution Bulletin, 51(5-7):495-506.

Kaufman, L. 1977. The threespot damselfish: Effects on benthic biota of Caribbean coral reefs. Proceedings, Third International Coral Reef Symposium, 1:559-564.

Kim, K., and C.D. Harvell. 2002. Aspergillosis of sea fan corals: Disease dynamics in the Florida Keys. In *The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook,* J. Porter and K. Porter (eds.). CRC Press, Boca Raton, FL, 813-824.

Kleypas, J.A., and C.M. Eakin. 2007. Scientists' perceptions of threats to coral reefs: Results of a survey of coral reef researchers. Bulletin of Marine Science, 80(2):419-436.

Kleypas, J.A., R.W. Buddemeier, D. Archer, J.-P. Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science, 284:118-120.

Koop, K., D. Booth, A. Broadbent, J. Brodie, D. Bucher, D. Capone, J. Coll, W. Dennison, M. Erdmann, P. Harrison, O. Hoegh-Guldberg, P. Hutchings, G.B. Jones, A.W. Larkum, J. O'Neil, A. Steven, E. Tentori, S. Ward, J. Williamson, and D. Yellowlees. 2001. ENCORE: The effect of nutrient enrichment on coral reefs, synthesis of results and conclusions. Marine Pollution Bulletin, 42(2):91-120.

Lapointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnology and Oceanography, 42:1119-1131.

Lapointe, B.E., and M.W. Clark. 1992. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. Estuaries, 15(4): 465-476.

Lapointe, B.E., W.R. Matzie, and P.J. Barile. 2002. Biotic phase-shifts in Florida Bay and fore reef communities of the Florida Keys: Linkages with historical freshwater flows and nitrogen loading from Everglades runoff. In *The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook,* J. Porter and K. Porter (eds.). CRC Press, Boca Raton, FL, 629-648.

Lapointe, B.E., P.J. Barile, and W.R. Matzie. 2004. Anthropogenic nutrient enrichment of seagrass and coral reef communities in the Lower Florida Keys: Discrimination of local versus regional nitrogen sources. Journal of Experimental Marine Biology and Ecology, 308(1):23-58.

Lapointe, B.E., B.J. Bedford, and R. Baumberger. 2006. Hurricanes Frances and Jeanne remove blooms of the invasive green alga *Caulerpa brachypus* forma *parvifolia* (Harvey) Cribb from coral reefs off northern Palm Beach County, Florida. Estuaries and Coasts, 29(6A):966-971.

Lee, T.N. 2012. Ocean currents connect South Florida coastal waters and link remote regions. In *Tropical Connections: South Florida's Marine Environment,* W.L. Kruczynski and P.J. Fletcher (eds.). IAN Press, University of Maryland Center for Environmental Science, Cambridge, MD, 74-79.

Lee, T.N., J.A. Yoder, and L.P. Atkinson. 1991. Gulf Stream frontal eddy influence on productivity. Journal of Geophysical Research, 96(C12):22,191-22,205.

Leetmaa, A., P. Niiler, and H. Stommel. 1977. Does the Sverdrup relation account for the mid-Atlantic circulation. Journal of Marine Research, 35:1-10.

Lidz, B.H., E.A. Shinn, J.H. Hudson, H.G. Multer, R.B. Halley, and D.M. Robbin. 2008. Controls on late quaternary coral reefs of the Florida Keys. In *Coral reefs of the USA,* B.M. Riegl and R.E. Dodge (eds.). Springer, Netherlands, 9-13.

Lighty, R.G. 1977. Relict shelf-edge Holocene coral reef: Southeast coast of Florida. Proceedings, Third International Coral Reef Symposium, 2:215-221.

Lighty, R.G., I.G. Macintyre, and R. Stuckenrath. 1978. Submerged early Holocene barrier reef southeast Florida shelf. Nature, 275:59-60.

Lirman, D. 2001. Competition between macroalgae and corals: Effects of herbivore exclusion and increased algal biomass on coral survivorship and growth. Coral Reefs, 19(4):392-399.

Lirman, D., and P. Fong. 1997. Susceptibility of coral communities to storm intensity, duration, and frequency. Proceedings, Eighth International Coral Reef Symposium, 1:561-566.

Lirman, D., B. Orlando, S. Maciá, D. Manzello, L. Kaufman, P. Biber, and T. Jones. 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: Diversity, abundance, distribution, and environmental correlates. Aquatic Conservation, 13:121-135.

Lirman, D., N. Gracias, B. Gintert, A.C.R. Gleason, G. Deangelo, M. Dick, E. Martinez, and R.P. Reid. 2010. Damage and recovery assessment of vessel grounding injuries on coral reef habitats by use of georeferenced landscape video mosaics. Limnology and Oceanography Methods, 8:88-97.

Lutz, S.J. 2006. A thousand cuts? An assessment of small-boat grounding damage to shallow corals of the Florida Keys. In *Coral Reef Restoration Handbook,* W.F. Precht (ed.). CRC Press, Boca Raton, FL, 25-38.

Manzello, D.P., R. Berkelmans, and J.C. Hendee. 2007. Coral bleaching indices and thresholds for the Florida Reef Tract, Bahamas, and St. Croix, U.S. Virgin Islands. Marine Pollution Bulletin, 54(12):1923-1931.

Maragos, J.E. 1972. A study of the ecology of Hawaiian reef corals. PhD thesis, University of Hawaii, 580 pp.

Maragos, J.E. 1974a. Coral communities on a seaward reef slope, Fanning Island. Pacific Science, 28(3):257-278.

Maragos, J.E. 1974b. Coral transplantation, a method to create, preserve, and manage coral reefs. University of Hawaii Sea Grant Publication, UNIHI-SEAGRANT, AR-74-03, 30 pp.

Maragos, J.E., and K.E. Chave. 1973. Stress and interference of man in the bay. In *Atlas of Kaneohe Bay: A Reef Ecosystem Under Stress.* University of Hawaii, Sea Grant Advisory Program, Manoa, 119-123.

McCook, L.J. 1999. Macroalgae, nutrients and phase shifts on coral reefs: Scientific issues and management consequences for the Great Barrier Reef. Coral Reefs, 18(4):357-367.

McCook, L.J., J. Jompa, and G. Diaz-Pulido. 2001. Competition between corals and algae on coral reefs: A review of evidence and mechanisms. Coral Reefs, 19(4):400-417.

Moffatt and Nichol. 2006. Port Everglades, Florida, offshore anchorage feasibility study. Final Report, MNI Project No. 5905, NY, 119 pp.

Morris, J.A., K.W. Shertzer, and J.A. Rice. 2010. A stage-based matrix population model of invasive lionfish with implications for control. Biological Invasions, 13(1):7-12.

Moyer, R.P., B. Riegl, K. Banks, and R.E. Dodge. 2003. Spatial patterns and ecology of benthic communities on a high-latitude South Florida (Broward County, USA) reef system. Coral Reefs, 22(4):447-464.

Nugues, M.M., and C.M. Roberts. 2003. Coral mortality and interaction with algae in relation to sedimentation. Coral Reefs, 22(4):507-516.

Ogden, J.C., S.M. Davis, T.K. Barnes, K.J. Jacobs, and J.H. Gentile. 2005. Total system conceptual ecological model. Wetlands, 25(4):955-979.

Ortner, P.B., T.N. Lee, P.J. Milne, R.G. Zika, M.E. Clarke, G.P. Podesta, P.K. Swart, P.A. Tester, L.P. Atkinson, and W.R. Johnson. 1995. Mississippi River flood waters that reached the Gulf Stream. Journal of Geophysical Research, 100(C7):13,595-13,601.

Palm Beach County Department of Environmental Resources Management. 2008. Lake Worth lagoon management plan revision. Palm Beach County, 152 pp.

Pastorok, R.A., and G.R. Bilyard. 1985. Effects of sewage pollution on coral-reef communities. Marine Ecology Progress Series, 21(1):175-189.

Paul, V.J., R.W. Thacker, K. Banks, and S. Golubic. 2005. Benthic cyanobacterial bloom impacts the reefs of South Florida (Broward County, USA). Coral Reefs, 24:693-697.

Peters, E.C., N.J. Gassman, J.C. Firman, R.H. Richmond, and E.A. Power. 1997. Ecotoxicology of tropical marine ecosystems. Environmental Toxicology and Chemistry, 16(1):12-40.

Philipp, E., and K. Fabricius. 2003. Photophysiological stress in scleractinian corals in response to short-term sedimentation. Journal of Experimental Marine Biology and Ecology, 287(1):57-78.

Port of Palm Beach District. 2011. Welcome to our Port of Palm Beach District (http://www.portofpalmbeach.com/).

Precht, W.F. 2006. *Coral Reef Restoration Handbook*. CRC Press, Boca Raton, FL, 384 pp.

Ray, C., and C.W. Coates. 1958. A case of poisoning by the lion fish, *Pterois volitans*. Copeia, 1958(3):235.

Raymond, W.F. 1972. A geologic investigation of the offshore sands and reefs of Broward County, Florida. MS thesis, Florida State University, Tallahassee, FL, 95 pp.

Richards, V.P., M. Henning, W. Witzell, and M. Shivji. 2009. Species delineation and evolutionary history of the globally distributed spotted eagle ray (*Aetobatus narinari*). Journal of Heredity, 100(3):273-283.

Richardson, L.L., and J.D. Voss. 2005. Changes in a coral population on reefs of the northern Florida Keys following a coral disease epizootic. Marine Ecology Progress Series, 297:147-156.

Riegl, B. 1995. Effects of sand deposition on scleractinian and alcyonacean corals. Marine Biology, 121(3):517-526.

Rogers, C.S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean Reef corals in the field. Marine Pollution Bulletin, 14(10):378-382.

Rogers, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. Marine Ecology Progress Series, 62:185-202.

Rohmann, S.O., J.J. Hayes, R.C. Newhall, M.E. Monaco, R.W. Grigg. 2005. The area of potential shallow water tropical and subtropical coral ecosystems in the United States. Coral Reefs, 24:370-383.

Roy, K.J., and S.V. Smith. 1971. Sedimentation and coral reef development in turbid water: Fanning Lagoon. Pacific Science, 25(2):234-248.

Sano, M., M. Shimizu, and Y. Nose. 1984. *Food Habits of Teleostean Reef Fishes in Okinawa Island, Southern Japan*. University of Tokyo Press, 128 pp.

SFWMD (South Florida Water Management District). 2011a. Available at http://www.sfwmd.gov/portal/page/portal/sfwmdmain/home%20page.

SFWMD (South Florida Water Management District). 2011b. Biscayne Bay Coastal Wetlands Project – Phase 1.

SFWMD (South Florida Water Management District). 2011c. Water Resources Advisory Commission (WRAC) (available at http://www.sfwmd.gov/portal/page/portal/xweb%20about%20us/wrac).

Shinn, E.A., J.H. Hudson, R.B. Halley, and B.H. Lidz. 1977. Topographic control and accumulation rate of some Holocene coral reefs, south Florida and Dry Tortugas. Proceedings, Third International Coral Reef Symposium, 2:1-7.

Smith, S.V., W.J. Kimmerer, E.A. Laws, R.E. Brock, and T.W. Walsh. 1981. Kaneohe Bay sewage diversion experiment: Perspectives on ecosystem responses to nutritional perturbation. Pacific Science, 35(4):279-395.

South Florida Economic Forecasting Partnership. 2006. Southeast Florida regional demographic and economic profile (available at http://www.sfrpc.com/remi.htm).

South Florida Regional Planning Council. 2008. Southeast Florida 2060 (available from http://www.sfrpc.com/2060/2060%20booklet.pdf).

Sponaugle, S., T. Lee, V. Kourafalou, and D. Pinkard. 2005. Florida Current frontal eddies and the settlement of coral reef fishes. Limnology and Oceanography, 50(4):1033-1048.

Steidinger, K.A. 1983. A re-evaluation of toxic dinoflagellate biology and ecology. In *Progress in Phycological Research,* F.E. Round and D.T. Chapman (eds.). Elsevier, New York, 147-188.

Strait, R., M. Mullen, B. Dougherty, A. Bollman, R. Anderson, H. Lindquist, L. Williams, M. Salhotra, and J. Schreiber. 2008. Final Florida greenhouse gas inventory and reference case projections, 1990-2025. Center for Climate Strategies, 104 pp.

Sutherland, K.P., and K.B. Ritchie. 2004. White pox disease of the Caribbean elkhorn coral, *Acropora palmata*. In *Coral Health and Disease,* E. Rosenberg and Y. Loya (eds.). Springer Verlag, Berlin, 289-300.

Szmant, A.M. 2002. Nutrient enrichment on coral reefs: Is it a major cause of coral reef decline? Estuaries, 25(4):743-766.

Torres, A.E., A.L. Higer, H.S. Henkel, P.R. Mixson, J.R. Eggleston, T.L. Embry, and G. Clement. 2003. U.S. Geological Survey, Greater Everglades Science Program: 2002 Biennial Report.

Trnka, M., K. Logan, and P. Krauss. 2006. Land-based sources of pollution: Local action strategy combined projects 1 and 2. Report prepared for the Southeast Florida Coral Reef Initiative, Miami, FL, 200 pp.

Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel, and R.J. Zimmerman. 2001. Confronting climate change in the Gulf Coast region: Prospects for sustaining our ecological heritage. Union of Concerned Scientists, Cambridge, MA and Ecological Society of America, Washington, DC, 82 pp. (available at http://www.ucsusa.org/assets/documents/global_warming/gulfcoast.pdf).

Van Oppen, M.J.H., and J.M. Lough. 2009. *Coral Bleaching: Patterns, Processes, Causes and Consequences*. Springer Verlag, 178 pp.

Vargas-Angel, B., J.D. Thomas, and S.M. Hoke. 2003. High-latitude *Acropora cervicornis* thickets off South Lauderdale, FL. Coral Reefs, 22:465-473.

Vernberg, W.B., and F.J. Vernberg. 1972. *Environmental Physiology of Marine Animals.* Springer-Verlag, Berlin, 346 pp.

Ward-Paige, C.A., M.J. Risk, and O.A. Sherwood. 2005. Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. Marine Pollution Bulletin, 51:570-579.

Wenner, E.L., D.M. Knott, R.F. Van Dolah, and V.G. Burrell. 1983. Invertebrate communities associated with hardbottom habitats in the South Atlantic Bight. Estuarine, Coastal and Shelf Science, 17(2):143-158.

Wilkinson, C. 2002. Status of coral reefs of the world: 2002. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, 378 pp.

Wilkinson, C. 2008. Status of coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, 296 pp.

Williams, D.E., and M.W. Miller. 2005. Coral disease outbreak: Pattern, prevalence, and transmission in *Acropora cervicornis*. Marine Ecology Progress Series, 301:119-128.

Work, T.M., A.M. Beale, L. Fritz, M.A. Quilliam, M. Silver, K. Buck, and J.L.C. Wright. 1993. Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. In *Toxic Phytoplankton Blooms in the Sea,* T.J. Smayda and Y. Shimizu (eds.). Elsevier, Amsterdam, 643-650.

Yentsch, C.S., C.M. Yentsch, J.J. Cullen, B. Lapointe, D.A. Phinney, and S.W. Yentsch. 2002. Sunlight and water transparency: Cornerstones in coral research. Journal of Experimental Marine Biology and Ecology, 268(2):171-183.