Shoreline Habitat: Beaches

Frank E. Marshall
Cetacean Logic Foundation, Inc.

Kenneth Banks
Broward County Environmental Protection and Growth Management Department

In a nutshell:

- Beaches are the part of the coastal marine ecosystem most visited by people.
- People value beaches for the ecosystem services that they provide, including (but not limited to) flora and fauna habitat, storm protection, beach use, aesthetics, human health effects, recreation, beach-related jobs (tourism), and ocean access.
- Drivers of change include natural factors, such as the wind/wave climate, sea-level rise, submerged groundwater discharges, and upwellings, and anthropogenic factors, such as encroaching development, shoreline structures, storm water runoff, inlet discharges, and beach nourishment.
- Most beaches along the southeast Florida coast have been altered in some manner, and this must be taken into account when evaluating the status and trends in ecosystem services.

Role of Beaches—Habitat Linkages

Beaches are dynamic landscapes valued by humans because of the proximity of the ocean, the access for recreation and hunter-gatherer purposes, and the habitat beaches provide for plants and animals. Geologically, a beach is comprised of unconsolidated material affected by wave and wind forces and ocean currents. The parent material that forms the beach may be rock, sand, gravel, pebbles, cobblestones, shells, coral, or other. The term "seashore" is also commonly used for an ocean beach since some beaches front onto a river or lake.

Biotic communities of beaches provide a wide range of ecosystem services not available from any other ecosystem. Sandy beaches that remain as intact coastal ecosystems are capable of supporting both ecological processes and sustainable use by humans (Schlacher *et al.,* 2008). However, the SEFC beach and shoreline, which extends from St. Lucie Inlet to Cape Florida (Figure 1), includes some of the most densely populated coastal areas in the world. Because of this large urban footprint, the remaining natural beach habitat is limited to isolated areas, primarily in parks or other protected areas. The subtropical location of South Florida means that the beaches are influenced by both temperate and tropical oceanic environments.

Beach environments in southeast Florida are linked through the food web to the adjacent marine ecosystems, such as nearshore hardbottom, worm rock reefs, soft sediment infaunal marine communities, offshore coral reefs, estuaries,

Figure 1. The southeast Florida region including the beaches of Martin, Palm Beach, Broward, and northern Miami-Dade counties.

and pelagic waters. This occurs primarily through feeding forays by birds and fish, detrital movement across ecosystem boundaries, macrophyte wrack (primarily Sargassum spp. from offshore and *Thalassia testudinum* from bays to the south), and by multiple habitat requirements for different life history stages of a number of organisms. Some species spend different parts of their life cycle between the beach and open-water habitats.

The ghost crab (*Ocypode quadrata*) spends its adult life in dry sand burrows on the open beach. It feeds primarily at night on clams, insects, plant material, detritus, sea turtle hatchlings, and other crabs. Ghost crabs must return to the ocean to release their eggs, which develop into larval zooplankton that remain in the ocean for a period of time. Thus, the adult ghost crab depends, in part, on food from other ecosystems, and part of its life history is spent in the pelagic marine ecosystem.

Many fishes, such as the goatfish, *Mulloidichthys* spp., feed in soft bottom areas from the nearshore to deeper offshore reef sand patches. These fishes consume food and deposit waste across ecosystem boundaries. They are prey for higher trophic level predators as they transit ecosystems.

Sea turtles also represent organisms with multiple ecosystem linkages. The adults and subadults, particularly green and hawksbill turtles, forage in nearshore hardbottom habitats. In nesting season, they deposit eggs on the beach at night then return immediately to the ocean. The eggs and hatchlings (which must travel across open beach to get into the ocean) are preyed upon by beach organisms (crabs and birds), terrestrial vertebrates (foxes, raccoons, snakes, and rats), and marine predators (fish).

Based on information from coastal scientists at the MARES SEFC workshop in March 2011, it was concluded that beaches are vulnerable to change because they are a naturally dynamic physical environment and are often the focus for intensive human use. According to Jones *et al.* (2009), the primary threats to the world's beaches include climate-change, erosion, nourishment, shoreline hardening, off-road vehicles, beach cleaning, pollution, fisheries, sand removal (mining), and introduced species, all of which apply to the beaches in the SEFC except off-road vehicles. Jones *et al.* (2009) argued that an important goal for a coastal society should be to maintain beaches in a near-pristine state since most of the value of beaches to humans comes from that natural state. In South Florida, the encroachment of urban development, recreational use, and other human activities has resulted in loss of habitat and ecosystem diversity.

Attributes People Care About that are Measured

The attributes of the beach and shoreline ecosystem that people care about include the unique oceanfront habitat, storm protection, ocean access, a continuation of the status quo for beach use, aesthetics, human health effects, recreation, and beach-related jobs for tourism (Johns *et al.,* 2013). According to the MARES Human Dimensions Ecosystem Services White Papers (Johns *et al.,* 2013; Lee *et al.,* 2013), the most important beach ecosystem services that are comprehensively measured include coastal park visitation (indicator for recreation) and dollar value of insurance claims for coastal storm damage (indicator for storm protection). In southeast Florida, coastal park visitation increased from 2009 to 2010, while the dollars spent for storm damage decreased over the same period (Lee *et al.,* 2013). The Center for Urban and Environmental Solutions at Florida Atlantic University (CUES, 2005) indicates that 44 percent of the tourists that visit a Florida beach do so in southeast Florida.

The number of jobs created by beach tourism in southeast Florida is the highest in the state, as are direct and indirect beach-related spending. Over one-third of the out-of-state Florida visitors in 2000-2003 visited a beach, and beach-oriented trips increased over the same period.

Other examples of the economic value of coastal resources for 2000-2003 include the following (CUES 2005):

- Out-of-state beach tourists spent $19.1 billion in 2003, an amount equal to 3.8 percent of the gross state product.
- Out-of-state beach tourists paid about $600 million in state sales taxes and created more than 500,000 jobs.
- Almost one-half of the more than 500,000 jobs created in Florida by beach tourism resulted from spending in southeast Florida.
- 77 percent of Florida's population lives in coastal areas.
- 80 percent of the personal income received by Florida's residents comes from coastal areas.
- 79 percent of the state's payrolls are earned in Florida's coastal areas.

Data exist for attributes of the various ecosystem services related to beaches and shorelines in southeast Florida. Categories of available beaches data and relevant references include:

- Areas of dune habitat, beach and dune fauna, and change in habitat (Defeo *et al.,* 2009; Miller *et al.,* 2010).
- Shoreline geomorphology and change (Bruun, 1962; USACE, 1996; Bush *et al.,* 2004; Jones *et al.,* 2009; Absalonsen and Dean, 2010).
- Areas of nearshore reefs and hardbottom (Perkins *et al.,* 1997; Banks *et al.,* 2008; CSA International Inc., 2009; Lindeman *et al.,* 2009).
- Water quality (Peterson and Manning, 2001; Bonilla *et al.,* 2007).
- Beach restoration (Nelson, 1993; Mota, 2011).
- Number of visitors and their economic impact (CUES, 2005).
- Values of the property on and surrounding the shoreline (Murley *et al.,* 2003).
- Economic values of the non-resident beach use (CUES, 2005; Murley *et al.,* 2005).
- Common fauna, protected species, and impacts to habitat (Johnson and Barbor, 1990; Salas *et al.,* 2006; Irlandi and Arnold, 2008; Schlacher and Lucrezi, 2009; Lucrezi *et al.,* 2009; Mota, 2011; Noriega *et al.,* 2012;),
- Other fauna including charismatic megafauna, birds, and non-natives (Schlacher *et al.,* 2008).

Drivers of Change and Pressures for Beaches and Shorelines

Drivers of change on South Florida beaches range over relatively large temporal and spatial scales, from localized overuse to global-scale sea-level rise (Defeo *et al.,* 2009; Schlacher *et al.,* 2007). *Pressures* also cause impacts at multiple temporal and spatial scales. For example, coastal engineering projects and urban development permanently impact the beach over tens of kilometers, and impacts from climate change continue for millennia over larger spatial extents. Recreation, the addition of sand for beach nourishment, and pollution impact beaches at temporal scales of weeks to years and over spatial scales of 10-100 kilometers (Defeo *et al.,* 2009).

In southeast Florida, the most widely-used environment by the residents and tourists is the beach because of its proximity to urban areas, the ease of vehicular access, and the social and cultural desirability of "hanging out" by the ocean. There are numerous federal, state, county, city, and non-government owned beachfront parks in the southeast Florida region. Most of these areas were designed to protect remaining coastal flora and fauna, provide access to the public, facilitate beach restoration, or a combination of these purposes. However, the majority of beachfront parks along the SEFC were developed to accommodate parking for public access to the beach. As a result, the development, operation, and maintenance of beach parks has resulted in significant loss of the natural aspects of the coastal landscape and increased use of the beach for active recreation.

Because beaches are popular places for people to visit, deposited waste and litter can affect the recreational and ecological uses of the beach. In severe cases, litter can cause health-related issues. In years past, beaches were commonly used for stormwater runoff disposal; though the practice continues, it is being phased out over time.

When native beach vegetation is removed, exotic species have a chance to invade. Exotic species of plants that have had an impact on beach environments in southeast Florida are *Casaurina equisetifolia*, usually called Australian Pine, and *Scaevola taccada*, also known as beach scaevola. Southeast Florida has the lowest percentage of coastline with natural vegetation in the state with only about 10 percent remaining in Broward and Miami-Dade counties (Absalonsen and Dean, 2010).

A natural beach is resilient to the frequent coastal storms that are common to the SEFC that occur several times each year. However, less frequent (every 5-30 years) hurricanes and tropical storms can significantly alter beach morphology, destroy dune vegetation, and negatively affect habitat. Southeast Florida beaches can experience major hurricanes that may cause significant changes to the form of the beach and wash away large numbers of sea turtle eggs (Figure 2). Where the energy-absorbing dune system has been replaced by urban development, even relatively minor storms cause some negative impact on the habitat and recreational uses of the beach, and the habitat loss (if any is present) can be permanent.

Most coastal communities in southeast Florida clean beaches often to remove seaweed wrack and debris. However, wrack is an important energy source to the beach ecosystem and is assimilated into the beach ecosystem via two pathways into trophic webs: decomposition and incorporation. The primary pathway is incorporation by herbivores, such as amphipods (small crustaceans with no carapace) and dipterans (two-winged insects [flies]). Subsequent predation on these grazers transfers nutrients and energy into higher trophic levels (Duong, 2008). Wrack also provides habitat for macrofauna and decomposes, remineralizing nutrients. In this manner, wrack helps to establish and support colonial dune vegetation which contributes to the storm protection function of dunes.

The shoreline of southeast Florida prior to human alteration was typical of the barrier island complexes of north and central Florida seen today. Inlets associated with river drainage (e.g., Jupiter Inlet/Loxahatchee River, New River/

Figure 2. Hatched sea turtle nest on the beach at John U. Lloyd State Park exposed by erosion from Tropical Storm Isaac (August 2012).

New River Inlet in Ft. Lauderdale) were open much of the time, depending on river flow rates. Many other inlets were ephemeral, frequently changing locations or periodically opening and closing, the dynamics of which were controlled by inland water discharge, wind patterns, and offshore storms.

As coastal development and commerce increased in southeast Florida, a need arose for stable navigational inlets of adequate water depth. The implemented solution was to install rock jetties at the desired location and dredge a channel from inland water through the barrier island or spit to the ocean. The construction of jetties interrupted the littoral sediment drift process, and down-drift beaches have been starved of their sediment supply ever since. Some of the barrier islands/spits subsequently migrated shoreward (west) until they were welded to the mainland shoreline, whose position is fixed by underlying rock formations. A prime example of a natural beach becoming beach eroded by inlet jetties is at Port Everglades in Broward County.

Based on the observed effects described above, *Drivers* and *Pressures* for South Florida beaches and shorelines were identified. *Drivers* include numerous anthropogenic factors (encroaching beach development, beach structures, beach cleaning, direct and indirect beach lighting, stormwater runoff, inlet discharges, and beach nourishment), as well as natural factors (wind/wave climate, sea-level rise, submerged groundwater discharges, and upwellings). *Pressures* on South Florida beaches and shorelines are loss of beach habitat, beach erosion/accretion, impacts to nearshore hardbottom habitat (shoreline and further out), reduced water quality, marine debris, and continued economic growth.

Beaches and Shorelines Conceptual Models

Available studies relevant to conceptual modeling of beach ecosystems were reviewed for their approach, but only a small number of existing conceptual models for beaches and shorelines were found. Most conceptual models of the shoreline have focused on beach morphology. For example, the U.S. Army Corps of Engineers developed a conceptual model for the oceanfront shoreline in New York from Fire Island Inlet to Montauk Point. This conceptual model focuses on the stresses created on shoreline habitats by alternative approaches to shoreline protection. The impact on the habitat was scored (scale of 1-3) for vegetation, invertebrates, finfish, birds, and marine mammals (USACE, 2006).

Dyson (2010) used a broker-local-tourist, place-based conceptual model of beaches as a structure for examining interactions between pollution and beach tourism. Pollution in this study included litter, construction debris, recreational boating debris, stormwater, etc. The impacts varied by category but it was concluded that beach pollution negatively affects all three categories of beach-users (broker, local, and tourist).

The Northeast Coastal and Barrier Network (NCNB) developed a conceptual model to guide a monitoring program (Figure 3; Milstead et al., 2005). The NCNB spans eight ecologically similar parks along the northeastern U.S. coast from Massachusetts to Virginia. Included are critical coastal habitat for rare and endangered species and migratory corridors for birds, sea turtles, and marine mammals. A monitoring approach was developed using conceptual ecosystem modeling to assess ecosystem agents of change, stressors and the ecosystem responses, focal resources, and key properties and processes of ecosystem integrity. Agents of change that were identified included sea-level rise, fire, biological invasions, hydrologic cycle alterations, and natural disturbance events. Stressor examples included altered hydrologic properties, altered landscape, invasive species, altered sediment, and chemical inputs. Focal resources were identified including species that are harvested, endemic, historically significant, or have protected status, as well as biological integrity. Focal resources have paramount importance for monitoring by virtue of their special protection, public appeal, or other management significance (Milstead et al., 2005).

For the southeast Florida coast, a beaches and shoreline submodel was developed by MARES, as presented in Figure 4. The state box includes beaches and shoreline attributes that people care about that are measured and the beach state variables (e.g., nearshore hardbottom and water quality). *Drivers* in the beaches submodel include wind/wave/tide, sea-level rise, upwelling, and storms, *Drivers* that are important agents of change on most beaches in Florida.

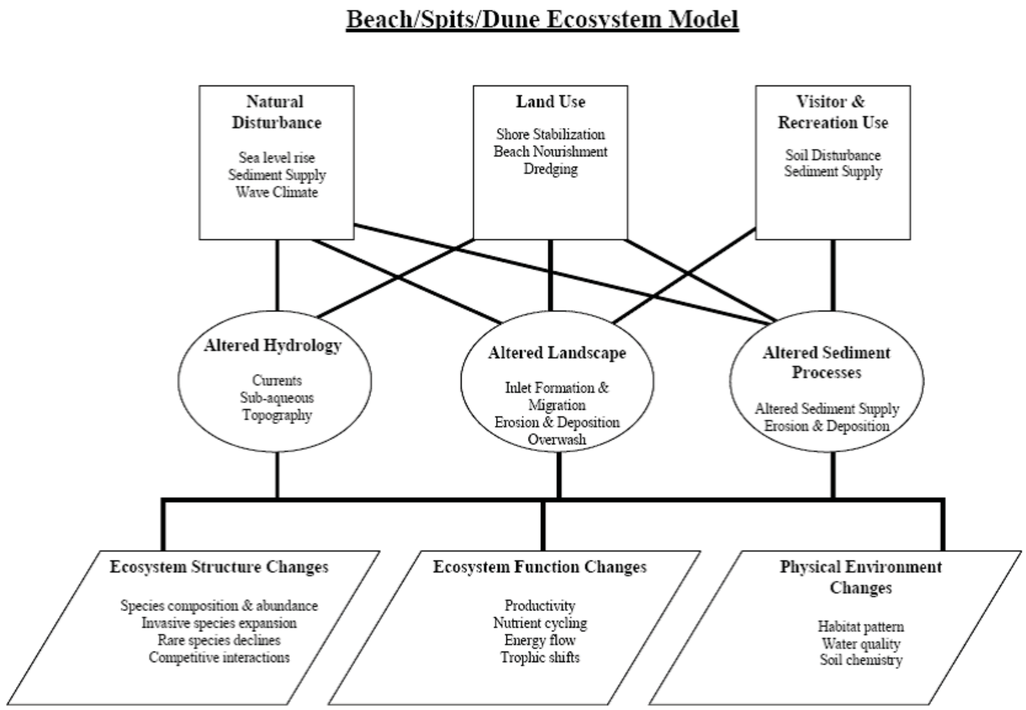

Figure 3. Conceptual ecosystem model for NCNB beach/spits/dunes (copied directly from Milstead *et al.,* 2005).

There are numerous *Pressures* in southeast Florida caused by the extent of urban development and the use of beaches, including encroaching beach development, beach lighting, mechanized beach cleaning, marine debris, beach structures, wastewater outfalls, stormwater runoff, inlet discharges, and beach nourishment. *Responses* in southeast Florida (not shown on Figure 4) include but are not limited to sea turtle conservation programs, land (beach) preservation efforts, land use plans and regulations, beach cleaning events, retro-fit and new stormwater management structures, elimination of wastewater outfalls, shielding of street lights, beach structure construction (also a pressure), and government programs to assist beach-related business efforts, and planning programs for sea-level rise.

Of particular importance as a *Driver* is the proximity of the urban development to the beach. Because a beach is a dynamic system it needs space to move, and encroachment of urban areas onto the dune and open beach areas in southeast Florida through the construction of seawalls and other permanent structures has compromised the natural function of the beach for storm protection and habitat. Beach nourishment projects are used to improve storm protection and recreational opportunities, but these projects are costly, require a great deal of time to implement, and have a large environmental impact. Improper lighting of shorefront and adjacent properties impacts sea turtle nesting and disorients hatchlings as they attempt to crawl to the ocean. The *Drivers* of change resulting from human activities that translate to *Pressures* on the ecosystem are sea-level rise and climate change. Urbanization and shoreline hardening limit the ability of the remaining beach and shoreline system to react to these drivers.

When the urban areas are located back from the shoreline, the stored sand in the dunes provides an effective and cost-efficient method of storm protection for the built environment. There is limited support for the importance of this function or the ecological value of beach habitat and, as a result, beach function as storm protection and habitat has been negatively impacted by development. When erosion or urban encroachment (or both) reduce the size of the beach and threaten storm protection or recreation, the solution is often to import beach material (beach nourishment) from elsewhere. To date, beach nourishment has not been carried out solely for the purpose of enhancing ecological value in South Florida.

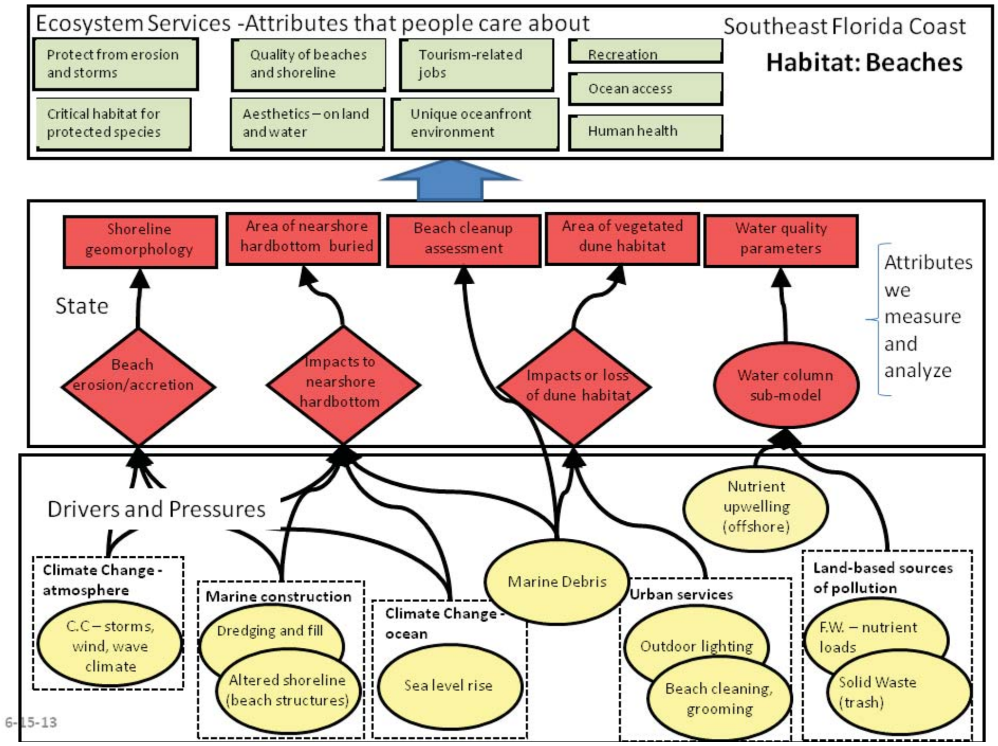

Figure 4. The beaches conceptual ecological submodel for the southeast Florida coast.

Status and Trends

The southeast Florida coastal ecosystem consists of beaches and shorelines that range from pristine to highly-impacted. Most beaches in southeast Florida have been subjected to some level of disturbance. Because of this, the discussion of status and trends for beaches and, therefore, the indicators of condition, were divided into two categories: (1) undeveloped to mostly undeveloped beaches; and (2) developed to highly developed beaches. The rationale behind this subdivision underlines the permanence of disturbance in the beach habitat. In general, undeveloped to mostly undeveloped beaches are characterized by predominately or mostly functional habitat. Beach nourishment projects must have occurred long enough in the past that the habitat is in recovery. For developed to highly developed beaches, beach nourishment has occurred relatively recently (within the past decade) and there is a high probability of a future beach nourishment project. On these beaches, the natural habitat is not likely to recover for an extended period even without any natural or human disturbance. Further details on these beach types can be found in the beaches and shorelines indicators document (Marshall *et al.,* in press).

The Southeast Florida Beach Regional Ecosystem

The southeast Florida beach ecosystem study area is comprised of several beach types including barrier islands and spits/peninsulas, as well as oceanfront areas where the Atlantic Coastal Ridge fronts directly on the Atlantic Ocean. Most beaches in the study area are experiencing long-term erosion (Table 1). The only beaches in the region that are accreting at the time that Table 1 was prepared are in Martin County. The SEFC includes many oceanfront areas that have been subjected to sand nourishment projects as a response to erosion caused by natural beach and barrier island processes, sea-level rise, and development practices.

In general, the level of development in the study area is high for all counties except Martin Country (Table 1). As a result, all counties in the study area, except Martin County, have large portions of the shore that are armored. Armoring practices include seawalls, revetments, bulkheads, groins, and boulder mounds. The existing inlets that separate the sections of beach are in locations where inlets have historically existed (e.g., Jupiter Inlet), as well as inlets

Table 1. Summary information on beaches and shorelines within the counties of the southeast Florida study area (from Bush *et al.,* 2004).

County	Ocean Shoreline (miles)	Long-Term Erosion (accretion)	Short-Term Erosion (accretion)	Beach	Level of Development	Types of Armoring
Martin	24	(4.05 ft/yr)	(2.09/ft/yr)	Yes	Low to medium	Seawalls, jetties
Palm Beach	42	0.19 ft/yr	1.17 ft/yr	Yes	High	Seawalls, groins, jetties, revetments, bulkheads
Broward	24	0.02 ft/yr	4.47 ft/yr	Yes	High	Seawalls, groins, jetties, revetments, bulkheads, boulder mounds
Miami-Dade	21	0.98 ft/yr	10.41 ft/yr	Yes	High	Seawalls, groins, jetties

that were created by dredging, often in locations where ephemeral inlets existed in the past. All of the inlets along the SEFC area are protected by jetties.

The Dynamic Physical Environment of Local Beaches

An ocean beach has several parts or zones that fluctuate in spatial extent and location with the movement of the overall beach and barrier island due to natural factors (e.g., storms) and anthropogenic alterations (e.g., hardening of shoreline). The part of the beach that may be influenced by the waves and tide is generally called the beach berm (Figure 5). A beach berm has a fore-shore or face (sloping material from the land into the water) and a wide crest called the back-shore (commonly called the open beach). Seaward of the beach berm, under water at high tide, a trough may exist beyond which longshore sand bars and other troughs may be present. Landward of the open beach, dunes of deposited beach material typically exist on natural beaches. The berm and dune forms are subjected to relatively frequent natural disturbances, less frequent storm-caused alteration, and often-permanent anthropogenic impacts.

Under natural conditions, beaches and barrier islands are dynamic environments that are influenced by climate (wind and storms), waves, and tidal action. The topography of the natural beach is shaped by the interaction of these physical processes and the mitigating effect of vegetation. Native beach plants are capable of trapping wind-blown sand to create dunes and additional habitat and can tolerate the desert-like soil conditions, burial, and the effects of direct exposure to salt spray. Human activities influence the shape of the beach and, at larger scales, the entire shoreline.

The sand composition of a natural beach in southeast Florida is a combination of quartz plus calcium carbonate materials, with the carbonate fraction increasing southward in the region. The source of the quartz sand is the Appalachian Mountains, reworked by the currents and circulation patterns of the Atlantic Ocean and the Gulf Stream, as well as local circulation patterns. Little, if any, sand on the natural beaches in the study area originated from rivers in Florida. On many beaches in the study area, the sand that exists today is sand from a borrow source via beach nourishment and may or may not have similar composition and characteristics to the native beach sand.

Higher elevation dunes form on beaches from wind and the sand-trapping process of vegetation. The above-ground portions of plants increase friction to wind. This causes deposition of aeolian sand, particularly on the fore dune. In South Florida, although the predominant wind direction is from the southeast, the greatest wind velocities come from the northeast (onshore wind). Dunes of natural sand in

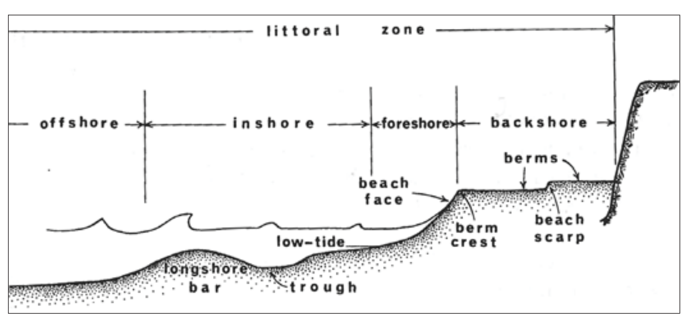

Figure 5. A typical beach profile with no anthropogenic influence (Komar, 1976).

some locations have been recorded that commonly reached heights of 25-30 ft. On developed and man-made beaches, dunes may not be present because the vegetation has been removed or destroyed. The heavy winds and turbulent seas of a hurricane can destroy dunes or alter them significantly.

Seaweed that washes ashore (wrack) may stay in the beach environment where it promotes dune formation or becomes part of terrestrial or marine food webs. During these natural processes, a diverse community of organisms, including bacteria, yeasts, fungi, nematodes, invertebrate larvae, mites, as well as macrofauna, finds shelter and engage in nutrient cycling and decomposition. If the seaweed is washed onto the berm near the dune, it can provide nutrients for dune-forming pioneer vegetation such as railroad vine (Zemke-White *et al.,* 2005). Most beaches in southeast Florida, however, are cleaned daily to remove wrack and debris, thus short-circuiting the beneficial ecological role of seaweed wrack.

Wave action moves sand in the beach system, which can result in erosion or accretion. Longshore currents transport sand over the long-term but, in the short-term, storms can alter the beach by transporting sand offshore where it is outside of the beach system (beyond depth of closure). In the vicinity of inlets, sand accretes on the updrift side (northern side in South Florida) and is eroded from the downdrift side (south side in South Florida). Most storms only erode the fore-shore or berm without over-washing, but hurricanes and winter storms (nor'easters) can accelerate erosion greatly and severely alter the beach and dune system. The beaches of southeast Florida are not as susceptible to nor'easters as the beaches of northeast Florida, due to the wave shadowing effect of the Bahamas, but they are more vulnerable to hurricanes than coastal areas in northeast Florida.

In southeast Florida the natural shoreline has been significantly altered by the dredging of inlets, construction of jetties and groins, and encroachment of urban land uses into all zones of the beach. In the most densely developed areas, the stable dune zone and the transition zone have been completely replaced by the built environment with seawalls instead of dunes and an open beach nourishment with offshore borrow sand. While beach nourishment projects are expensive, they have become commonplace activities in southeast Florida.

Absalonsen and Dean (2010) studied shoreline change in southeast Florida since the late 1800s. Their data reflect the significant impact that navigational inlets have on the littoral transport system. In general, there is a prograding of the shoreline position north of navigational inlets and a sharp erosion signal to the south. Variation in shoreline position is greater at these locations compared to the more stable beaches between inlets.

Climate

The beaches of southeast Florida are highly influenced by the variability of climate factors. The climate of southeast Florida is classified in the Köppen Climate Classification System as tropical savanna, characterized by a pronounced dry season (Trewartha, 1968). Air temperature averages 19.0ºC in the winter and 28.2ºC in summer, with an overall average of 24ºC. Water temperatures are moderated by the proximity of the northward flowing Florida Current, an arm of the Gulf Stream passing through the Straits of Florida. The minimum water temperature measured offshore Broward County during a 3-year period (2001-2003) was 18.3ºC and the maximum was 30.5ºC (Banks *et al.,* 2008).

During the dry season (November–March), Florida experiences the passage of mid-latitude, synoptic-scale cold fronts (Hodanish *et al.,* 1997) which bring strong winds from the northeast. These nor'easters usually last for 2-3 days. These fronts may have a significant impact on the beach ecosystem by increasing southward sediment transport (littoral transport), offshore loses of coarse beach sediment (with some burial of nearshore hardbottom), and shoreward aeolian transport of fine sediments which contribute to increases in dune elevation. Strong winds also generate waves which can cause a flattening of the beach profile and may form scarps on the beach berm and erosion of dunes.

In the wet season (late spring to early fall, June–September), differential heating generates mesoscale fronts, creating sea breezes. Convergence of these moisture-laden sea breezes, developing from the different water bodies (Atlantic Ocean, Gulf of Mexico, and Lake Okeechobee), coupled with high humidity in the Everglades, can result in a low-pressure trough developing across the Florida peninsula. This leads to intense thunderstorm activity, which moves from inland to the coasts, delivering large amounts of freshwater to the coastal shelf. South Florida receives 70 percent of its annual rainfall during these months. Trewartha (1968) referred to the daily sea breeze circulation as a "diurnal monsoon". The typical wind direction during most of the southeast Florida wet season is from the southeast (tropical). During these times, winds tend to be relatively light and cause little beach erosion.

From June through November, Florida is a prime landfall target for tropical cyclones, although storms have been documented as early as March and as late as December. Hurricanes and tropical storms affect the beach ecosystems similar to winter storms, except alteration of the physical environment is magnified because of stronger winds with the added impact of high water levels caused by storm surge. Because winds in a hurricane shift in direction as the storm passes, longshore sediment transport direction can shift. The numbers of direct hits of hurricanes (strength based on the Saffir-Simpson scale) affecting southeast Florida in the 100 years from 1899-1998 (Neumann *et al.,* 1999) are:

- Category 1 (winds of 119–153 km/hr) – 5
- Category 2 (winds of 154–177 km/hr) – 10
- Category 3 (winds of 178–209 km/hr) – 7
- Category 4 (winds of 210–249 km/hr) – 4
- Category 5 (winds > 249 km/hr) – 1

The number of tropical storms or hurricanes passing within a 50-mile radius of Palm Beach, Broward, and Miami-Dade counties (a single storm may affect more than one county) are presented in Table 2.

Waves and Tides

Long-period swells result in increased sediment suspension and turbidity in nearshore waters. Hanes and Dompe (1995) measured turbidity concurrently with waves and currents in situ at depths of 5 m and 10 m offshore Hollywood, Florida (Broward County) from January 1990 to April 1992. They found a significant correlation between wave height and turbidity. In addition, there was a threshold wave height (0.6 m), below which waves do not materially influence turbidity.

In winter, low-pressure systems form on the Atlantic Ocean coast of the U.S. Short-period, wind-driven waves develop near the center of these lows. As these seas move away from the center of low pressure, they can develop into long-period swells, locally known as "ground swells" that may affect southeast Florida. The wave climate of southeast Florida is influenced by the shadowing effect of the Bahamas and, to a lesser extent, Cuba. In the northern part of the southeast Florida region, swells from the north are of relatively high energy since they are not influenced by the shallow Bahamas Banks. Broward and Miami-Dade counties are less affected

Table 2. Storm occurrences for southeast Florida (USACE, 1996).

	Palm Beach County		Broward County		Miami-Dade County	
Period	Hurricanes	Tropical Storms	Hurricanes	Tropical Storms	Hurricanes	Tropical Storms
1871–1880	3	0	1	0	0	0
1881–1890	2	2	1	2	2	2
1891–1900	0	2	0	1	1	1
1901–1910	2	4	2	3	3	2
1911–1920	0	0	0	0	0	1
1921–1930	3	1	4	0	3	0
1931–1940	3	0	2	1	1	2
1941–1950	5	1	4	1	5	1
1951–1960	0	2	0	2	0	2
1961–1970	2	0	2	0	2	0
1971–1980	1	1	1	1	0	1
1981–1990	0	2	0	2	1	1
1991–2000	0	2	1	0	1	1
2001–2006	3	0	1	0	0	1

by this wave energy because of the shadowing effect of the Bahamas Banks.

Tides in the region are semi-diurnal with amplitudes of approximately 0.8 m. Tidal forces influence coastal circulation near navigation inlets. Nine navigational inlets, approximately 16 km apart, are maintained in southeast Florida. At the southern extent of the region, tidal passes allow exchange of water from Biscayne Bay onto the coastal shelf. The relative contribution of the inlets to coastal circulation can be estimated by comparing inlet tidal prisms (volume of water exchanged in the estuary between high and low tide). Coastal circulation is affected by the tidal prism, inlet dimensions, shelf width at the inlets, offshore distance of the Florida Current, tidal plume constituents, and salinity. The salinity of the plumes discharging from the inlets is significantly different in the wet season (June–September) compared the dry season (October–May).

Ecological Communities and Characteristic Species

Natural beaches in the Southeast Florida study area have or had vegetation that is (was) somewhat similar throughout the extent of the study area, although tropical species are a larger portion of the native ecosystem in the southern extremes and subtropical beach vegetation may be seen in the northern part of the study area on natural beaches (Johnson and Barbour, 1990). Beach vegetation within the study area typically occurs in the berm and back dune areas that are generally parallel to the shoreline and oriented in a north-south direction. The transition (ecotone) from temperate to tropical canopy trees occurs in the northern reach of the study area. North of the study area, the tropical species, when present, prefer the calcareous substrate. There are a number of animals that depend upon the beach habitat for at least part of their life cycle, including sea turtles, numerous birds, and rodents.

Based on plant lists by Johnson and Barbour (1990), beach and fore dune representative species in the study area include sea oats (*Uniola paniculata*), sea purslane (*Sesuvium portulacastrum*, *Distichlis spicata*) beach dropseed (*Sporobolus virginicus*), Mexican beach peanut (*Okenia hypogaea*), Remirea maritima, railroad vine (*Ipomoae pes-caprae*), seashore paspalum (*Paspalum distichum*), sea lavender (*Argusia* sp.), beach sunflower (*Helianthus debilis*), beach berry (*Scaevola plumier*), and bay cedar (*Suriana maritima*). Because the barrier island and non-barrier beaches of southeast Florida are narrow, the transitional zone may be dominated by woody species of plants including sea grape (*Cocoloba uvifera*), Serenoa repens, Sable palmetto, *Dalbergia ecastophyllum*, Spanish bayonet (*Yucca aloifolia*), agave (*Agave decipiens*), and prickly pear (*Opuntia stricta*). The native stable dune zone in southeast Florida contains primarily woody shrubs and canopy trees dominated by tropical species, although the northernmost reaches of the study area contain subtropical species. Representative native stable dune canopy plants include *Eugenia foetida, Aradis escallonioides, Bursera simaruba, Eugenia axillaris, Metopium toxiferum, Cocothrinax argentata, Mastichodendron foetidissimum, Zanthoxylum fagara, Amyris elemifera, Krugiodendron ferreum, Nectandra coriacea, Casuarina equisetifolia* (exotic, invasive), *Pithecellobium keyensis, Chrysobalanus icaco,* and *Rivina humilis*. Johnson and Barbour (1990) indicate that about ten endemic plant species were found in the study area, although the number may be decreasing due to the intensity of development and the loss of tree canopy habitat.

Sea turtles spend most of their life in the ocean but females return to the beach to deposit eggs in nests. From May to September (earlier for leatherbacks), female sea turtles emerge from the ocean mostly at night onto the beach to lay a clutch of eggs that will hatch in about 60 days. The hatchlings then leave the nest and travel across the open beach to enter the ocean and swim to offshore nursery areas. The beaches of southeast Florida are globally important beaches for sea turtle nesting (Witherington *et al.,* 2009). In the vicinity of inlets, sea turtles can also be found in the estuary.

The sea turtle species that use southeast Florida beaches for reproduction are, in order of presence (common to rare): loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempii*). According to the U.S. Fish and Wildlife Service, there are about 35 leatherback (endangered) nests in all of Florida each year, over 10,000 loggerhead nests (threatened), and about 200-1100 green turtle nests (endangered). There are five subpopulations of loggerheads worldwide, and the southeast Florida subpopulation is genetically distinct from the loggerhead subpopulation in north Florida and other sub-populations. The only nesting regions in the world with over 10,000 loggerhead nests a year are southeast Florida and Masirah (Oman). The southeast Florida subpopulation experienced population increases for many years, although current data indicate that this trend may have slowed. The Florida green turtle nesting aggregation is recognized as a regionally significant colony (http://www.fws.gov/northflorida/SeaTurtles/seaturtle-info.htm).

Data are collected by Florida Fish and Wildlife Conservation Commission (FWC) for the number of sea turtle nests that are laid in the southeast Florida region. These data are summarized by year and by county in Table 3 for 2006-2010. Year 2010 was a year of high nest numbers for both loggerhead and green sea turtles. By comparison, 2006 was a year of low or reduced nesting for all three species (Witherington *et al.,* 2009).

For some birds the beaches of southeast Florida are important nesting sites. For other species, the beach is used as a wintering ground. Johnson and Barbour (1990) indicate that there are 13 bird species in Florida that use the beach for nesting, usually from April to August, with no detail on southeast Florida. Examples of wintering species in southeast Florida may include sanderlings (*Calidris alba*), western sandpiper (*C. mauri*), dunlin (*C. alpine*), short-billed dowitcher (*Limnodromus griseus*), red knot (*Calidris canutus*), black-bellied plover (*Pluvialis squatarola*), and willet (*Castrophorus semipalmatus*).

Small rodents are also an important component of the natural beach habitat. Barrier island rodent populations are distinct from populations of mainland subspecies, and subspecies in other parts of Florida are distinct from those in southeast Florida. Little detail on the subspecies of rodents in southeast Florida was found.

The interstitial spaces of the sand on a beach near the waterline support a relatively diverse infauna that experience cyclic changes of water due to diurnal tide cycles and seasonal variation in the nearshore marine areas. Chemical stratification of the sand can result in varying environmental conditions over short vertical distances. Infaunae are represented by fungi, algae, bacteria, metazoans, and protozoans (McLachlan, 1983). In the swash zone of southeast Florida where wave action and tides dominate, the physical processes, coquina clams (*Donax* spp.), and mole crabs (*Emerita talpoida*) are commonly present (Wade, 1967). On an undisturbed open beach, the most obvious organism is the ghost crab (*Ocypode quadrata*).

Table 3. Marine turtle nesting data by year and by county (FWC data, http://myfwc.com/research/wildlife/sea-turtles/nesting/beach-survey-totals/).

Species	County	2006	2007	2008	2009	2010
Loggerhead	Martin	5,532	5,210	7,356	6,643	9,120
	Palm Beach	11,196	10,559	12,704	11,565	15,775
	Broward	1,740	1,593	1,929	1,808	2,283
	Miami-Dade	302	295	323	358	352
	Total	18,770	17,657	22,312	20,374	27,530
Green	Martin	579	1,307	1,111	679	1,591
	Palm Beach	1,324	3,389	2,272	1,263	3,378
	Broward	138	233	276	71	268
	Miami-Dade	0	20	0	12	13
	Total	2,041	4,949	3,659	2,025	5,250
Leatherback	Martin	205	494	274	663	561
	Palm Beach	225	490	243	615	368
	Broward	15	41	14	45	14
	Miami-Dade	3	8	10	5	2
	Total	448	1,033	541	1,328	945

Nearshore hardbottom areas are found in proximity seaward of most beaches in southeast Florida, particularly south of Hillsboro Inlet in Broward County. Much of the nearshore hardbottom substrate in the northern areas of the region was created by sabellarid polychaete worms. Nearshore hardbottom substrate in the central region is primarily Anastasia Formation (coquina), while south of Port Everglades (Broward County) carbonate grainstones dominate. Nearshore hardbottom may be ephemeral due to offshore sand movement from the beach system during high wave energy events. This ephemeral nature may be greatly enhanced by sediment inputs from beach nourishment projects. CSA International, Inc. (2009) provides a review of the nearshore hardbottom communities in southeast Florida.

Microbial Contamination of Water and Sand

Water quality of southeast Florida's beaches is routinely monitored for fecal indicator bacteria. If standards are exceeded, the beach is closed to bathers. Beach sand, however, is not monitored, yet sands and sediments provide habitat where fecal bacteria may persist and grow in some cases (Halliday and Gast, 2011). Bonilla *et al.* (2007) found that the length of time a person spent in wet sand and time spent in the water were correlated with increased gastrointestinal illness in southeast Florida. Gull feces were responsible for some of the elevated levels, yet could not account for the overall higher microbial concentrations in sands.

Discussion and Topics of Scientific Debate and Uncertainty

Even though there is information on the effect of natural and human disturbances of the beaches and shore habitats from site-specific studies and on-going monitoring programs, there is also scientific debate and uncertainty regarding the damaging effects of some activities. Data collection and discussion continue on the impacts of beach nourishment on nearshore hardbottom, sea turtle nesting, and shore fishing, as well as sea-level rise and beach erosion.

Burial of nearshore hardbottom can occur during nourishment of eroded beaches or afterwards, when the fill profile is adjusting to the wave climate (fill equilibration). This habitat loss has to be mitigated under permit requirements, but questions remain regarding successful mitigation strategies, prediction of the amount of nearshore hardbottom burial, and subsequent amount of necessary mitigation. Determining successful mitigation requires a detailed knowledge of the nearshore ecosystem, including natural variation across space and time. Often, long term ecological data are lacking. Predicting the effects of burial is difficult because of the complexity of nearshore sediment dynamics and a paucity of studies to support the modeling that has been done. Mitigation requirements are based on time of recovery of damage, mitigation community development trajectories, and quantification of services provided by both. Input data for these requirements are often based on hypothetical assumptions.

The effect of beach nourishment projects on sea turtle nesting is manifested by reduction in nest densities and/or nesting success (the percentage of crawls resulting in a nest). This occurs for the first few seasons following construction. This has been thought to be caused by escarpments and increased sediment compaction. In 2004, however, the Florida Department of Environmental Protection proposed that beach profiles might have an impact on nest success. Earnest *et al.* (2011) proposed a "turtle-friendly" design profile based on review of previous monitoring studies. Additionally, Mota (2011) found that hatchling fitness is affected by oxygen and carbon dioxide fluxes in nests. Beach nourishment can increase the calcium carbonate content of sand which increases compaction, decreasing circulation of atmospheric gases.

Shore or surf fishing is a popular activity in southeast Florida. The most commonly targeted fish is the pompano whose preferred food is the sand flea or mole crab (*Emerita talpoida*). Sand fleas are captured in the intertidal zone so disruptions from beach nourishment could have detrimental effects on the populations. Surf fishing is a recreational activity and the impact of beach nourishment on the fishery is currently not known.

Beach erosion (shoreline retreat) from sea-level rise can be quantified by the Bruun Rule (Bruun, 1962). Areas hemmed in by urban development may not be able to adapt to sea-level rise, and erosion is expected to increase with loss of beach habitat.

Methods to hold sand on beaches, such as artificial seaweed, littoral "speed bumps," beach dewatering, structures (groins, breakwaters), and amino acid applications have not been successful to date and some have caused increased erosion impacts downdrift. The future approach that offers the least environmental impact is small scale (small volume), frequent beach nourishment, using upland or foreign sand sources. However, the most cost-effective method of holding sand on southeast Florida beaches is to protect the natural beach physical environment and habitat. Unfortunately that is now only possible in limited beach locations.

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