Ecological Indicators 44 (2014) 81–91

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Ecosystem indicators for Southeast Florida beaches

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ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form 9 November 2013
Accepted 17 December 2013

Keywords:
Beach
Ecosystem indicator
Human dimension indicator
South Florida ecosystem
MARES

ABSTRACT

Beaches are landscapes valued greatly by society that, when left intact, support both ecological processes and sustainable use. In Southeast Florida, alteration of beaches for human activities has resulted in substantial loss of naturally functioning beach habitat and reduced biological diversity. Of particular importance is the impact on beach ecosystems by the nearby urban environment. Beaches are dynamic ecosystems that require space to respond to natural or anthropogenic drivers and pressures. In Southeast Florida urban development has restricted or eliminated the ability of most beaches to react in a manner that conserves the natural beach ecosystem. The frequent result has been oceanfront areas with little or no intact habitat and limited opportunities for restoration, though disturbed beaches may still provide opportunities for ocean access, recreation, and other socioeconomic benefits in highly urbanized areas. In this study we present a framework for selecting relevant ecosystem and human dimension indicators for the beaches of Southeast Florida based on a conceptual ecosystem model. To capture the level of beach disturbance relatively pristine beaches and heavily altered beaches are endpoints in a continuum of beach development. Across this continuum nine indicators were developed to quantify beach condition. For ecosystem and human dimension assessment purposes, beaches were placed in one of two overarching categories: undeveloped to relatively undeveloped, or developed to highly developed. Nine selected indicators are then assessed as good (3), fair (2), or poor (1). The indicator scores are then summed to produce a total condition score for a particular beach. This simple 'stop-light' method is applicable even when there are limited data and provides a useful relative determination of ecosystem condition. Case studies employing this methodology are presented for three Southeast Florida beaches ranging from mostly natural to highly developed condition.

The indicators directly address both ecosystem and human dimension goals to maintain healthy, sustainable, and useable beaches and shorelines in Southeast Florida. They balance the ecological benefit of remaining natural beaches with the societal benefit of recreational opportunities and access for a beach that can no longer sustain a suitable ecosystem. Each indicator is interpreted in the context of the trade-offs among multiple ecosystem and human dimension services provided by most beaches in Southeast Florida.

1. Introduction

Beaches are dynamic landscapes valued by humans because they provide critical habitat for plants and animals, opportunities for active and passive recreation, storm protection, and beach-related employment, particularly tourism (Johns et al., 2001). Beaches and beach-related tourism activities create over 400,000 jobs and contribute more than $15 billion dollars to Florida's economy annually (Stronge, 2000; Murley et al., 2003). In Broward County in southeast Florida beaches are estimated to add $1.4 billion to local property values, increase local economic production by more than $500 million, and generate almost $30 million in revenue for the local government (Stronge, 1998a,b). Within this region the beach is a widely used coastal environment by residents and tourists because of proximity to urban areas, easy vehicular access, and the social and cultural desirability of "hanging out" by the ocean. Approximately 44% of tourists visiting a Florida beach do so in Southeast Florida (CUES, 2005).

The drivers and pressures that cause change on Southeast Florida beaches range widely over spatial scales from localized overuse to global-scale sea level rise (Schlacher et al., 2007; Defeo et al., 2009). The primary threats to the world's beach ecosystems

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1470-160X/$ – see front matter
http://dx.doi.org/10.1016/j.ecolind.2013.12.021

include erosion, artificial sand placement, shoreline hardening, off-road vehicles, beach cleaning, pollution, fisheries, sand removal (mining), climate-change, and introduced species; all of these, except off-road vehicles, apply to Southeast Florida beaches (Jones et al., 2009).

There are numerous beachfront parks in Southeast Florida managed by governmental and nongovernmental organizations. Most of these areas were designed to protect coastal flora and fauna, provide public beach access, facilitate beach nourishment, or a combination thereof. The majority of beachfront parks in the region include parking, beach access, and support facilities (restrooms, picnic areas, etc.). When left intact coastal beach ecosystems support both ecological processes and sustainable use by humans (Schlacher et al., 2008). However, in Southeast Florida, alteration of beaches for urban development, recreation, and other human activities has resulted in a loss of naturally functioning beach habitat and biological diversity. Only about 10% of natural vegetation remains at Broward and Dade County beaches; some natural areas remain in Palm Beach and Martin Counties (Bush et al., 2004). Unfortunately, as native beach vegetation is lost or removed in Southeast Florida, exotic vegetation, such as *Casaurina equisetifolia* (Australian pine) and *Scaevola taccada* (beach scaevola), frequently invades at the expense of native vegetation.

This spectrum of beach alteration has been taken into account in this study when creating indicators to quantify beach condition. Relatively pristine beaches and heavily altered beaches were used as endpoints in a scale of beach development and the Marine and Estuarine Goal Setting for South Florida (MARES) project provided a framework for developing indicators for the Southeast Florida coastal beach ecosystem. Here we present a methodology for selecting relevant ecosystem and human indicators and the information needed to assess the condition of beach ecosystems. The link between the beach ecosystem and the nearshore marine ecosystem is an important component of the indicators. Case studies provide applications of this methodology for Southeast Florida beaches ranging across the development gradient.

2. Methods

2.1. Characterization of Southeast Florida beaches

The study region is comprised of the ocean beach and immediately adjacent near-shore area in Southeast Florida, from St. Lucie Inlet to Cape Florida (Fig. 1). This coast includes 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. The latitude of South Florida means beaches are seasonally influenced by temperate and tropical oceanic environments. The Gulf Stream, locally comprised of the Florida Current, is a powerful oceanic current passing between the Bahamas and Florida that moderates the coastal water temperatures within the study area and affects regional climate.

Southeast Florida is frequently impacted by strong storm systems (e.g. hurricanes, 'nor'easters') as well as large swells that originate from storm systems farther offshore. Hurricanes and tropical storms can significantly alter beach habitat, morphology, and dune vegetation causing erosion and accretion through sand transport. Where the energy-absorbing dune system has been replaced by coastal structures such as seawalls, even relatively minor storms may negatively impact habitat and recreational uses of the beach.

Geologically, Southeast Florida beaches are comprised of unconsolidated material affected by waves, wind, and ocean currents. The sand composition of a natural beach in Southeast Florida is a combination of quartz and calcium carbonate, with the carbonate fraction increasing toward the south (Mayhew and Parkinson, 2007). Nearshore hardbottom areas are the remains of sabellariid polychaete worms, coquina (Anastasia Formation), and carbonate grainstones (Banks et al., 2008).

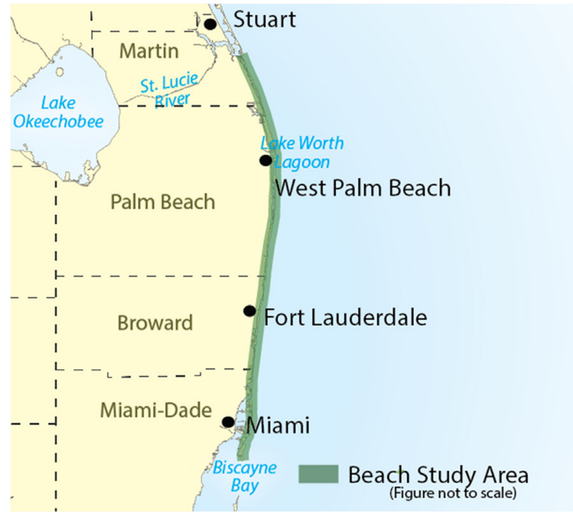

Fig. 1. The MARES Southeast Florida Region including the beaches of Martin, Palm Beach, Broward, and northern Miami-Dade counties.

Most beaches in southeast Florida are in close proximity to urban development. Often the natural sand transport mechanisms are frequently altered, resulting in chronic beach erosion. Sand nourishment and armoring have been the primary management responses to erosion. All counties in the study area, with the exception of Martin County, have nourished and/or armored large portions of the shoreline.

The existing natural beaches are characterized by similar vegetation, though tropical species comprise a larger proportion of the native vegetation in the south while subtropical beach vegetation predominates in the north (Johnson and Barbour, 1990). Beach vegetation within the study area typically occurs in the fore and back dune areas with hammock and scrub vegetation further landward. The transition from temperate to tropical trees occurs in the northern reach of the study area. Because of the large urban footprint, the remaining natural beach habitat is limited to isolated areas, primarily in protected parks.

As an example of the linkages between the open ocean and the beach ecosystem, marine vegetation (primarily *Sargassum* spp. and *Thalassia testudinum*) and marine debris – called wrack – frequently wash onto the beaches of Southeast Florida. While drifting in the surf zone, the presence of macrophyte detritus leads to greater abundance and diversity of surf-zone fishes (Robertson and Lenanton, 1984). Once washed upon the beach, many coastal communities in Southeast Florida mechanically remove seaweed wrack. However, wrack is an important energy source that assimilates into higher trophic levels via two pathways: grazing and decomposition (Ince et al., 2007). The primary pathway is incorporation by grazing herbivorous invertebrates inhabiting the wrack, such as amphipods and dipterans. Subsequent predation on these grazers transfers nutrients and energy to higher trophic levels (Ince et al., 2007; Duong, 2008). As wrack decomposes it remineralizes nutrients necessary for the growth of colonial dune vegetation which indirectly contributes to storm protection, an important ecosystem service.

The interstitial spaces of the sand on a beach support a relatively diverse infauna that experiences cyclic changes of water due to diurnal tidal cycles and seasonal variation. Infauna are represented by microalgae, bacteria, protozoans, and metazoan meiofauna (McLachlan, 1983; Schlacher et al., 2008; Defeo et al., 2009). In this same zone, macrobenthic invertebrates such as crustaceans, molluscs, and polychaetes act as predators, scavengers, and filter-and-deposit feeders (Defeo et al., 2009). In the swash zone where wave action and tides are the predominant physical processes, coquina clams (*Donax* spp.) and mole crabs (*Emerita talpoida*) are common (Wade, 1967; Gorzelany and Nelson, 1987).

A number of organisms depend upon the beach habitat for some portion of their life cycle, including sea turtles and birds. The beaches of Southeast Florida are globally important beaches for sea turtle nesting (Nelson, 1993). Five species of sea turtle use Southeast Florida beaches for nesting: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempii*). By far, the most common species is *C. caretta*. There are five subpopulations of loggerheads worldwide and the Southeast Florida subpopulation is genetically distinct from the others. The Gulf Stream provides a useful transportation conduit for sea turtles, and hatchlings leaving Southeast Florida beaches may eventually enter the Gulf Stream if they survive the predators inhabiting the open beach and nearshore environment.

The beaches of Southeast Florida are important spring and summer nesting sites for some birds of conservation significance (e.g. least tern, *Sternula antillarum*); other birds use the beach as critical foraging and feeding grounds as they overwinter (Schlacher et al., 2008). Small rodents are also an important component of the natural beach habitat. Barrier island rodent populations are distinct from populations of mainland sub-species, and sub-species in other parts of Florida are distinct from those in Southeast Florida (Johnson and Barbour, 1990).

Beaches are trophically linked to adjacent marine ecosystems including nearshore hardbottom areas through feeding forays between ecosystems by birds and fish, detrital/wrack movement across ecosystem boundaries, and by multiple habitat requirements for different ontogenetic stages of numerous organisms (Delancey, 1989; Defeo and Mclachlan, 2005). Some species have bipartite life cycles linking them to both terrestrial and marine environments. A common beach species is the ghost crab, *Ocypode quadrata*; it spends its adult life in dry sand burrows on the open beach feeding on clams, insects, plant material, detritus, sea turtle hatchlings, and other crabs. However, ghost crabs return to the ocean to release their eggs, which develop during a protracted pelagic larval dispersal phase.

Many fishes, such as the goatfish, *Mulloidichthys* spp., feed in soft bottom areas seaward of the intertidal zone. This region of the beach is an important foraging and nursery ground for many fishes of commercial and recreational importance, providing refugia and habitat for invertebrate prey such as shrimp and zooplankton (Ince et al., 2007; Schlacher et al., 2008). Florida pompano (*Trachinotus carolinus*) and gulf kingfish (*Menticirrhus littoralis*) are two important fishes that inhabit the beach surf-zone (Finucane, 1969; Layman, 2000). Coastal surf-zones represent the primary recruitment grounds for young-of-the-year pompano (Solomon and Tremain, 2009). The pompano is a benthic invertivore. When smaller (15–44 mm) the primary prey of pompano are small crustaceans (e.g. amphipods, dipterans). As they increase in size, larger crustaceans (e.g. mole crabs, *Emerita talpoida*) and molluscs (e.g. *Donax* spp) comprise larger proportions of prey (Finucane, 1969; Gilbert, 1986; Layman, 2000). Fishes are predator and prey for higher trophic level species, as such they are important contributors to the transport and deposition of carbon and nutrients across ecosystem boundaries.

2.2. Beaches ecosystem conceptual model

Most conceptual models of the shoreline focus on aspects of the beach other than the beach ecosystem (Milstead et al., 2005; U.S. Army Corps of Engineers, 2006). Using the published literature and considering the data available for the Southeast Florida coast, we developed a beaches and shoreline ecosystem-based management (EBM) Driver-Pressure-State-Ecosystem Service-Response (DPSER) model of the Southeast Florida coastal environment (Fig. 2). The EBM-DPSER model evolved from a Driver-Pressure-State-Impact-Response (DPSIR) framework, intending to directly address how various pressures influence the things that people care about (i.e. ecosystem services; see Kelble et al., 2013).

The drivers and pressures for the beach ecosystem are important agents of change (Fig. 2). Through the MARES process, the following natural and anthropogenic drivers and pressures were identified: climate change (sea-level rise, rainfall and evaporation variability, tropical storm intensity and/or frequency), marine construction (beach nourishment, sea walls, dredge and fill activities), marine debris, urban services (outdoor lighting, beach cleaning), land-based sources of pollution (stormwater nutrient loads, solid waste), and nutrient enrichment of the water column by upwelling.

The MARES process identified numerous beneficial ecosystem attributes for all coastal habitats, not just beaches. Beach ecosystem attributes contribute directly to ecosystem and human dimension services. Primary ecosystem attributes for coastal habitats include abundant and diverse fish and bird communities, seafood safety, habitat for protected species, storm protection, esthetic benefits, opportunities for science and education, and human health issues (MARES Human Dimensions Ecosystem Services White Paper No 7, http://www.sofla-mares.org/download.html). Specific beneficial aspects of beaches and shorelines include storm protection, critical habitat for protected species, beach and shoreline quality, absence of human health issues (for example bacterial contamination), esthetics for both land- and water-scapes, unique oceanfront habitats, ocean access, recreation, and beach-related employment. Information about the attributes is gathered by collecting data on beaches including shoreline geomorphology, area of hardbottom habitat offshore of the beach, dune habitat area, and water quality. Impacts to these attributes include but are not limited to beach erosion/accretion, burial of hardbottom habitat, loss of dune habitat, and water-quality deterioration. Of these, the beach attributes that can be measured are shoreline geomorphology, area of buried hardbottom habitat offshore of the beach, dune habitat area, water quality, oceanfront habitat, ocean access, recreation, and beach-related employment.

Abundant data exist for some attributes of the various ecosystem services related to beaches and shorelines in Southeast Florida (Johnson and Barbour, 1990; Nelson, 1993; U.S. Army Corps of Engineers, 1996; Perkins et al., 1997; Bonilla et al., 2007; Irlandi and Arnold, 2008; CSA International Inc., 2009; Lindeman et al., 2009; Absalonsen and Dean, 2010; Mota, 2011). The most comprehensively quantified beach ecosystem services in the study area include coastal park visitation (indicator for recreation), dollar value of insurance claims for coastal storm damage (indicator for storm protection), and sea turtle nests (indicator for habitat). To-date, responses to drivers/pressures and impacts (not shown on Fig. 2) have included 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 and "lights out" programs, beach structure construction (also a pressure), government programs to assist beach-related business efforts, and planning programs for sea level rise.

2.3. Indicator development and selection

The condition of the beach ecosystem (the State in the EBM-DPSER model) can be quantified by analyzing data collected for possible indicators such as beach biota, dune habitat,

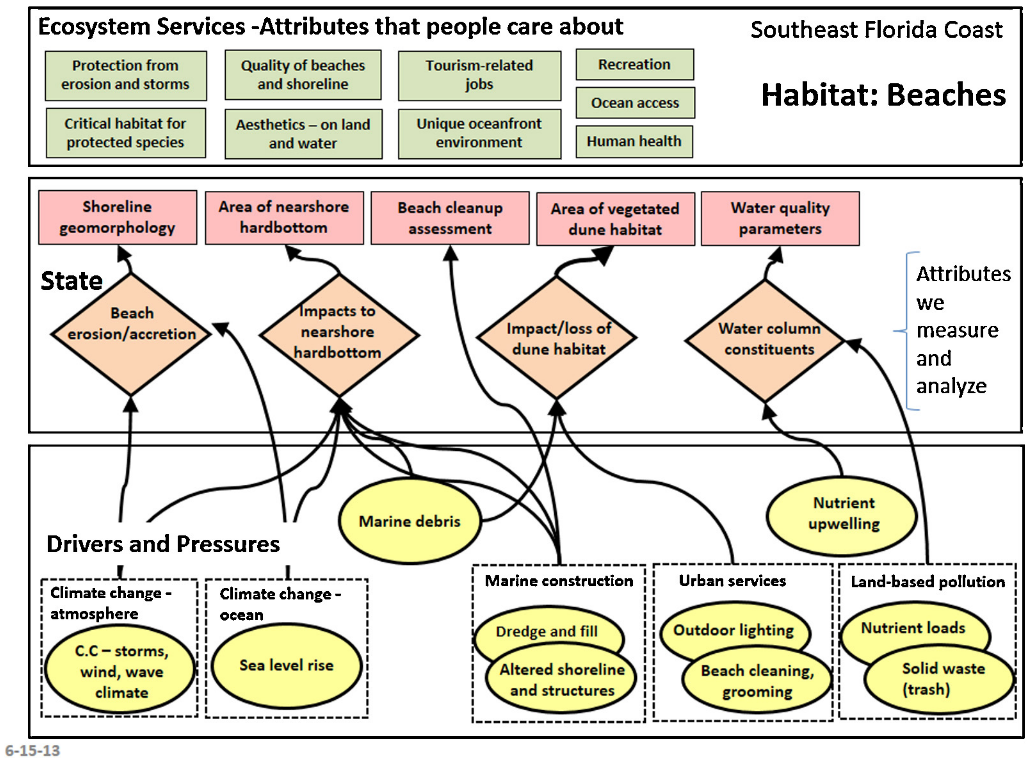

Fig. 2. The Beaches Conceptual Model for Southeast Florida coastal ecosystems. Dominant pressures are yellow ovals. Ecosystem attributes that are measured are maroon boxes. Attributes that people care about are green boxes. The arrows depict how various pressures interact with the attributes.

erosion/accretion, nearshore hardbottom, water quality, and economic growth. A review of existing indicators for beaches produced a number of methods for evaluating the condition of a beach area, including the National Resources Defense Council (http://www.nrdc.org/water/oceans/ttw/) annual report on the water quality of the beaches of the United States, the "Dr. Beach" top beach list (http://www.drbeach.org/top10beaches.html), the Surfrider Foundation beach health indicators, and UNESCO (2006).

Candidate indicators of beach ecosystem quality from the literature were assessed and evaluated for use in quantifying the condition of Southeast Florida beaches. The MARES screening criteria were used to determine which biotic factors would be useful for developing indicators for beaches. These "screening" criteria included relevance to management goals, sufficient data with high accuracy and precision, ability to predict how the indicator will respond to management actions, and ease of comprehension by managers and the general public. Based on these criteria, ghost crabs, coquina clams, mole crabs, and sea turtles were short-listed as candidate indicators for the condition of the Southeast Florida beach ecosystem.

Ghost crabs, coquina clams, and mole crabs were suggested as beach ecological indicators because they respond to disturbance, are quantifiable, and provide important ecological functions in coastal environments, including cycling of organic matter and acting as prey (Florida Fish and Wildlife Conservation Commission, 2005). Following disturbance coquina clams experience reductions in abundance and mole crabs have been found to take up to a year to re-establish former populations (Peterson and Manning, 2001). Also, mollusks (such as coquina clams) are affected by the type of sand, grain size, degree of sorting, beach slope, wave climate, and sand organic content (Wade, 1967; Salas et al., 2006). Some studies suggest that the distribution and abundance of ghost crabs can measure short- and long-term effects of beach nourishment projects (Lucrezi et al., 2009). Similarly, Schlacher et al. (2011) and Noriega et al. (2012) successfully used ghost crabs as indicators of beach and dune disturbance; i.e. reduced ghost crab densities were related to human use and disturbance while beach width and abundance of natural vegetation provide better ghost crab habitat. However, in an evaluation of beach nourishment, changes in the abundance and distribution of ghost crab, mole crab, and coquina clam could not detect statistically significant impacts; more extensive monitoring programs generating larger sample sizes would be necessary to remedy this (Irlandi and Arnold, 2008).

Ghost crabs, coquina clams, and mole crabs are relevant to habitat management goals, but there are not sufficient data in Southeast Florida for use as a quantitative indicator. On the other hand sea turtle nesting data have been collected for many years. For this reason, sea turtles were selected as the primary biological indicator of beach ecosystem condition in Southeast Florida.

In Florida, all sea turtle species are protected and nests are considered important beach ecosystem indicators (Florida Fish and Wildlife Conservation Commission, 2005). We identified the level of human interaction required to protect turtle nests as a good indicator of the level of human disturbance to beaches. Anthropogenic impacts on nesting include direct loss of habitat due to shoreline hardening and structural changes, and indirect effects such as artificial light disorientations of hatchlings and feral animals depredating nests (Bjorndal and Bolten, 2003). The State of Florida has been collecting data on sea turtle nests on Index Beaches and other surveyed beaches since 1989. These data suggest nesting habitat has decreased over the past 20 years despite limited changes in the linear extent of beaches used for nesting during this period, and variability due to climate and physical environmental factors (Bjorndal and Bolten, 2003; Witherington et al., 2009). Additionally, it was noted that sea turtles have shown some adaptation to using disturbed beaches for nesting even though habitat disturbance due to development of adjacent areas has been significant.

Table 1
The ratings of potential indicator measurements for Southeast Florida based on the four MARES screening criteria for ecosystem indicators (H = high potential, M = medium potential, and L = low potential;).

	Relevant to management goals	Sufficient data with accuracy and precision	Predict response to changes	Understood by managers and public
Presence of built environment	H	H	M	M
Dune condition	H	H	H	M
Berm condition	H	M	M	M
Sea turtle nests	H	H	M	H
Value for low-cost shore protection	H	M	H	L
Access	H	M	H	H
Human health issues	H	M	M	H
Level of passive and active recreational use	H	L	L	M
Beach-related jobs	H	M	M	M

Modern society places significant value on the services provided to humans by beaches that are not related to the natural components of the ecosystem (e.g. access, recreation, fishing, sunbathing, socializing). For some beach visitors their beach experience does not require a natural beach environment; benefits are derived from opportunities for recreation and socializing. Therefore, indicators of human dimension services were also considered as candidate indicators.

2.4. Using indicators for beach assessments

All candidate indicators for both ecosystem and human dimension services were evaluated using MARES screening criteria (Table 1). In general, all candidate indicators were relevant to the goals of managing beaches, but no single indicator was considered to have high potential across all criteria. Low potential is only scored for recreation and value for low-cost shore protection. All candidate indicators ranked high for relevance to management goals and were selected for implementation as beach ecosystem indicators. The nine indicators range across the ecological and socioeconomic domains.

Cendrero and Fischer (1997) developed a framework for assessing the condition of coastal areas. They identified attributes important to humans including air, marine water, fresh water, terrestrial biota, marine biota, geological and topographic features, hazards, resources, landscape, and human aspects. Quantifiable indicators were selected for each component of the coastal environment and a weighted score was computed to enable relative comparisons. This indicator method includes environmental and human components, meaning that it may apply to beaches that have already experienced alteration by urbanization. However, this scoring method requires large amounts of data, limiting its application.

Araújo and da Costa (2008) recognized that the coastal environment is comprised of interacting natural and socioeconomic subsystems. They ranked the environmental condition of recreational beaches in three categories (undeveloped, developed, over-developed) using a four grade system (A, B, C, and D; A = excellent and D = poor). They then applied their method to beaches in Brazil with varying levels of urban development.

During the MARES process managers stressed the need for simple, 'stop-light' methods that are applicable to data-sparse systems but still provide a relative determination of ecosystem condition. Adapting the methodologies of Cendrero and Fischer (1997) and Araújo and da Costa (2008) we identified criteria to place a Southeast Florida beach in one of these two overarching categories (Table 2): (1) undeveloped to relatively undeveloped beaches or (2) developed to highly developed beaches. Undeveloped and relatively undeveloped beaches are characterized by pristine or predominately functional habitat and beach nourishment projects, if conducted, must have occurred more than 10 years ago and the natural habitat is in recovery. For developed to highly developed beaches, some functional habitat may be present but nourishment has occurred within the past decade, there is a high probability of future beach nourishment, and the altered habitat is not likely to recover for an extended period.

For undeveloped to relatively undeveloped beaches, the natural ecosystem service indicators are primary and the human dimension services are secondary when assessing beach condition. For developed to highly developed beaches, the human dimension services are primary, and the natural ecosystem services secondary, because there is little or significantly reduced natural habitat. In the application of indicators, an undeveloped or relatively undeveloped beach within a park is also assessed for access, value for low-cost storm protection, and level of passive and active recreational use but it is not desirable to maximize parking, beach access, and active recreation at the expense of natural habitat. On a developed or highly

Table 2
Screening criteria for categorizing the level of development for a beach site in Southeast Florida.

Criteria for level of disturbance	Category of development	
	Undeveloped to relatively undeveloped	Developed to highly developed
Previous history of nourishment	Beach has never been nourished, or the last nourishment project was at least ten years prior, and there are no plans for nourishment in the foreseeable future	Beach has been nourished in the past ten years and may or may not have a plan for future nourishment.
Presence/absence of seawalls or other engineered structures	No seawalls or other engineered structures	Beach has seawalls or other engineered structures are present
Method of beach cleaning	Beach is not cleaned or is cleaned by hand and macrophyte wrack is left on the beach	Beach is mechanically cleaned and/or the wrack is removed from the beach
Level of protection for human and environmental co-use	Land is part of a local, State, or Federal park with recognition in a management plan (or similar)	Land may be private land or under government ownership

developed beach site, a small section of limited but useful habitat for sea turtles or other beach flora and fauna should still be conserved to the extent possible, in a balance with opportunities for active recreation.

After categorizing the development state of a beach, existing data are used for each indicator to assign a value of good (3), fair (2), or poor (1) for the criteria in Table 3 (undeveloped to mostly undeveloped beaches) or Table 4 (developed to highly developed beaches). To facilitate decision-making there are few indicators and a simple scoring system, and the outcome of the assessment is clear. The indicator scores are then summed to produce a total assessment score for a beach condition. Total scores range from 9–27. Scores (totals) between 9 and 14 indicate poor condition (red), 15–20 indicate fair condition (yellow), and 21–26 indicate good condition (green) with a score of 27 indicating excellent condition.

Many of the indicators can be evaluated through the use of aerial photographs followed by ground-truthing (Table 5). For some indicators, data are readily available, such as sea turtle nests, crime reports, health department reports, and insurance claims/payments. Economic data on beach-related jobs exist, however there are no known programs to maintain a centralized database of beach-related socio-economic data. For ecosystem services, scientific studies and data that describe stressor response may be available. Some indicators integrate the effects that occur in other categories. For example, dune condition and berm condition provide useful information on the health and suitability of a beach for sea turtle nesting which is also an indicator.

3. Results – case studies

The nine indicators for Southeast Florida presented in Tables 3 and 4 were used for three case studies to illustrate the utility of the beaches indicators. The beaches chosen included an undeveloped beach, a highly developed beach, and a beach with some characteristics of both.

3.1. Undeveloped beach: Blowing Rocks Preserve, Martin County

Blowing Rocks Preserve is so named because of the one-mile long, rare (to Southeast Florida) coquina rock shoreline on Jupiter Island where plumes of saltwater can be sent skyward during storm events. While the 73-acre beach ecosystem at Blowing Rocks Preserve is not an undisturbed habitat it is an accepted model for a large-scale, native coastal habitat restoration project undertaken by the Nature Conservancy beginning in 1969. While the rock formation forms the primary line of defense for storm protection, the restored ecosystem behind the dune lines contributes greatly.

The human dimension services (besides low-cost storm protection) include a small parking area, beach access, native plant demonstration garden, and interpretative signs along three hiking trails and boardwalks. Swimming, snorkeling and scuba diving are allowed from the beach during specified hours. Restrooms and other facilities are available and exhibits and guest lectures are offered.

We applied the screening criteria in Table 2 to the Blowing Rocks Preserve site. The beach has never been nourished, has no coastal structures, is not mechanically cleaned, beach wrack is left intact except for removal of trash, and the property is protected by the Nature Conservancy. Therefore this beach is categorized as an undeveloped to mostly undeveloped beach and was assessed using the criteria in Table 3.

Even though predation of sea turtle nests is sometimes noted on the Blowing Rocks Preserve beach, all sea turtle nests are left *in situ* with no human interaction needed. The swash zone contains mole crabs which are collected by surf fishermen and used as bait for desirable species such as Florida Pompano. The most difficult human dimension service to be provided by undeveloped and mostly undeveloped beaches is beach-related jobs. Blowing Rocks Preserve provides research and educational opportunities, as well as being a tourist destination for visitors desiring an undeveloped beach. All indicators delineate a relatively pristine condition with scores of 3 for all indicators (green); total score = 27 out of 27 points.

3.2. Highly developed beach: South Hollywood beach, Broward county

The southern beaches in Hollywood, Florida are fully developed with condominiums and hotels including protective seawalls and narrow beaches. Creed et al. (2010) analyzed erosion patterns along the beaches of Broward County and found that beach erosion correlated positively with the seaward extent of the shorefront development line. The development line in south Hollywood Beach is farther seaward than that in the north/central areas and erosion rates are substantially higher.

Application of the screening criteria in Table 2 categorizes this beach as highly developed with nourishment last occurring in 2006, continuous seawalls, daily mechanical cleaning, and private ownership to the Erosion Control Line (ECL), a line representing a fixed property boundary along the beach. When beach nourishment is partially funded by the State of Florida an ECL must be established, and property can be gained or lost with accretion/erosion. The private property boundary is fixed by the ECL in agreement with the upland property owner.

The indicator scoring for south Hollywood Beach using the criteria in Table 4 is as follows:

Presence of built environment = 1.
Dune condition = 1.
Berm = 2.
Sea turtle nests = 2.
Value for low-cost shore protection = 1.
Access = 1.
Human health issues = 3.
Level of recreational use = 2.
Beach-related jobs = 1.
Total score = 14 (poor condition, red).

The indicators for “level of recreational use” and “beach-related jobs” both benefit from activities in the adjacent central Hollywood Beach and Hallandale Beach (south) which have greater public access and vendors catering to beach users. Because of this, the score is almost enough for the condition (Table 3) to be considered as “fair”.

3.3. Developed beach: John U. Lloyd State Park, Broward County

John U. Lloyd State Park (JUL) is located adjacent to the south jetty at Port Everglades, a commercial/industrial port with a direct ocean inlet (man-made). As a result, there is substantial shoreline erosion due to the inlet protection structures (Nelson, 1989; Creed et al., 2010). In 2005 sand was placed on the entire beach in the park. The southern portion of the shoreline has a relatively well-formed dune with natural vegetation landward of the beach. There is no urban development behind the back dune area. Although the southern shoreline has characteristics of a Relatively Undeveloped beach (Table 2), the north end of JUL has characteristics of a Developed category. The erosion and coastal structure issues on the north end prevent JUL from being considered a “relatively undeveloped beach”.

Indicator scoring of JUL using the criteria in Table 4:

Table 3
Indicators for undeveloped to relatively undeveloped beaches in Southeast Florida.

Condition	Indicator								
	Presence of built environment	Dune condition	Berm	Sea turtle nests	Value for low-cost shore protection	Access	Human health issues	Level of passive and active recreational use	Beach-related jobs
Good (relatively pristine)	No built environment present	Continuous undisturbed vegetated dune with back-dune hammock present	Natural berm in front of natural dune formation	Sea turtle nest left in situ because of no threats	Natural beach protecting personal property with no intervention required	Very good access with restrooms for general public, no crime issues	Never	Mostly passive use such as swimming, sunbathing, walking, fishing, etc. with some limited active use	Beach is used for research, conservation-education, or tourist-promotion jobs
Fair (slightly disturbed, mostly functional habitat)	Built environment, if present, well back from beachfront, behind a full dune system	Continuous undisturbed vegetated dune with impacted back-dune hammock	Wide berm unless beach is naturally narrow	Measures needed occasionally to protect sea turtle nest left in situ	Shore protection provided back of beachfront with limited or no disturbance of beach for protection purposes; no seawalls	Limited access or small number of parking spaces, public restrooms available, limited crime issues	Occasional	Reasonable opportunity for passive recreation with limited active recreational opportunities	Jobs are available related to off-beach activities
Poor (moderately disturbed, contains functional habitat and/or limited human function	Built environment is directly behind partial dune system, seawalls may be present back of dune	Vegetated dune present but slightly impacted and may not be fully developed; no back dune	Berm, wide enough for sunbathing and passive beach recreation	Measures needed each season to protect sea turtle nest left in situ	Shore protection measures (nourishment) needed in past and may be needed in future	Poor access (ex: limited parking) and/or no public restrooms, crime issues documented	Recurring	No or limited passive recreational opportunities; poor opportunities for active recreational use	No or limited job opportunities related to beach activities

Table 4
Indicators for developed to highly developed beaches in Southeast Florida.

Condition	Indicator								
	Presence of built environment	Dune condition	Berm	Sea turtle nests	Value for low-cost shore protection	Access	Human health issues	Level of passive and active recreational use	Beach-related jobs
Good (impacted, substantial public benefit from use)	Built environment near beachfront is single family or low-rise multi-family with development restrictions; no shorefront protection	Dune system present in reduced form or has been restored	Wide berm	Sea turtle nests can be left in situ with limited need for protection from lighting and predators	Low probability of shore protection needed in near future	Good, safe access for general public with clean restrooms	Never	Good passive and active recreational opportunities available	Jobs are available related to on- and off-beach activities
Fair (moderately impacted), some public benefit from use)	Seawalls present back from beachfront; no groins, jetties, or shorefront protection	Restored dune system in need of refurbishment	Narrow berm but wide enough for sunbathing and limited recreation	Sea turtle nests can be left in situ with active protection from lighting and predators	Probability good that active shore protection needed now or in near future	Poor access for general public, limited parking, restrooms available, limited crime issues	Occasional	Limited passive recreational opportunities available	Limited number of jobs are available related to on- and off-beach activities, construction of shore protection measures
Poor (severely impacted, little public benefit from use	Bulkhead, jetty, groin, seawall, or shorefront protection present near high tide water	No dune system	No berm	Sea turtle nests cannot be left in situ	Human intervention needed to provide shore protection from erosion	Limited or no access and/or no bathrooms, crime issues documented	Frequent	No passive or active recreational opportunities	Only jobs available are related to nourishing or construction of shore protection

Table 5
Data and other information sources to be used for assessments of beach sites in Southeast Florida.

Indicator	Sources of information
Dune condition	Aerial photographs with a follow-up visit to ground-truth the condition.
Berm condition	Aerial photographs with a follow-up visit to ground-truth the condition.
Sea turtle nests	Statewide and Index Beach data from the Florida Fish and Wildlife Conservation Commission (FWC) and/or counts and beach survey reports provided by State-recognized, local sea turtle conservation organizations
Presence of built environment	Aerial photographs with a follow-up visit to ground-truth the condition.
Safe access	Access and restrooms are measured through the use of aerial photographs with a follow-up visit to ground-truth the observations. Incidence of crime is measured by crime reports from city or county law enforcement agencies.
Level of passive and active recreational use	Aerial photographs with a follow-up visit to ground-truth the condition.
Value for low-cost shore protection	Aerial photographs with a follow-up visit to ground-truth the observations and the use of insurance claims paid for damages to properties.
Beach-related jobs	Beach-related jobs are measured by reviewing data and/or other information available from Counties or metropolitan planning agencies, supplemented by available economic studies by universities.
Water and sand quality (human health issues)	The measures of condition include reports from County Health Departments or from the National Resources Defense Council (www.nrdc.org) annual report on the water quality of the beaches of the United States.

Presence of built environment = 3.
Dune condition = 3.
Berm = 3.
Sea turtle nests = 3.
Value for low-cost shore protection = 1.
Access = 3.
Human health issues = 3.
Level of recreational use = 3.
Beach-related jobs = 2.
Total score = 24 (green).

The indicators for shore protection and beach-related jobs are adversely affected by the recent beach nourishment and the limited potential for jobs in the state park. It is noted that there are park jobs, some vendors, and short-term employment opportunities when the beach is nourished.

4. Discussion

The beach ecosystem represents the transition between the terrestrial and marine environments. Under natural conditions, it is a fringe of sand and colonial vegetation in a dynamic environment where long- and short-term disturbance is a defining characteristic, particularly along the leading edge. It is a fragile ecosystem, easily disturbed or impacted by human activities. In Southeast Florida more of the beach has been disturbed than has not. While no longer pristine, many of the disturbed beaches are frequently used as parks and public areas (some with remnant beach ecosystem vegetation) serving an important open space function in a highly urban region.

The condition of the beach in terms of the natural environment, municipal services, and socioeconomic expectations can be determined through the use of ecosystem and human dimension indicators. Data on biota (if available) can be used to assess the condition of the beach ecosystem, and data on provisioning services can be used to determine if the land is successfully achieving its designated use as a public facility. Key human and habitat indicators play a critical role in beach ecosystem assessments.

Of particular importance as an anthropogenic pressure on the beach ecosystem is the proximity of the urban environment. Because beaches are dynamic systems, they require space to move in an onshore/offshore direction and alongshore. Encroachment into habitat, including urban development, sand nourishment, and coastal structures compromises the ability of the beach to provide low-cost storm protection and critical habitat for protected species. When urban areas are located farther from the shoreline the beach can naturally react to climate drivers by allowing natural sand movement. This promotes formation of sustaining, protective dune systems.

Stored sand in dunes provides a cost effective method of protecting the human environment from storms. The general public has limited knowledge of the importance of this function or the ecological value of beach habitat, and as a result ecosystem services have been lost to beach development. When erosion or urban encroachment (or both) reduce the width of the beach and threaten storm protection or recreation, the response is often to nourish the beach or implement structural stabilization, exacerbating the problem.

For many urbanized coastal areas in Southeast Florida, oceanfront development has reduced or eliminated the ability of a beach to sustain a natural biotic community. To avoid unnecessary conflict in the manner of use for human and natural components of the beach ecosystem, beach sites were divided into two categories across a gradient of development to recognize the value of the human dimension services that may be provided by altered shorelines with limited potential for generating natural ecosystem services. To enable relative comparisons the indicators are the same for both categories of beach development; the manner in which the collected data are used (i.e. the ruler) differs.

The high degree of disturbance of nearshore and beach communities makes it difficult to find suitable experimental controls for impact monitoring. While there is information on the effect of natural and human disturbances on beach and shoreline habitats from site-specific studies and on-going monitoring programs, there is also scientific debate and uncertainty regarding the damaging effects of some activities. For example, consensus on data collection methods continues to be debated on the impacts of beach nourishment on nearshore hardbottom (NHB), sea turtle nesting, and surf fishing (CSA International Inc., 2009). Burial of NHB can occur during nourishment of eroded beaches or afterwards, when the fill profile is adjusting to the wave climate (fill equilibration). Beach nourishment projects also affect sea turtle nesting by reducing nest densities and/or nesting success for the first few seasons following construction. Earnest et al. (2011) have proposed a 'turtle-friendly' design profile based on review of previous monitoring studies.

Surf fishing, a component of ecosystem services (Recreational Fishing), is a popular activity in Southeast Florida. Two of the most commonly targeted and highly valued fish are Florida Pompano and gulf kingfish (*Menticirrhus littoralis*, a/k/a croaker) whose preferred foods (*E. talpoida* and *Donax spp.*) are captured in the intertidal zone which may be disturbed by beach nourishment activities (Solomon and Tremain, 2009). However, the impact of beach nourishment on the surf fishery can be ambiguous; during active beach nourishment in New Jersey *M. saxatalis* were more abundant, while other common species (e.g. bluefish, *Pomatomus saltatrix*) decreased in abundance (Wilber et al., 2003).

Other topics of regional interest are the anticipated effects of sea level rise (SLR) and associated increased erosion. Beach erosion (shoreline retreat) from SLR is most often quantified by the Bruun Rule (Bruun, 1962), though there is debate surrounding this method (Cooper and Pilkey, 2004). Areas hemmed in by urban development may not be able to adapt to SLR, and loss of beach habitat is expected to increase as a result of erosion.

For many beaches data exist for evaluating change. If additional data are needed the measurements for most of the indicators herein can be made easily and accurately because indicators requiring extensive data collection were excluded from use. In most cases it is possible to predict through existing studies of beaches in and outside of Southeast Florida how most of the indicators will respond to drivers and pressures over time, such as natural disturbances, anthropogenic stresses, and changes in other pressures. For example, existing shore profile surveys have made it possible to understand that a well-developed and protected berm and dune system may erode during substantial storms, but it will re-build over time if there is a sufficient interval before the next storm and the presence of the urban environment is sufficiently distant from the shoreline. This is a cost-effective way of providing storm protection for the built environment, an important human dimension service. In some cases additional data collection may be needed to provide an adequate assessment. For some of the human dimension services indicators (e.g. access or level of passive and active recreation) the response of the indicator to stressors may not be quantified in the scientific literature, yet a qualitative or directional determination of improvement or decline may be possible.

Several biological indicators of beach condition that have been used in other areas may be applicable to Southeast Florida if additional data are acquired. Noriega et al. (2012) and Schlacher et al. (2011) found that ghost crabs could be characterized by counting burrow openings and were good indicators of human use of beaches. Mole crabs are common in the intertidal zone of Southeast Florida beaches, and beach nourishment eliminates these populations (Peterson and Manning, 2001). Monitoring recovery would provide an indication of intertidal zone recovery following these projects, yet this is normally not included in beach project monitoring.

In Southeast Florida mitigation of beach erosion is a primary focus for most local governments. Sea turtle nesting is elevated in importance due to Endangered Species Act listing and potential impacts from erosion mitigation activities. Municipalities may argue that the cost of beach ecosystem monitoring is an additional expense with no economic return. However, it may be possible to leverage existing programs and personnel (e.g. lifeguards, volunteer groups) to record some of the simple metrics needed for these additional indicators. Fortunately, most of our proposed indicators circumvent this lack of information because they are easily measured with existing information and provide a good metric of beach condition.

5. Conclusions

A framework for the development of indicators for beach ecosystem and human dimension conditions has been presented that is based on a conceptual ecosystem model. The indicators in the Southeast Florida beaches conceptual model directly address both ecosystem and human dimension goals to maintain healthy and sustainable beaches and shorelines. They balance the ecological benefit of conserving the remaining natural beaches with the use of beaches that can no longer support a sustainable ecosystem for recreation and access. Because of this, each indicator can be interpreted in the context of the trade-offs among multiple ecosystem and human dimension services provided by most beaches. To avoid conflicts in Southeast Florida between beaches with sustainable coastal ecosystem and beaches where the natural coastal ecosystem was lost decades ago, beaches were divided into two categories across the development gradient prior to assessment using indicators.

The selected indicators provide a measure of the overall health of the beach ecosystem in Southeast Florida and capture the essential ecosystem and human dimension services of the beach ecosystem. Each of the indicators provides information about the condition of the beach in a particular development category and some indicators integrate the effects from other categories. As a result the indicators assess ecosystem services in both categories.

The effects of human use of the beach ecosystem are directly measured in the assessment of ecosystem and human dimension services provided by beaches and shorelines in Southeast Florida. Because coastal areas around the globe are rapidly developing through urbanization, the pressure of this development may result in areas with over-extension of the urban area into the beach ecosystem resulting in the loss of ecosystem services that are of value to society. The availability of indicators for both ecosystem and human dimension services as presented herein will help to protect the existing examples of sustainable beach ecosystem habitat and allow for acceptable use of areas where the natural environment no longer exists and the chance for restoration is remote.

Acknowledgements

We would like to thank everyone involved in the MARES process. We would also like to thank Chris Kelble, Peter Ortner, Joe Boyer, and 2 anonymous reviewers for comments on an earlier draft. This work was made possible with support from the Broward County Natural Resources Planning and Management Division, the University of Miami, Cooperative Institute for Marine and Atmospheric Studies, and the National Oceanographic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory.

This paper is a result of research under the Marine and Estuarine Goal Setting (MARES) for South Florida Project funded by the National Oceanic and Atmospheric Administration Center for Sponsored Coastal Ocean Research (Coastal Ocean Program), under award NA08OAR4320889 to the University of Miami, NA09NOS4780224 to Nova Southeastern University, NA09NOS4780225 to the University of Massachusetts Amherst, NA09NOS4780226 to the National Audubon Society, NA09NOS4780227 to Florida Gulf Coast University, NA09NOS4780228 to Florida International University, and to the NOAA Atlantic Oceanographic and Meteorological Laboratory.

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