Suitability Analysis for Living Shorelines Development in Southeast Florida's Estuarine Systems

Technical Report

SUBMITTED TO:
THE NATURE CONSERVANCY

SUBMITTED BY:
Diana Mitsova, PhD
Principal Investigator
School of Urban and Regional Planning
FLORIDA ATLANTIC UNIVERSITY

This project was funded by The Nature Conservancy under Grant Agreement #FLFO-FAU-090115.
The views expressed herein are those of the authors and do not necessarily reflect the views of The Nature Conservancy or any other agency.

Suitability Analysis for Living Shorelines Development in Southeast Florida's Estuarine Systems

Prepared by:

Diana Mitsova, PhD
Associate Professor and Principal Investigator

Allison Goldberg
Graduate Research Assistant

Kevin Cresswell
Graduate Research Assistant

Rayan Alhawiti
Graduate Research Assistant

School of Urban and Regional Planning
FLORIDA ATLANTIC UNIVERSITY

Boca Raton, FLORIDA
January 31, 2016

EXECUTIVE SUMMARY

Coastal hazards including storm damage and sea level rise threaten coastal cities and may drive major shifts in urban development patterns. With elevations of 3 to 4 feet, South Florida is one of the most vulnerable coastal regions in the world. Areas at risk are likely to see increased shoreline armoring which may have long-term environmental impacts on the health of our estuaries and the ecosystem services they provide. The hard-armoring approach is known to reduce sediment sources by interrupting natural sediment transport, affect water quality, reduce habitat viability, and fundamentally disrupt the connectivity between terrestrial and estuarine and marine ecosystems. Shoreline restoration and enhancement techniques have been shown to provide comparable protection under suitable landscape and environmental conditions. An emerging approach to shoreline stabilization is to create "living shorelines" in which natural habitats are incorporated into a resilient shoreline stabilization design.

The project titled "Suitability Analysis for Living Shorelines in Southeast Florida Estuarine Systems" is a continuation of a previous project titled "South Florida Living Shorelines Spatial Database: Shoreline enhancement, restoration, and stabilization projects" which was funded by a Grant Agreement #FLFO-FAU-060114. The Southeast Florida (SEFL) Regional Climate Change Compact Shoreline Resilience Working Group (SRWG) provided the impetus for this effort as well as invaluable expertise, input and feedback. The database itself was a continuation of a shoreline database pilot study supported by a seed grant from the FAU Climate Change Initiative in 2012-2013. The spatial extent of the database encompasses the estuarine areas alongside inland waters in Broward County, Miami-Dade County, Palm Beach County, and the Blowing Rocks Preserve in Martin County. This database was created based on our understanding of the importance of nature-based shoreline stabilization options at reducing the impacts of coastal hazards, and their contribution to the health of estuarine and marine environments, and protection of economic and cultural resources. Several shoreline stabilization projects included in the database use a range of naturally occurring features to stabilize and protect shorelines.

Drawing upon the scientific literature, expert opinion and shoreline management best practices, we propose a decision framework for multiclass suitability classification of generic project types that use a range of naturally occurring features to stabilize and protect shorelines. We apply a modified version of the InVEST Coastal Vulnerability model (Sharp et al. 2015) to calculate an exposure index based on spatial attributes such as wind/wave exposure, boat wake, nearshore slope, storm surge, water depth, nearshore habitat, and distance to inlet. An expert opinion survey was conducted to elicit parameter weights. The calculated Exposure Index was then used to develop a suitability framework based on decision trees for multi-criteria evaluation to facilitate future efforts to establish the use of vegetated shorelines or a combination of plant communities and stabilization to attenuate wave action, dissipate wave energy, and mitigate erosional forces. The results of the analysis will facilitate decisions regarding the use of vegetated shorelines or a combination of plant communities and structural stabilization to attenuate wave action, mitigate erosional forces, and reduce storm damage. The successful implementation of innovative shoreline stabilization techniques is particularly important in the context of sea level rise which will most likely amplify the flood management challenges faced by residents, planners, coastal managers, and decision-makers. Re-evaluation of the existing regulatory basis for including living shorelines provisions and demonstration projects on public and private lands will increase awareness and acceptance of these alternative shoreline stabilization options. As a step in this direction, section 2(a)(2) of Executive Order 11988 was recently amended to include the use of natural systems and ecosystem services in the development of flood control alternatives (EO 13690/Jan. 30, 2015, FR 80 (23)/6425-28/Feb. 4, 2015). Living shorelines have the potential to enhance ecosystem services in estuaries and other sheltered shorelines which are particularly vulnerable to the effects of development and hardening. The management challenge here is to find ways to allow property owners to protect their valuable real estate while at the same time minimize long-term environmental impacts on the health of our estuaries and the ecosystem services they provide. The benefits can be mutual as a waterfront lot with natural wetlands and living shorelines is more aesthetically pleasing and hence potentially more valuable leading to increased property values and tax base.

Section 1 provides an overview of the pertinent literature with a focus on alternative approaches to shoreline stabilization. Factors that affect the establishment of nature-based approaches are discussed and the objectives of the study are formulated. In Section 2, the Southeast Florida context and the methods employed in this study are discussed. Section 3 contains the results of the analysis. Appendix 1 lists the shoreline description together with the proposed stabilization option for each shoreline type. Appendix 2 includes several maps displaying locations where alternative solutions to hard armoring could be implemented. A synopsis of attribute labels, attribute type, attribute definition, and attribute data source of the Exposure Index shapefile is given in Appendix 3. Appendix 4 contains the research participation invitation. Appendix 5 includes the survey instrument. Appendix 6 contains the report generated by Qualtrics.

ACKNOWLEDGMENTS

This project was funded by a Grant Agreement #FLFO-FAU-090115 between The Nature Conservancy and the Florida Atlantic University Board of Trustees.

We gratefully acknowledge the contribution of many individuals and organizations. First and foremost, we would like to thank the members of the Southeast Florida Climate Compact Shoreline Resilience Working Group who provided invaluable support in all phases of the project.

DISCLAIMER

This study is based on publicly available data sources and expert knowledge. The results from this study are not intended to create or constitute any legally binding obligation and no party shall have any liability or obligation to another with respect to using the result from the analysis as is. All users should carefully consider scale, purpose and intended uses and consult the best available data sources as certain assumptions developed under the project may not be suitable for all purposes, tasks and/or planned objectives.

Data for shoreline restoration, enhancement and stabilization projects in the study area were not generally available through public data sources. The data were obtained through direct communication and data requests, or derived from historical documents. Data for several parameters used in the suitability analysis were available only in permits and reports. Every effort was made to ensure the completeness and accuracy of the information in each spatial layer. However, some discrepancies may still persist due to the variety of sources used to compile the information. Some spatial layers may not be as comprehensive as others because such data were not produced by the owner of the data source.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Coastal regions are some of the most vulnerable to disasters and ecosystem disturbances due to co-location of critical infrastructure, high population densities, and major resource use to maintain vital economic activities (Walker et al. 2004, Adger et al. 2005, Adger 2006, Becker 2012, Beichler et al. 2014). In fact, the linkages between socio-economic and ecological systems in coastal areas are so intertwined that the very concept of socio-ecological resilience draws upon the ability of interconnected social-ecological systems to withstand, mitigate, absorb shocks, and recover from extreme events while simultaneously maintaining the functionality of human infrastructures and allowing for provision of essential societal services (Walker et al. 2004, Adger et al., 2005, Beichler et al. 2014). Recent studies evaluating the risks of climate change on coastal regions highlight increased exposure and vulnerability due to continued population growth and placement of critical economic resources in harm's way (Nicholls 2004, Adger et al. 2005, Rosenberg and McLeod 2005, Leslie and McLeod 2007, McGranahan et al. 2007, UNEP 2009). In 2007, scientists at the Center for International Earth Science Information Network and the International Institute for Environment and Development published a study of global population at risk of sea level rise impacts (McGranahan et al. 2007). The study found that over 600 million people live in coastal areas at elevation of less than 10 meters (McGranahan et al. 2007). In addition, the largest and most populous urban areas around the globe are situated, partially or entirely, in the low-lying coastal zone (McGranahan et al. 2007). More recently, data from the UN Atlas of the Oceans developed by six UN agencies in collaboration with various partners from the private and public sectors indicated that currently 44 percent of the global population resides in coastal areas (UN Atlas of the Oceans 2015) with an expected increase to 50 percent by 2030 (Nicholls 2004, Adger et al. 2005).

The increasing pressures on coastal ecosystems due to accelerating pace of urban development have led to the degradation of many of the ecosystem functions on which human prosperity and well-being depend (MA 2005, Rosenberg and McLeod 2005, Leslie and McLeod 2007, UNEP 2009). The Millennium Ecosystem Assessment concluded that 15 out of the 24 most important ecosystem services have been critically impacted by human activities over the past 50 years (MA 2005). UNEP (2009) prioritized 11 of the 15 declining ecosystem services placing climate, natural hazards, water, energy, and nutrient cycling at the top of the priority list. Pew Oceans Commission (2003) estimated that more than 20,000 acres of coastal wetlands and estuaries that support habitat for fisheries, birds and other aquatic and terrestrial species have been destroyed as a result of the coastal zone overdevelopment. Recognizing the need for change in current sector-based approaches, both the US Commission on Ocean Policy (2004) and UNEP (2006) proposed several recommendations that highlight the importance of ecosystem-based approaches and integrated coastal resources management to improve the health and enhance coastal habitats while at the same time provide the nature-based services necessary to strengthen our response to hazards and climate change, decrease pollution, and create conditions for successful economic development, increased food security, and protection of human health.

In the wake of hurricane Sandy, the U.S. Army Corps of Engineers published the North Atlantic Coast Comprehensive Study (NACCS) which formulates several principles and strategies for enhancing coastal resilience. The report draws particular attention to the need for undertaking "a systems approach" that validates the interaction between natural, social, and built dimensions (USACE 2015, p. ii). The full array of proposed solutions includes engineered as well as nonstructural nature-based approaches to reduce vulnerability to coastal hazards (USACE 2013, USACE 2015). Restoration and shoreline enhancement projects provide both ecosystem services and potential for shoreline protection against the threats of sea level rise. A meta-analysis of living shoreline research showed overwhelmingly that marsh and mangrove vegetation can effectively attenuate wave action and protect people, property and infrastructure (Gedan et al. 2011, Click et al. 2014). Mangroves fringe swamps are key habitat for the survival of many species and provide natural defense against hurricanes and erosion (FDEP 2011). These resilient, pioneer tree communities can buffer wave action generated by high winds and are particularly adept at accreting sediment at rates likely to keep pace with average sea level rise (Alongi 2008, Kirwan and Magonigal 2013). In the context of sea level rise, shoreline restoration projects and natural defenses are considered in several recommendations addressing the designation and implementation of Adaptation Action Areas (SEFL-CCC 2012b). More specifically, the Southeast Florida Regional Climate Action Plan suggests that adaptation actions with respect to natural systems be based on "monitoring, management, and conservation programs designed to protect natural systems and improve their capacity for climate adaptation" (SEFL-CCC, 2012b, p. 32). Recommended actions NS-2, NS-5, NS-6, and NS-7 of the Compact's Regional Climate Action Plan include protection of natural areas, restoration of coastal wetlands, and use of "living shorelines" and other types of natural infrastructure to "create and maintain resilience and adaptive capacity" (SEFL-CCC, 2012b, p. 33).

1.1 Shoreline Processes

The coastal zone is a fundamentally dynamic and shifting system influenced by wind, wave action, upland disturbances, and underlying morphology and geology. Shore erosion is a natural phenomenon involving "detachment and transportation of sediment particles from the shore, resulting in the landward retreat of the land-water boundary" (Byrne and Anderson 1979). Erosion can occur gradually over time as a result of sea level rise and continuous wave action or suddenly in the event of a storm. Littoral drift is the movement of sand both perpendicularly to the shore or parallel to it due to wave dynamics. The forces affecting littoral drift are complex and human activities can often disturb the sand transfer equilibrium along the shore which can result in sand accretion or sand loss (Burke and Hardaway, 2007). In addition to littoral drift, shoreline dynamics are influenced by the wave climate which is determined by prevailing winds, frequency and magnitude of storms, and bathymetry (WMO 1998). Waves are limited by wind duration and fetch distance (FDOT-FHA 2011). Fetch is the distance over which wind can blow over open water seaward from a shoreline to the next landmass (Burke and Hardaway 2007). Shorelines can be generally categorized by their fetch exposure as low-energy, medium energy or high-energy depending on fetch distance (Byrne and Hardaway 1999). Diffraction due to gradients in the bathymetry is another important factor to consider as local wave growth over shallow, enclosed areas can be influenced by nearshore hardbottom. In such cases, the nearshore bottom provides sufficient attenuation to limit finite-depth wave growth (Van der Westhuysen 2012) and offset the effect of longer fetch distances as is the case of Biscayne Bay, Florida. Tidal cycles, boat wakes, and occurrence of extreme events such as hurricanes and storm surge can affect changes in shoreline position over relatively short periods of time. Sea level rise can be a contributing factor to shoreline change in the long run as it affects the position of the land-water interface (ASMFC 2010, Craft et al. 2008).

1.2 Approaches to Shoreline Stabilization

Engineering approaches including structural shoreline armoring have been widely used to protect development on the coastline (Berman et al. 2007). Hardening control measures include rip rap revetments, breakwater systems, seawalls and spurs. While often very effective especially in high wave energy systems, a review of the scientific literature suggests that bulkhead erosion control methods can lead to accelerated erosion, toe scouring, habitat degradation, and inability to adapt to changing stressors in the natural environment (Currin et al. 2010). This hard-armoring approach is known to reduce sediment sources by interrupting natural sediment transport, affect water quality and reduce habitat viability in adjacent water bodies, and fundamentally disrupt the connection between coastal and offshore ecosystems. These structures are also associated with decreasing wetland ecosystem services (Berman et al. 2007) as the resulting high energy environment around the bulkheads creates poor quality habitat for fish and other species (Peterson and Lowe 2009). Seawalls in California, for instance, have been shown to reduce habitat quality by narrowing the upper intertidal and mid-intertidal zones in front of armoring structures with accompanying losses in intertidal invertebrate and avian biodiversity (Komar 2000, Dugan and Hubbard 2010). With the anticipated effects of more intense storm damage and flooding as a result of sea level rise and climate change, armoring of shorelines is likely to increase (Defeo et al. 2009).

Recognition of the pitfalls of traditional coastline management approaches has led to a shift toward more holistic practices (Currin et al. 2010). A recent report by the National Wildlife Federation emphasizes the benefits of preserving and restoring natural infrastructure for reducing the vulnerability of local communities to flood and hurricane risks, in addition to numerous ecological and economic benefits (Glick et al. 2014). The report highlights the important role that healthy natural ecosystems can play in building resilient communities and provides several examples of successful implementation of nature-based strategies to counteract the damaging effects of extreme events. In 2011, Virginia state law incorporated living shoreline techniques as the preferred method of shore stabilization. In Jamaica Bay, New York, for example, 150 acres of restored wetlands helped mitigate the destructive backwash waves brought about by super-storm Sandy (Glick et al. 2014). In 2014, USACE issued "A Design Manual for Engineering with Nature Using Native Plant Communities" which describes specific tools and techniques for native plant use in design elements for engineered water resource projects (Bailey 2014).

Figure 1. A hybrid shoreline stabilization using limestone riprap and mangrove planting, Oleta River State Park, Miami-Dade County

Studies have shown the beneficial effects of coastal wetlands and vegetated shorelines on wave propagating time, wave height and damaging wave energy of coastal storms thus affording additional protection beyond what a hard structure can provide (Wamsley et al. 2009, Wamsley et al. 2010). Creating living shorelines is also a major effort in Chesapeake Bay to restore fisheries habitats. Applying soft armoring techniques, including living shorelines, is consistent with NOAA shoreline management planning policies that support shoreline protection with a "no net loss" of the shoreline ecological functions (NOAA, 2012). Shoreline restoration and enhancement techniques have been shown to provide comparable protection under suitable landscape and environmental conditions (Berman et al. 2007; Burke and Hardaway 2007; Swann 2008). An emerging alternative is to sustain "living shorelines" in which natural habitats are incorporated into the shoreline stabilization design (Berman and Rudnicky 2008; FDEP 2008, Reay and Lerberg 2008, Currin et al. 2010; McGuire 2011). This approach allows for the long-term protection, restoration and/or enhancement of vegetated shoreline habitats, even during tropical storms.

Figure 2. Mangrove planting and dune vegetation at the Blowing Rocks Preserve, The Nature Conservancy

Living shoreline practices use a range of naturally occurring features to stabilize and protect shorelines, including vegetated buffers; beach nourishment; reefs, oyster beds, and mangrove habitat restoration. Dense vegetation (e.g., seagrasses and mangroves) can attenuate wave action, dissipate wave energy, and mitigate the erosion of the underlying substrate. Studies of living shorelines' efficiency show measurably improved erosion rates compared to nearby upstream and downstream reaches, giving evidence of living shorelines viability as an erosion control measure (Berman et al. 2007). Whalen et al. (2012) review the provisions for living shoreline implementation adopted by multiple states in planning and coastal resource management. While living shoreline techniques can be highly effective in most coastal conditions, high wave energy conditions or risk from flooding can make hardened structures necessary (Mitsova and Esnard 2012). Even under these conditions, living shorelines can provide additional protection by extending the life of the hard structure. Subsequently, living shorelines can become part of hybrid shoreline stabilization solutions which combine vegetation with a stabilizing structure, and while these may be more appropriate in higher energy systems (Currin et al. 2010), there are possible tradeoffs in biodiversity and habitat services that must be considered when choosing hybrid over purely natural stabilization technique (Bilkovic and Mitchell 2013).

1.3 Suitability models for living shorelines

One of the first living shorelines suitability models was developed by the Center for Coastal Resources Management (CCRM) at the Virginia Institute of Marine Science (VIMS) to assist the shoreline management decision-making process (Berman and Rudnicky 2008). VIMS-CCRM has compiled a series of indexed, coded shoreline maps for the Chesapeake Bay Foundation showing where and which types of shoreline stabilization techniques were used. The maps also indicate proposed treatments for candidate locations and provide helpful suggestions to landowners who may be considering living shoreline treatments (Burke and Hardaway 2007). Virginia Institute of Marine Sciences (VIMS) was contracted by the Virginia Marine Resources Commission to create a GIS-based Living Shoreline Suitability Model which brings together information on ecosystem-based approaches and site conditions to guide coastal managers (VIMS-CCRM 2012). A scorecard is developed to aid decision-makers in identifying site-specific living shoreline alternatives (VIMS-CCRM 2012). The model considers two types of living shoreline treatments; *soft stabilization* associated with planting fringing vegetation to stabilize unaltered shorelines, and *hybrid treatments* which include any combination of soft stabilization with permanent structures such as riprap revetments, breakwaters, stone, oyster or wooden sills, and bio-logs (Berman and Rudnicky 2008, Hardaway and Duhring 2010, Currin et al. 2011). The suitability model is based on the following six parameters: fetch, bathymetry, beach presence, marsh presence, bank condition, and presence/absence of vegetation. Carey (2013) adapted the CCRM model with a few modifications. The model is based on two criteria: wave energy and presence/absence of vegetation. Wave energy is determined based on fetch, boat traffic, and nearshore water depth. The vegetation component includes presence of marshes and submerged aquatic vegetation (SAV). Fetches are calculated for 225° and 10°, southwest and north-northeast, respectively, to account for prevailing winds (Carey 2013).

2.4 **Research Objectives**

Our study builds upon these efforts with recognition of the distinctive challenges and opportunities presented by the unique ecosystems of South Florida. The considerations and technique for assessing the suitability of the shoreline for a specific type of stabilization option differ based on the type and characteristics of the shoreline (Brown et al. 2011, Daniels 1996, Coates and Mason 2001).

The project has two specific objectives:

(1) develop a generic suitability model for nature-based shoreline stabilization options in estuarine environments specific to South Florida; and

(2) assess the feasibility of the generic model to a range of shoreline types, including developed, undeveloped, and protected.

2. CONTEXT AND METHODS

This section of the report provides an overview of the South Florida context and the methods employed in the analysis.

2.1 The South Florida context

The spatial extent of the study area was based on the South Florida Water Management District's delineation of the coastal ecosystems of South Florida watersheds (SFWMD 2015). Florida is likely to suffer great impacts from climate change. Its low-lying topography, extensive coastline, and high coastal population density make it especially vulnerable to sea-level rise, flooding and extreme weather events. According to Sylvia Earle, marine biologist and former chief scientists at the National Oceanic and Atmospheric Administration (NOAA), "Florida can and must be a leader not only in curbing the build-up of CO_2 and other greenhouse gases in the atmosphere, but also implementing smart, common-sense coastal and ocean policies that will help preserve the state's natural coastal and ocean heritage" (Glick & FCOC 2008).

Florida faces multiple challenges in the years ahead. Unrestrained population growth and ill-conceived development patterns have already significantly degraded our coastal and marine systems. This degradation makes us all the more vulnerable to the upcoming effects of climate change. In its 2008 report, the Florida Coastal and Ocean Coalition (FCOC) recommended that we use a more ecosystem-based approach to managing Florida's coasts and it provided specific suggestions for scientifically based action steps we can take to face climate change. Increasing urban development in the shore zone has resulted in substantial shoreline armoring, water quality impairment due to sedimentation and pollution, and loss of habitat and intertidal ecological functions (FDEP 2011). Probabilistic models of sea-level change scenarios for Florida predict a shift in return period for major storms wherein 1-in-50-year storm events may become as frequent as 1-in-5-year storms (Park et al. 2011). Changing climate and sea level rise will most likely amplify the shoreline management challenges faced by residents, planners, coastal managers, and decision-makers. The Southeast Florida Regional Climate Change Compact Inundation Mapping and Vulnerability Assessment (SEFL-CCC 2012a) indicates the magnitude of the anticipated sea level rise impacts. The study is based on high resolution LiDAR data, infrastructure and tidal gauge data and identifies locations where priority action is needed.

Nature-Based Coastal Defenses in Southeast Florida (TNC 2014) is a compilation of seven case studies that showcase shoreline restoration and enhancement efforts in southeast Florida. The report is a collaborative publication of The Nature Conservancy and the Southeast Florida Regional Climate Change Compact Shoreline Resilience Working Group (TNC 2014). Building shoreline resilience using natural infrastructure provides immediate ecological benefits (Jancaitis 2008, Glick et al. 2014). Soft armoring and living shoreline techniques can provide site-specific solutions. Achievement of regional sustainability and resilience requires an integrated approach to shoreline management and understanding of policy and planning processes at regional scales (Leafe 1998).

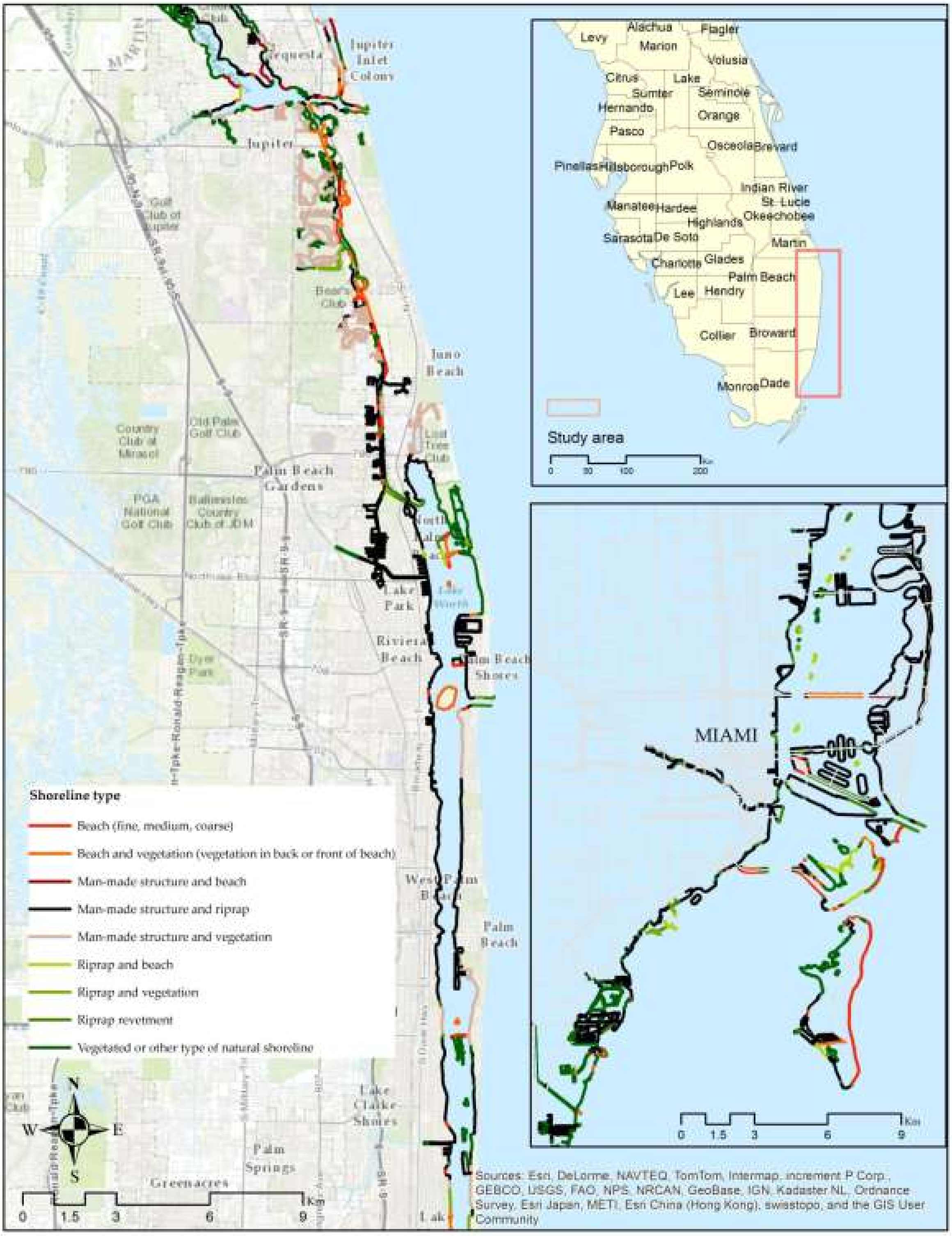


Figure 3. Study area map with estuarine shoreline descriptions (*Data source*: FFWCC, NOAA)

2.2 Decision framework for nature-based shoreline stabilization options

Corbett et al. (2009) identified eight physical variables that characterize the potential for erosion in estuarine shorelines. The factors include: fetch, nearshore bottom, bathymetry, shoreline configuration/ geometry, elevation, sediment type, fringing vegetation, boat wakes, and storms. High fetch values or average distance of open water of more than 1000 feet are associated with higher erosion potential. Lower elevations and unconsolidated sand/ peat are associated with higher erosion rates (Corbett et al. 2009). Shallow water depth and gradual slopes in nearshore areas reduce the erosion potential compared to deeper water and steep slopes (Corbett et al. (2009). Straight-line configuration of the shoreline and location on a headland is considered more conducive to erosion compared to irregularly shaped shorelines. Abundant and dense fringing vegetation (aquatic plants, marsh grasses, shrubs, trees, etc.) occurring at or in front of the shoreline reduce the erosion potential (Corbett et al. 2009). The proximity of the property to marinas and intra-coastal waterways as well as the level of boat channel use also play roles in determining the susceptibility of a shoreline to erosion (Bosch et al. 2006). It is generally accepted that low wave energy systems such as bays and estuaries are less susceptible to erosion than open ocean shorelines. However, boat traffic and less abundant sediment deposits can contribute to persistent trends in estuarine erosion (Bosch et al. 2006). Storms, including type, intensity, duration and frequency remain the single most important factor determining the occurrence of severe erosional events (Corbett et al. 2009).

The generic suitability model for nature-based shoreline stabilization options in estuarine environments incorporates three components: (1) shoreline exposure parameters; (2) prioritization and assignment of weights to the exposure parameters using an expert opinion survey; and (3) multi-objective/ multi-criteria suitability analysis and mapping. The exposure index calculation includes six parameters: wind/wave exposure, intensity of boat wake traffic, nearshore slope, water depth, presence/absence of nearshore habitat, and distance to inlet. An expert opinion survey was conducted to elicit weights for the parameters. The survey responses were summarized using the Analytic Hierarchy Process (AHP) (Saaty 1990) in which a reciprocal matrix of pairwise comparisons was constructed. The results from the exposure index calculation ranged from 1 (low) to 5 (high). These results were then evaluated in relation to existing shoreline type, presence/absence of existing structures, and land use and ownership to identify shoreline segments suitable for soft stabilization, hybrid treatments, of shoreline enhancements and assess the ease of access. The generic model was applied to a range of shoreline types including developed, undeveloped, and protected. Figure 4 describes the decision objectives, criteria, parameters, and alternative solutions.

Figure 4 illustrates the decision hierarchy organized around a goal, objectives, parameters, and alternative solutions. In this study, the overall goal is to develop a framework for suitability analysis of nature-based shoreline stabilization options. The objectives include (1) understanding of the shoreline properties, (2) developing an algorithm for exposure as a determinant of the shoreline vulnerability to natural and man-made disturbances, and (3) understanding of feasibility and ease of implementation issues when all other favorable environmental factors are present. The parameters are data-driven characteristics of the shoreline and its interaction with the natural and built environments. The alternative solutions are various combinations of vegetation ("soft" armoring), vegetation and hard structures (hybrid options), or enhancement with vegetation where hard armoring is already present. Examples are shown in Figure 5.

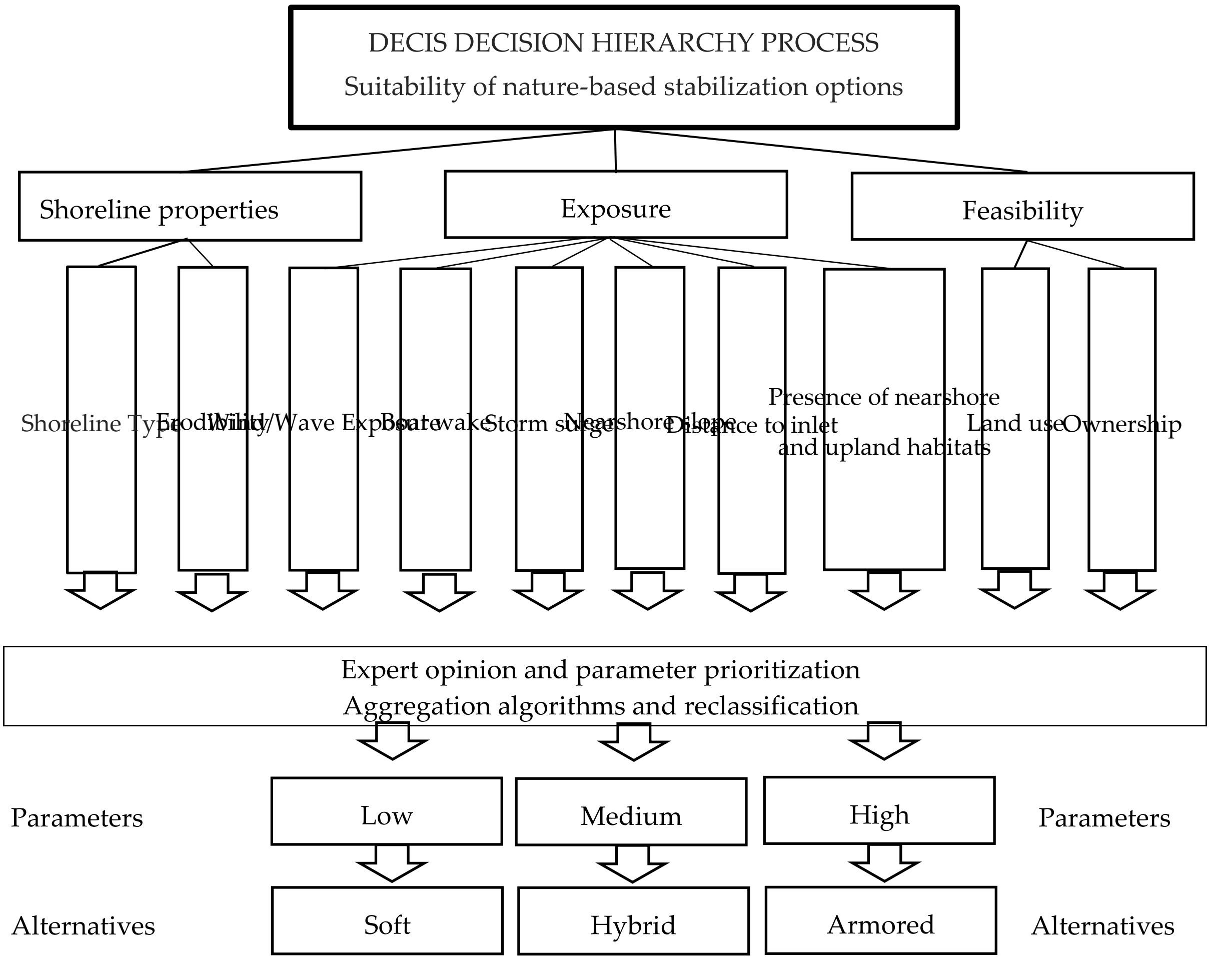


Figure 4. The analytic hierarchy process for shoreline suitability using nature-based stabilization options.

In this study, we use a scientifically established method to aggregate responses from survey data known as the Analytic Hierarchy Process (AHP) (Saaty 1990). The purpose of AHP is to facilitate the decision-making process by disaggregating a problem into a set of hierarchically ordered components (Figure 4). AHP is conducted in three steps (Meng et al. 2011). First, the decision-making process is structured as a hierarchy of goals, objectives, parameters, and alternative solutions (Meng et al. 2011). In the second step, a reciprocal matrix of pairwise comparisons is developed to elicit parameter weights from expert responses. The weights are based on eigenvectors derived from the squared reciprocal matrix. In the third step, the weights derived in step 2 are incorporated in Equation 1.

2.3 Exposure Index calculation

The Exposure Index calculation was partly based on the methodology developed by the Natural Capital Project for the InVEST Coastal Vulnerability Model (Sharp et al. 2015).In this case, we have used the weighted rankings average instead of the rankings geometric mean:

$$EI = (\sum_{i=1}^{n} R_i w_i + \ldots + R_n w_n) / n \quad (1)$$

where n denotes the number of variables, R_i is the ranking of each variable according to its contribution to exposure defined on a scale of 1 (low) to 5 (high), and w_i is the weight of the parameter derived from the expert opinion survey and the Analytic Hierarchy Process. Table 1 provides an overview of the variables included in the exposure analysis.

Shoreline data were obtained from the Florida Fish and Wildlife Conservation Commission (FFWCC 2012). The shoreline descriptions included in the Environmental Sensitivity Index (ESI) were updated using the 2013 aerial photography and expert opinion. In order to estimate exposure, the shoreline file was converted to a point file with equally spaced features. The point features were spaced 100 meters.

Elevation is an important factor in species distribution of mangroves and marsh plants and must be considered when replanting restoration sites. Due to Florida history of disturbance and urbanization, many restoration sites require clearance of exotic vegetation and re-grading by scraping back soils to elevations appropriate for native plants to recruit (FWS 1999).

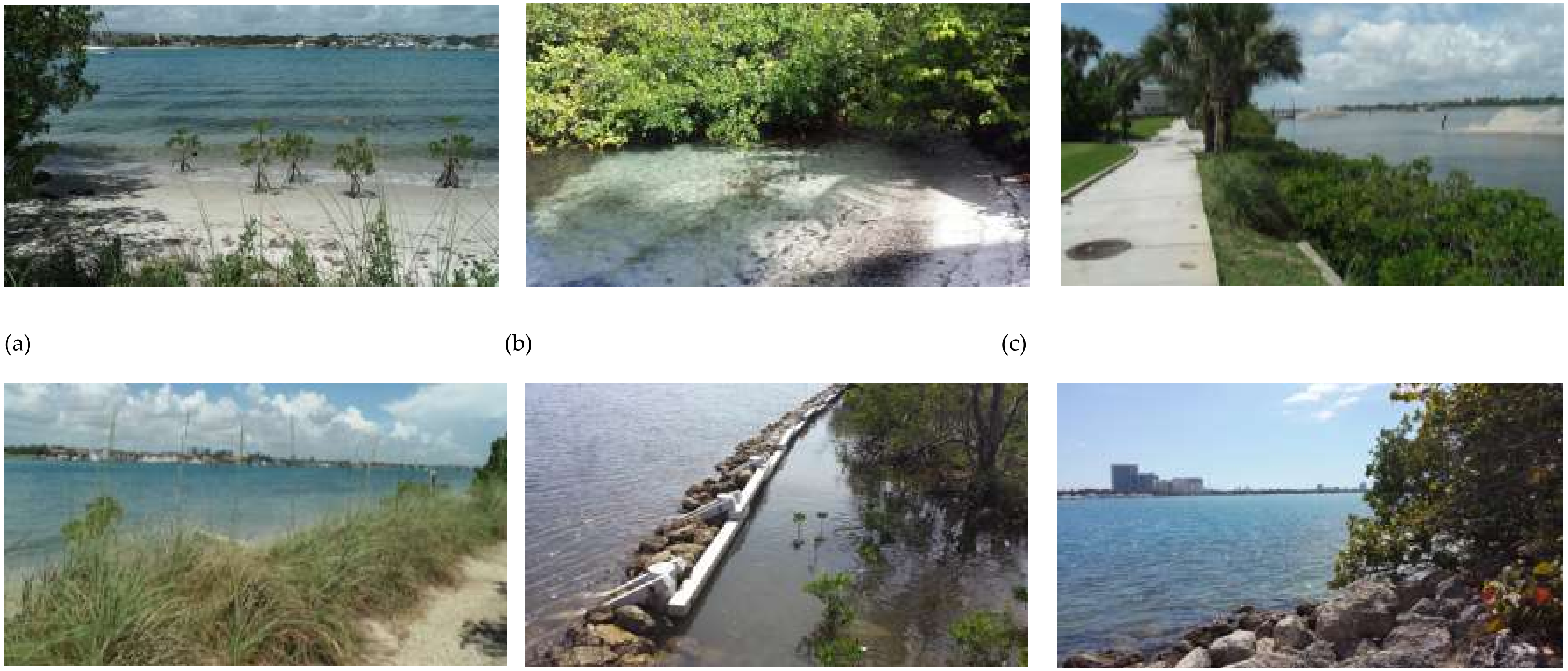
Table 1. A list of the exposure index variables and proposed categorization.

Rank/ Variable	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Average nearshore slope	Less than 5 percent	5 to 7 percent	7 -8 percent	9-10 percent	above 10 percent
Wave height (m)	0 to 20 percentile	20 to 40 Percentile	40 to 60 Percentile	60 to 80 Percentile	80 to 100 Percentile
Boat wakes	No wake zones		Medium boat wake exposure		High boat wake exposure
Storm surge Category 5	No storm surge	No strom surge	Less tham 2 m	2 to 3 m	Above 3 m
Distance to inlet	No tidal influence				Tidal influence within 3 miles
Presence of habitat	Presence of nearshore and upland habitat				No habitat

The elevation of each point was extracted from LiDAR data obtained from the South Florida Water Management District (SFWMD 2009). A topobathymetric LiDAR compiled by Taylor Engineering for FEMA (unofficial release) was used to extract water depths at a distance of 10 meters from each shoreline point. Elevations were also obtained from points located 10 meters from the shoreline point in landward direction. The elevation points were then used to calculate nearshore and landward slopes. The slope angle was found using the equation:

$$(\alpha) = \tan^{-1}\left(\frac{y}{x}\right) \qquad (2)$$

where y = Zvalue (Shoreline_point) –Zvalue (Water_point), and x = NEAR_Distance value estimated using the *Near* function wizard in ArcGIS. The slope angle was then used to estimate slope. If the slope angle is ~ 6.0° and the grade is less than 1 in 10 (i.e., the water depth was less than 1 meter approximately 10 meters from the shoreline), then the nearshore environment was considered "shallow" and suitable for living shorelines. Wave exposure was computed as compilation of wind/wave modeling, boat wake regulations, and vessel traffic reports. Wind/wave exposure was computed using the Wave Exposure Model in InVEST for points spaced 300 meters. The output was written into the baseline shoreline point file attributes using the *Near* function in ArcGIS. Calculated fetch distances, prevailing wind direction, and estimated water depths provided the inputs for the wind/wave modeling. The FEMA SLOSH model output for Category 5 hurricane storm surge was also included in the analysis. With respect to storm surge the shoreline was reclassified as follows: very low exposure (no storm surge); medium exposure (up to 2 meters), high exposure (between 2 and 3 meters); and very high exposure (above 3 meters). Presence of nearshore and upland habitat was included in the analysis as an indicator that enabling conditions are already present to support the establishment of nature-based stabilization options (Table 1).



(a) (b) (c)

(d) (e) (f)

Figure 5. Examples of generic project types for living shorelines in Southeast Florida: (a)Mangrove planting on a restored shoreline at the Blowing Rock Preserve managed by The Nature Conservancy; (b) shoreline restoration at Coral Cove Park on the Intracoastal Waterway in Palm Beach County; (c) A seawall enhanced with mangrove vegetation at Lake Worth Lagoon, Palm Beach County; (d) cordgrass planting at Blowing Rock Preserve; (e) An innovative crib rip-rap to protect eroding wetlands at West Lake Park, Broward County, and (d) a vegetated riprap at the Oleta River State Park, Miami-Dade County.

2.4 Expert opinion survey and elicitation of parameter weights

A common concern in any type of multi-criteria evaluation is to measure the relative importance of each criterion. Assigning weights to the variables included in the analysis involves ranking the criteria in order of their perceived influence on the composite score. Indices can be built with both unweighted and weighted variables. Research has shown that unweighted and weighted indices can yield statistically different results depending on weight distribution (Carey 2013). There are several mathematical algorithms for criterion weighting and ranking such as *rank sum*, *rank reciprocal*, or *rank exponential* (Carey 2013). A common weakness of these widely used methods is that the final decision on weight distribution is at the discretion of the analyst. Conversely, involving stakeholders and experts in the process of determining parameter weights has the potential to overcome this limitation. The scientifically established methods of expert opinion elicitation have proven its usefulness in achieving consensus and addressing uncertainty in the decision-making process (Meng et al. 2011).

For the purposes of this study, the list of experts was compiled by the Shoreline Resilience Working Group. Overall, 85 experts with diverse background were invited to participate in the survey nationally. The survey was anonymous. The participants were asked questions about their educational background, areas of expertise and years of experience in coastal management, coastal hazard mitigation efforts, ecosystem restoration, and hazard response. Shoreline type and exposure parameters were grouped in ten sets of pairwise comparisons. The survey respondents were asked to evaluate each pair and make a judgment of the relative importance of each parameter. Three options were given: (1) parameter $\boldsymbol{x}$ is more important than parameter y; (2) parameter y is more important than parameter $\boldsymbol{x}$; and (3) both are equally important.

The participants were also asked to suggest optimum distance to inlet as a proxy for tidal influence, overall circulation patterns, and observed boat traffic. In addition, the participants were requested to assess the feasibility of nature-based shoreline stabilization options based on land use and ownership. Malczewski (1999) explains in detail the process of GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) and AHP. The process combines geographical analysis with value judgments to prioritize and assign weights to the evaluation criteria (Meng et al. 2011). Responses are entered in a reciprocal pairwise comparison matrix in the form of $\mathbf{AA^{-1}} = \mathbf{1}$, whereas A = $[\eta ab]nxn$, ηab is the pairwise comparison value for attributes a and b, and the matrix is inverted so that $\eta ab = \eta ab^{-1}$ (Lipschutz 2013, Meng et al. 2011). The weights are derived by squaring the matrix and normalizing the row values for each alternative. The eigenvector solution provides the weight distribution.

2.5 Parameter aggregation and decision tree analysis

The Exposure Index variables were aggregated into a composite score using the equation below:

$$EI = [(0.315WWE + 0.072BWE + 0.199NS + 0.234ST + 0.148NH + 0.017PNH + 0.015DI) + StormSurgeCat] / n \quad (3)$$

where *WWE*, *BWE*, *NS*, *NH*, *PNH*, and *DI* are the variables described in Table 1, n is the number of variables in the exposure sub-index, and $StormSurgeCat$ are the reclassified storm surge heights as described in sub-section 2.3.2. Due to the destructive force of a Category 5 hurricane, this parameter was not weighted against the other variables in the Exposure Index calculation. Table 2 provides a summary of the decision criteria. The existing shoreline types were subdivided in four major categories: (1) natural, undisturbed and erodible shoreline, (2) erodible shorelines on spoil islands and other shoreline segments developed as a result of dredge and fill activities, (3) armored but permeable shorelines such as riprap revetments which provide some favorable environmental conditions for living shorelines, and (4) shorelines that are armored with hard structures such as bulkheads and seawalls.

Table 2. Decision framework for nature-based shoreline stabilization options

Existing Shoreline Type	Exposure	Generic Project Type
Natural and erodible	High	Hybrid, with harder features
	Med	Hybrid, with softer features
	Low	Soft, with vegetation only
Unnatural and erodible	High	Hybrid, with harder features
	Med	Hybrid, with softer features
	Low	Soft, with vegetation and potentially sediment only
Armored but permeable (riprap, etc.)	High	Enhancement, with harder features and vegetation
	Med	Enhancement, with harder features and vegetation
	Low	Enhancement, with vegetation only
Armored with wall/impermeable	High	Enhancement, with harder features and vegetation
	Med	Enhancement, with harder features and vegetation
	Low	Enhancement, with vegetation only

Each shoreline type is then evaluated in terms of its exposure to wind/wave action, boat wakes, storm surge, tidal influence and vessel clustering due to inlet proximity, nearshore slope, and presence of habitat. To facilitate the analysis, the exposure index composite scores were reclassified to low, medium and high as shown in Table 2. Finally, generic project types were developed based on expert knowledge and review of the literature. The project types discussed in this study are specific to the subtropical environment of South Florida. According to the *Florida Ecological Restoration Inventory* (FERI) (FDEP 2011) s*horeline restoration* involves fill removal or scraping, clearance of exotic vegetation, slope re-grading, creation of flushing channels, and re-vegetating with native plants. *Shoreline stabilization* refers to structural armoring, most commonly achieved through construction of seawalls and bulkheads. *Shoreline enhancement* refers to vegetation planting and replanting, and may involve some removal of exotic species. It may also include any aesthetic or recreational improvements (e.g., walking trails, oyster nesting platforms, etc.) (FDEP 2011). *Natural shoreline* refers to a shoreline unaltered by human activities. It is consistent with FLUCCS classification classes of mangrove swamp, freshwater marsh, saltwater marsh, exotic wetland hardwood, maritime hammock, beach dune, and developed unarmored shoreline. Natural or restored shorelines that are relatively stable and not modified by continual wave action are not considered candidates for living shorelines or other treatments. Table 2 provides further details on the rationale of the decision analysis.

Armored shorelines in shallow environments with gradual nearshore slope may be suitable for shoreline enhancement, that is, application of soft stabilization and riprap seaward of existing seawalls to improve both protection and habitat quality. If the structures are exposed to constant wave action, scour typically occurs and a toe protection is needed. Mangrove fringing can mitigate these processes. Enhancement of existing seawalls may require some additional fill and vegetation planting. A low profile revetment can be placed at the toe of a seawall and planted with mangroves to help reduce the scouring effect of wave action.

Shorelines with low exposure and nearshore gradient of less than 1:10 are considered suitable for soft stabilization. Those shoreline treatments will provide moderate to high erosion protection and a high level of ecosystem services. Soft stabilization involves the use of native plants to help reduce erosion rates and restore ecosystem services. For sandy beaches threatened by erosion, appropriate treatments include sand dune restoration and dune planting. Mangroves and other salt-tolerant species such as smooth cord grass (*Spartina alterniflora*), found at lower elevations that are regularly flooded, and saltmeadow cord grass (*Spartina patens*), typically found at slightly higher elevations subject to periodic inundation. Other salt-tolerant species typically found in South Florida include Bay Bean, Bay Cedar, Beach Creeper, Beach Elder, Biscayne Prickly Ash, Black Needlerush, Cabbage Palm, Coconut Palm, Cocoplum, Dune Sunflower, Green Buttonwood, Gulfcoast Spikerush, Gumbo Limbo, Inkberry, Lantana, Mangrove Spiderlily, Sand Cordgarss, Saw Palmetto, Sawgrass, Sea Lavender, Sea Oats, Sea Ox-eye Daisy, Sea Purslane, Seagrape, Silver Buttonwood, Spanish Stopper, and the White Stopper. Soft stabilization can also be achieved through beach nourishment.

Shorelines with a medium to high level of exposure are suitable for hybrid stabilization. Those shoreline treatments will provide a higher level of erosion control and, depending on other environmental constraints, a moderate to high level of ecosystem services. Hybrid stabilization usually consists of two elements: some type of structure (most commonly, a riprap revetment), and vegetation planting. Hybrid stabilization with harder features considers the use of permeable structures such as riprap revetments and/or breakwaters. Breakwaters are usually a system of rock structures placed at a certain distance from the shore to refract wave action. In additional to natural limestone, revetments and breakwaters can be constructed from precast concrete (Swann 2008). Hybrid stabilization with softer features may incorporate the use of vegetation, sand backfill or dredged material, oyster shells bags, geotubes, coir logs, and geotextile (straw and coconut fabrics). Examples of hybrid stabilization options include ripraps (limestone) with mangrove fringe or other wetland vegetation, ripraps with beach nourishment and dune planting, or breakwaters built from limestone with oyster shell bags, reef balls, or other wave attenuation devices. Table 3 below provides examples of various shoreline features as categorized by NOAA's Environmental Sensitivity Index. For each shoreline feature or combination of features, alternative solutions for enhancement and stabilization other than traditional armoring are proposed.

3. SHORELINE SUITABILITY FOR ALTERNATIVE STABILIZATION OPTIONS

Table 3 provides a summary of the initial screening of the shoreline types in the study area. The summary statistics indicate that 61.4 percent of the estuarine shorelines stretching from the Loxahatchee River/Southern Indian River Lagoon Estuary to the lower portion of Miami-Dade County have been altered using traditional hard armoring approaches. The percentage of man-made structures such as seawalls and bulkheads is the highest in Broward County (~84%), followed by Palm Beach County (~63%) and Miami-Dade County (~59%). Approximately one third of the estuarine shoreline (28.5%) consists of natural and undeveloped or restored shorelines where no armoring is currently present. Miami-Dade County has the highest percentage of undeveloped shoreline (~32%) followed by Palm Beach County (~21%) and Broward County (~13%). Palm Beach and Miami-Dade counties each have between three and five kilometers of estuarine beach areas as a result of restoration projects or natural sand deposition. In Miami-Dade and Palm Beach between 4% and 5% percent of the shoreline is fortified with ripraps and other permeable structures which are suitable for hybrid stabilization with vegetation enhancement. Table 3 describes the shoreline type with the corresponding percentage of total shoreline length in each county.

Table 3. Length of shoreline in percent per shoreline type.

Shoreline type	Study area (length in percent)	Palm Beach County (length in percent)	Broward County (length in percent)	Miami-Dade County (length in percent)
Beach (fine, medium, coarse)	4.0%	6.0%	0.8%	4.4%
Man-made structure and beach	0.5%	0.9%	0.2%	0.0%
Man-made structure and riprap	61.4%	63.0%	84.2%	58.6%
Man-made structure and vegetation	1.6%	5.0%	0.1%	0.1%
Riprap/ Riprap and vegetation	4.2%	4.0%	2.0%	5.0%
Vegetated or other types of shoreline	28.5%	21.0%	12.6%	32.0%

3.1 Exposure variables

3.1.1 Wind/wave exposure

The mean wave height for sheltered shorelines in the study area was 0.12 meters. The 99th percentile of the wind generated wave height in the estuary was found to be approximately 0.48 meters. Higher mean wave heights (1.38 m) were found in exposed areas near the inlets.

3.1.2 Boat wake and distance to inlet

The idle speed restrictions apply to approximately 20 kilometers of inland waters between the Jupiter Inlet and South Miami-Dade County. The slow speed restrictions apply to roughly 15 km of the estuarine shoreline. The longest stretch of the shoreline (roughly 6.6 km) where speed limitations on recreational boating apply is located in Broward County. Previous studies found higher clustering of vessels near Jupiter Inlet, Peanut Island and Blue Heron Bridge near Lake Worth Inlet, Pompano Inlet in southern Lake Worth and Boca Raton Inlets in Palm Beach County, along the lower portions of the New River and Stranahan River (Port Everglades Inlet?) in Broward County, and near Haulover Park (Haulover Inlet) in Miami-Dade County [47,48,49]. My changes in this section are based on the assumption that you are driving at the “distance to inlet” and not boat aggregation locations distinct from inlets.

3.1.3 Water depth and nearshore slope

The results indicate that despite the intensive urban development in the coastal zone, most of the natural and/or restored shorelines in the sheltered embayments and waterways of the study area have a nearshore slope of less than 5.71 percent which corresponds to a grade of 1 to 10. Undeveloped shorelines constitute roughly one third of the shorelines on the study area. Shallow water depths and gradual nearshore slopes in these areas are particularly suitable for soft or hybrid stabilization depending on wind and wave exposure, boat wakes influence, and storm action.

About 10 percent of the armored shorelines may also be suitable for vegetation enhancement since the nearshore environment is relatively shallow and the nearshore gradient is not excessively steep.

3.1.4 Storm surge

The output of the SLOSH model indicates that at least one-fourth of the estuarine shoreline in the study area will be impacted by a storm surge induced by a Category 1 hurricane. The model predictions range from 0.6 m to 2 m depending on elevation, bathymetry, exposure and location of the shoreline segments. Storm surge resulting from category 3 hurricanes will impact nearly 90% of the estuarine shoreline while during a category 5 hurricane the storm-induced surge at a level predicted to exceed 6 m will affect nearly 98.7% of the area.

3.1.5 Presence of nearshore or upland habitat

The root system of submerged aquatic vegetation (SAV) helps stabilize estuarine sediments, increases the amount of dissolved oxygen and nutrients, helps improve water quality, and enhances the habitat. The SAV presence is an important indication of the general health of the estuarine ecosystem. Submerged aquatic vegetation was found in close proximity to approximately 16.3 percent of the estuarine shorelines in the study area. Table 4 provides an overview of the SAV distribution near various types of shoreline. Approximately 50% of the SAV patches were found near vegetated or other types of natural shorelines including beach areas. Nearly 16% are located in close proximity to permeable hard structures such as ripraps, and 30% are near seawalls and bulkheads. The SAV presence along with the shallow environment and upland vegetation create favorable environmental conditions for establishment of living shorelines [28,29].

Table 4. Presence of submerged aquatic vegetation

Shoreline Type	Percent of shoreline	Average water depth (m)
Beach (fine, medium, coarse)	5.5%	-0.264
Beach and vegetation (vegetation in back or front of beach)	7.0%	-0.298
Man-made structure and beach	2.0%	-0.315
Man-made structure and riprap	30.0%	-0.442
Man-made structure and vegetation	5.0%	-0.410
Riprap and beach	6.8%	-0.147
Riprap and vegetation	3.7%	-0.233
Riprap revetment	6.0%	-0.349
Vegetated or other type of natural shoreline	34.0%	-0.251

3.2 Expert opinion survey and assignment of parameter weights

The response rate of the expert opinion survey was 38.8 percent. Thirty percent of the participants reported to have worked mostly in the public sector, 9% have worked mostly in the private sector, and 61% have worked in both sectors. The areas of expertise included coastal engineering, coastal science, restoration and systems ecology, marine biology and habitat restoration, community resilience, urban planning and sustainability, coastal hydrology, stormwater management and drainage, and architecture. Eighty-one percent of the respondents reported prior involvement in coastal management projects. Fifty-four percent reported having over 20 years of experience in coastal restoration and coastal management, out of which thirty percent had over thirty years of experience in the field. Thirty-nine percent took part in a response effort to a coastal flooding event or other coastal hazards in their respective community in the past 5 years, 47% in the past 10 years, and 34% in the past 25 years. Hazards in which the experts were involved included hurricanes, inland and coastal flooding, storm surge, wind/ice/snow, tornadoes, sea level rise, coastal erosion, emergency response and long term planning, restoration projects, and regional hazard preparation efforts for wildlife protection.

Table 5 displays the reciprocal pairwise matrix derived from the expert responses and the eigenvector solution which was used to determine the parameter weights. The results indicate that wind/wave exposure received the highest weight followed by shoreline type, nearshore slope, nearshore habitat, and boat wake. Public lands and educational institutions were singled out by the experts as the topmost choices in terms of feasibility and ease of implementation, followed by private golf courses. Right-of-ways, marinas, commercial hotel/time share and office, mixed use, and residential low density were considered next while residential high density and multi-family residential uses and condominiums were believed to offer the least in terms of ease of implementation.

Table 5. Pairwise matrix derived from the expert opinion survey and the eigenvector solution used to determine parameter weights.

	Wind/Wave Exposure (WWE)	Boat wake exposure (BWE)	Nearshore slope (NS)	Shoreline Type (ST) (natural, armored, hybrid	Nearshore habitat (NH)	Presence of upland natural habitat (PNH)	Distance to inlet	**Eigenvector**
Wind/Wave Exposure (WWE)	1.000	2.086	1.259	1.159	1.460	4.294	4.563	**0.315**
Boat wake exposure (BWE)	0.479	1.000	0.603	0.556	0.700	2.059	2.188	**0.072**
Nearshore slope (NS)	0.795	1.657	1.000	0.921	1.160	3.412	3.625	**0.199**
Shoreline type (ST) (natural, armored, hybrid)	0.863	1.800	1.086	1.000	1.260	3.706	3.938	**0.234**
Nearshore habitat (NH)	0.685	1.429	0.862	0.794	1.000	2.941	3.125	**0.148**
Presence of upland natural habitat (PNH)	0.233	0.486	0.293	0.270	0.340	1.000	1.063	**0.017**
Distance to inlet	0.219	0.457	0.276	0.254	0.320	0.941	1.000	**0.015**

The participants in the survey were also asked to assess the perceived ease of implementation of nature-based approaches to various land use categories. The respondents indicated that some land uses such as publicly-owned parks or educational institutions are perceived as allowing easier access and implementation of nature-based restoration and stabilization projects while residential uses are considered more likely to opt in favor of hard armoring or hybrid shoreline stabilization. Figure 6 shows the rankings for each land use category included in the survey. The scale indicates the perceived ease of action regarding the establishment of project types other than traditional armoring where 1 indicates a very low chance of implementing a project type other than traditional armoring, and 5 indicates a very high chance of implementing such a project, all other favorable conditions being present.

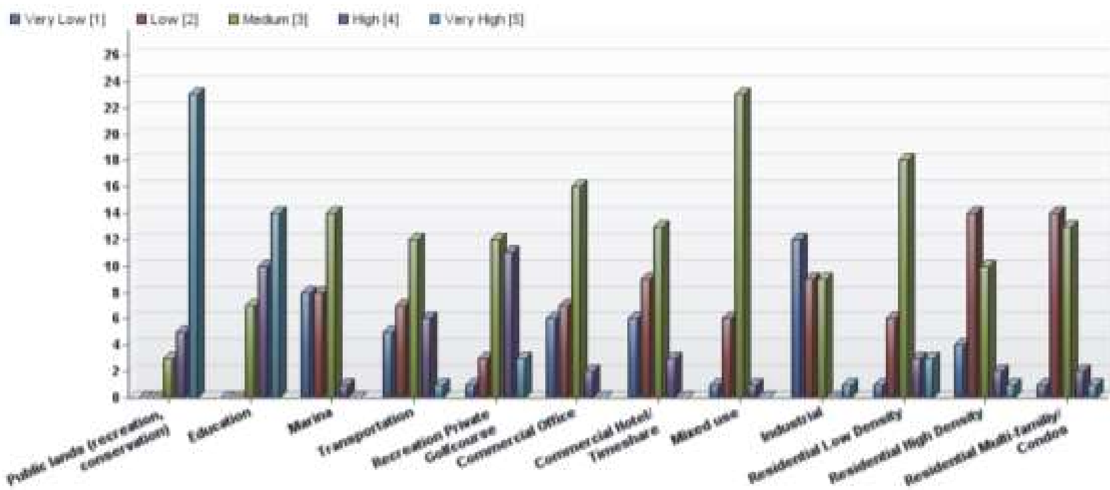


Figure 6. Survey responses indicating the perceived ease of implementation of nature-based approaches for various land use categories.

3.3 Results from the exposure index calculation

We estimated two subsets of the exposure index values for the estuarine shorelines in the study area. The first subset accounts for average exposure under the prevailing wind and wave conditions. The second subset takes into account the impact of a storm surge driven by a Category 5 hurricane. In both cases, the index values are scaled to a maximum value of 5. The average exposure values for the estuarine shorelines in the study area vary from 0.93 to 4.45 whereas a value of 5 stands for the highest possible score. The scores of the average exposure sub index were reclassified to low (0.93 to 2.25), medium (2.25 to 3.50), and high (above 3.50) (Figures 7 and 8). The results indicate low average exposure for 70% of the estuarine shoreline, medium exposure for 28% of the shoreline, and high exposure for 2% of the shoreline (mainly near the inlets exposed to unbounded fetch).

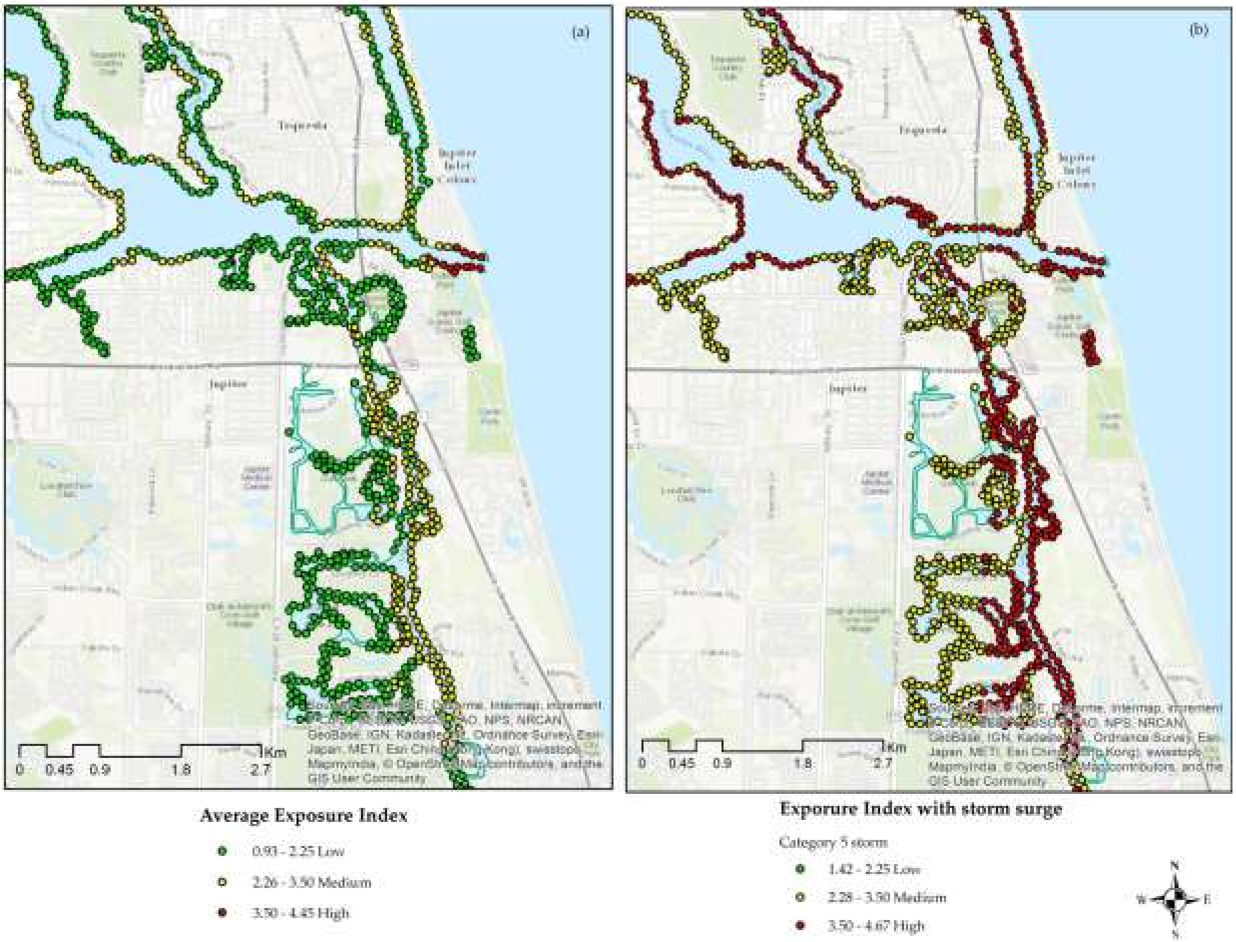


Figure 7. Two subsets of the Exposure index values near Jupiter Inlet, Florida: (a) average exposure index factoring in wind and wave exposure, boat wake influence, nearshore slope, presence/absence of SAV, presence/absence of upland habitat, type of shoreline, and distance to inlet; and (b) exposure with the compounding effect of the storm surge driven by a category 5 storm.

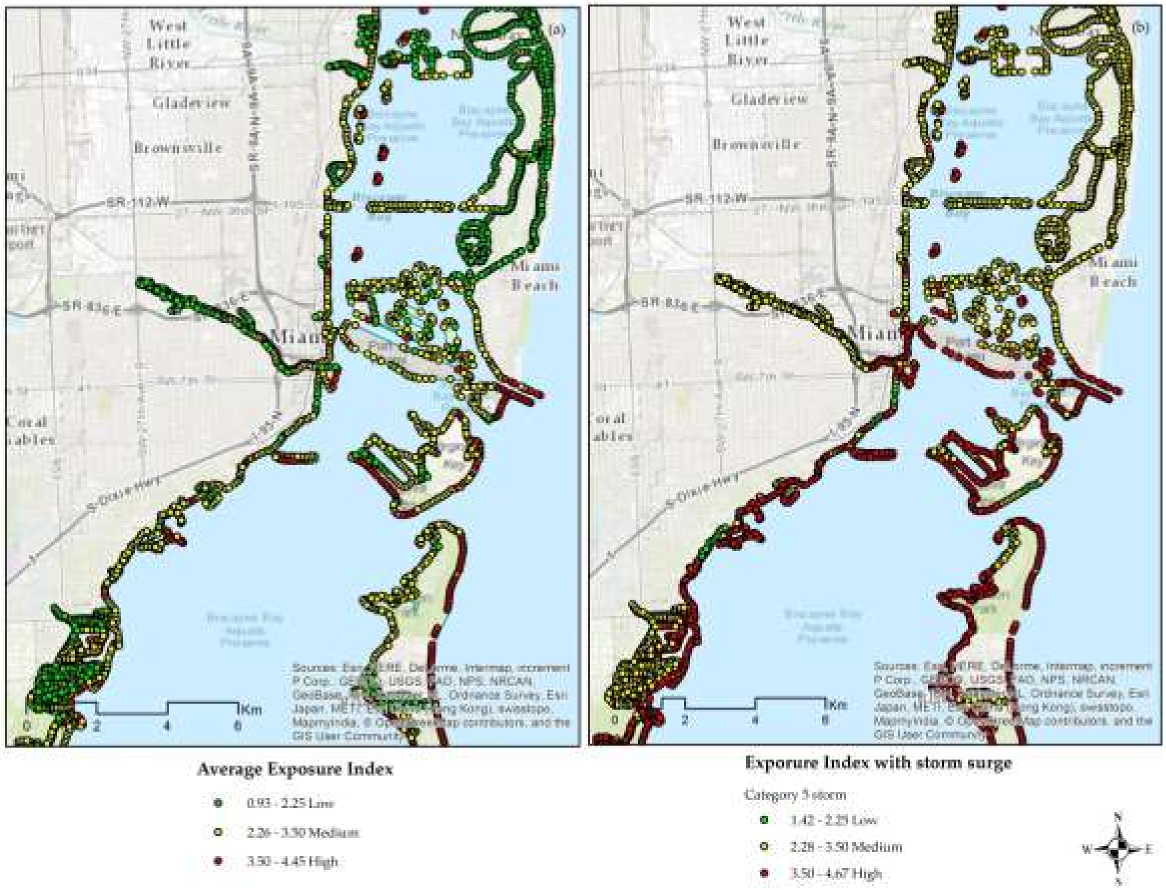


Figure 8. Two subsets of the Exposure index values near Miami, Florida: (a) average exposure index factoring in wind and wave exposure, boat wake influence, nearshore slope, presence/absence of SAV, presence/absence of upland habitat, type of shoreline, and distance to inlet; and (b) exposure with the compounding effect of the storm surge driven by a category 5 storm.

The values of the exposure index under extreme events range from 1.42 to 4.67. Adding storm surge for category 5 hurricane to the exposure index calculation depicts a different type of exposure. Although the range of values is quite similar, the frequency distribution of the exposure estimates differs noticeably. Under this extreme condition, only 1.5% of the estuarine shoreline is within the range of low exposure, 67.5% is subject to medium exposure, and 31% receives high exposure values. Figures 7 and 8 illustrate two subsets of the exposure index values near Jupiter Inlet, Florida. The map on the left shows average exposure index based on wind and wave exposure, boat wake influence, nearshore slope, presence/absence of SAV, presence/absence of upland habitat, type of shoreline, and distance to inlet. The map on the right depicts exposure index values with the compounding effect of the storm surge driven by a category 5 storm.

3.4 Results from the parameter aggregation and decision tree analysis

Table 6 provides a summary of the length of the shoreline segments suitable for various shoreline stabilization options. The results indicate that nearly 20% of the estuarine shoreline is not suitable for any type of alternative stabilization due to water depths greater than 3 feet and a slope gradient greater than 1:10. Shoreline enhancement with vegetation (e.g., a mangrove fringe) is an appropriate technique for shoreline segments where traditional hard armoring is already present or as a transition to an alternative solution. Enhancement with harder features and vegetation is a suitable option for existing seawalls and bulkheads. Approximately 18% of the already hardened estuarine shoreline may be suitable for this alternative solution. A riprap revetment with limestone boulders placed near the seawall can extend the life of the hard structure as it will mitigate the scouring effect of wave action. In addition, a riprap will allow for the establishment of mangroves and create habitat. A riprap built to an appropriate elevation (e.g., 0.30 m to 0.50 m NGVD) can facilitate self-recruitment of mangrove species.

Table 6. Estimated length of possible alternatives to hard armoring in the study area.

Suitability	Length (km)
Palm Beach County	
Soft, with vegetation and potentially sediment only	3.5
Hybrid, with harder features	0.1
Enhancement, with harder features and vegetation	19.7
Enhancement, with vegetation only	13.0
Hybrid, with harder features	3.5
Soft, with vegetation only	8.5
None, water depth > 3.0 feet, slope > 1:10	25.4
Broward County	
Enhancement, with harder features and vegetation	16.9
Hybrid, with softer features	6.8
Enhancement, with vegetation only	13.7
Soft, with vegetation only	1.9
None, water depth > 3.0 feet, slope > 1:10	26.8
Miami-Dade County	
Soft, with vegetation and potentially sediment only	0.5
Enhancement, with harder features and vegetation	12.9
Enhancement, with vegetation only	14.9
Hybrid, with softer features	3.7
Soft, with vegetation only	8.5
None, water depth > 3.0 feet, slope > 1:10	12.6

Figure 9. Undeveloped shorelines **s**uitable locations for sot stabilization.

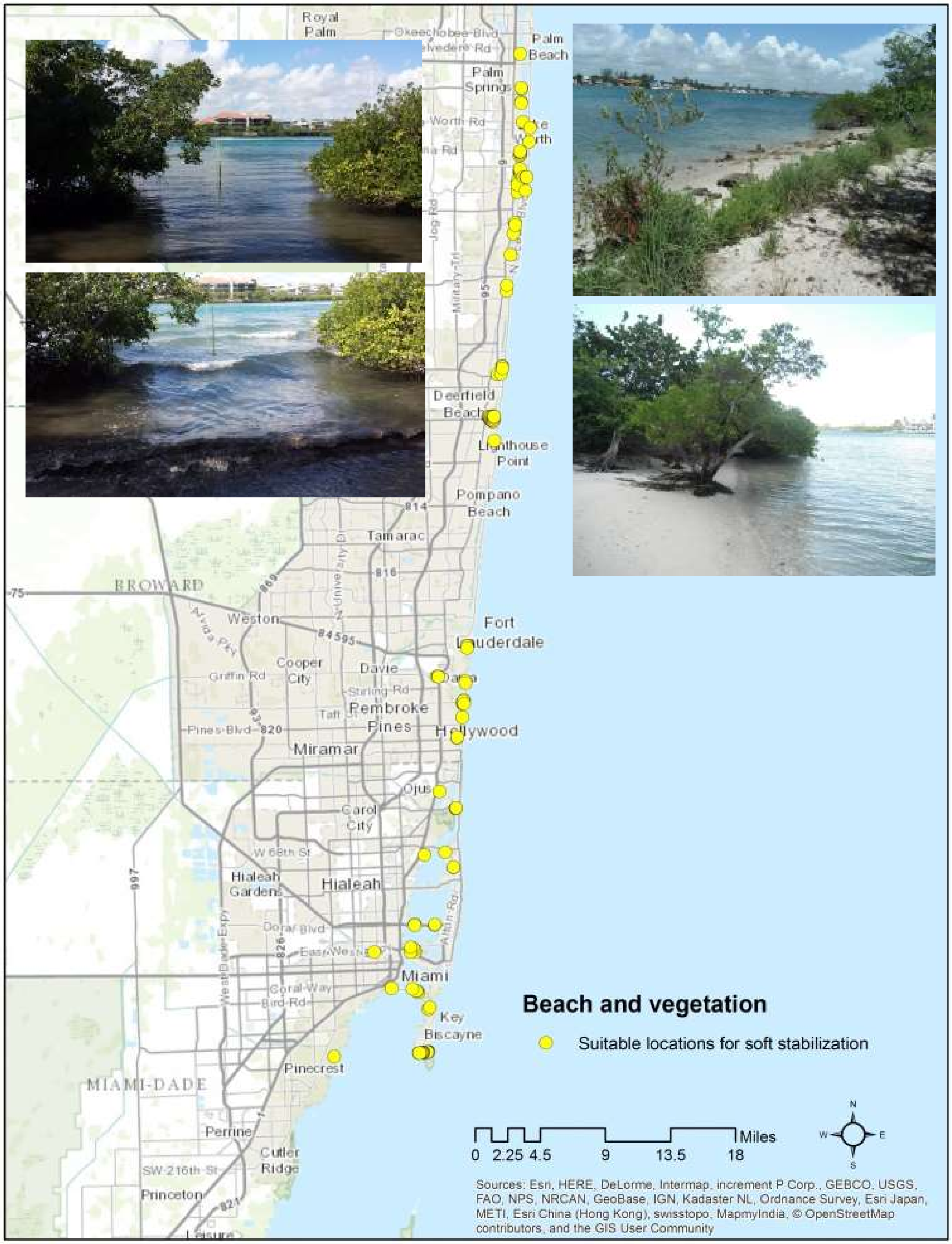


Figure 10. Areas where beach and vegetation are present with high suitability score for soft stabilization.

Small beach areas along inland waters can be enhanced with vegetation and potentially some sediment. Several relatively short stretches of this type of shoreline are found in Palm Beach County. Enhancement with vegetation only is an appropriate technique for different types of altered shorelines where wave energy exposure is relatively low. Hybrid options are a suitable solution for shorelines with medium to high wave exposure. Natural and restored shorelines in low and medium wave energy environments can be maintained with soft stabilization using various types of coastal vegetation. Figures 9 through 12 illustrate potential alternatives based on existing conditions and exposure.

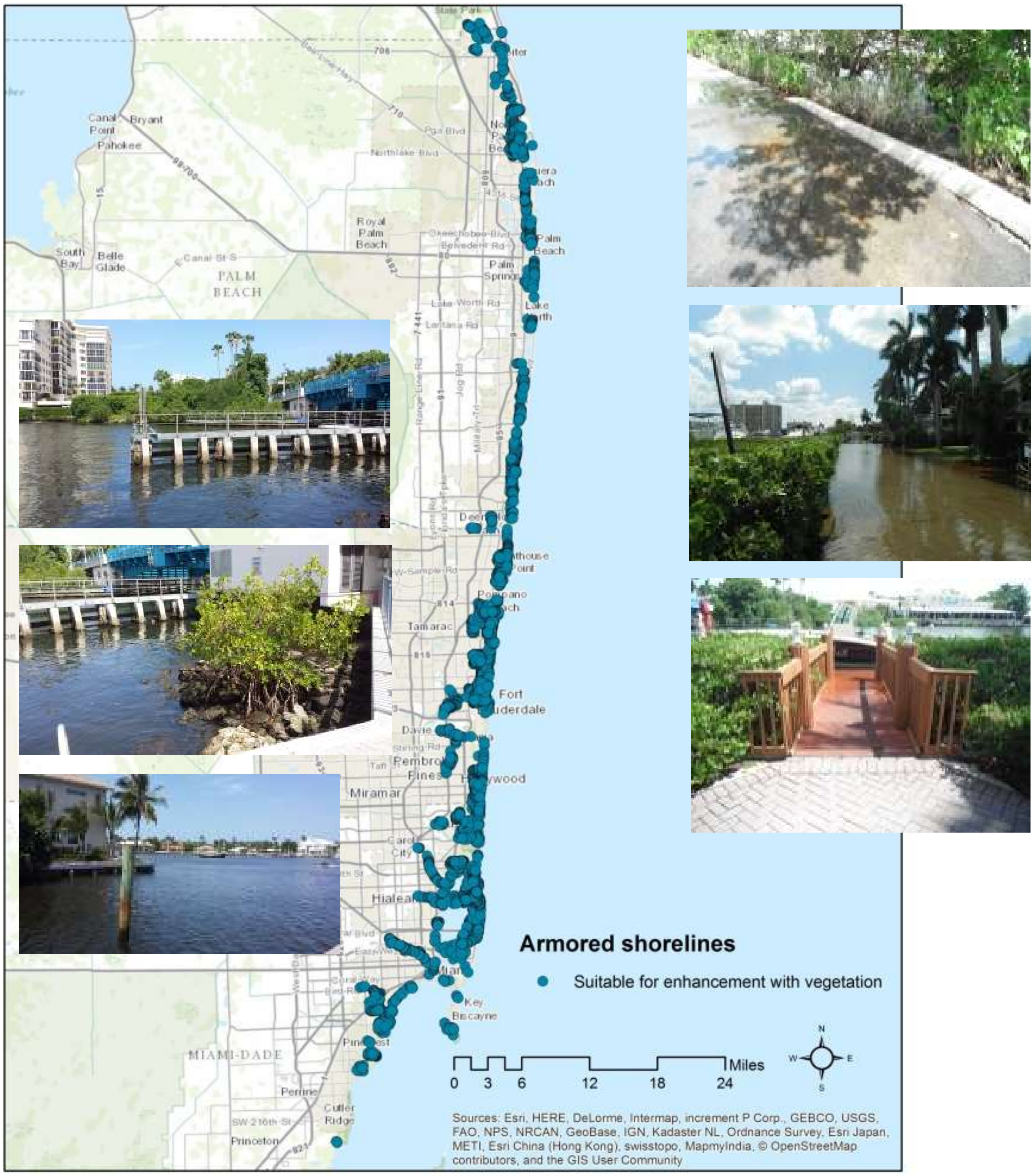


Figure 11. Armored shorelines suitable for enhancement with vegetation.

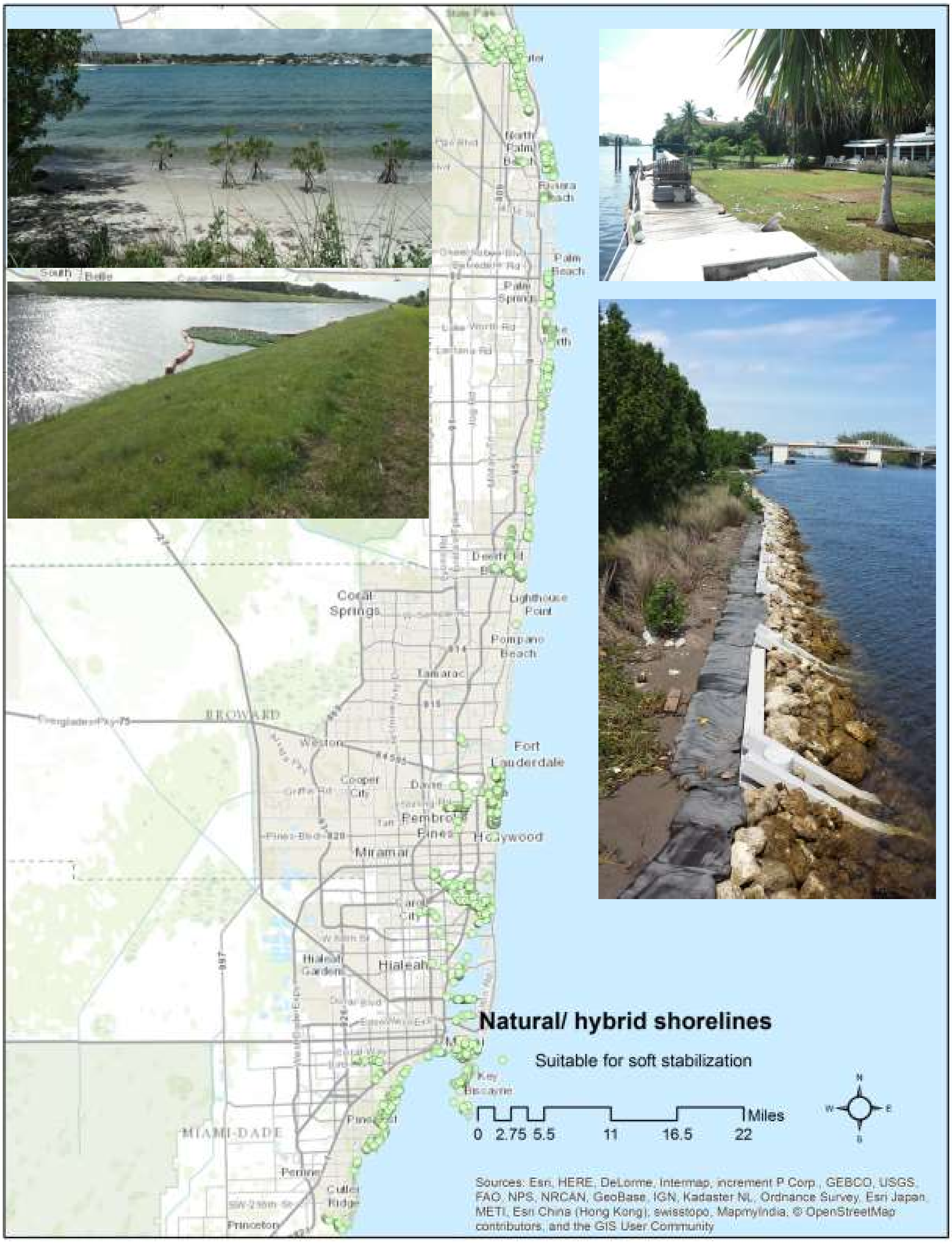


Figure 12. Natural /hybrid shorelines suitable for soft stabilization

The results from this study indicate that overall suitable conditions are present at several locations that would allow for successful implementation of nature-based solutions to shoreline stabilization. Nearly 30 percent of the natural shorelines in inland waters in South Florida are found on publicly owned land. Local governments have already established and continue to develop alternatives to hard armoring along some of these natural shorelines. In approximately 10% of the armored shorelines favorable conditions are present for enhancement of existing seawalls and bulkheads with vegetation such as creating a mangrove fringe. These conditions include gently sloping gradient, presence of submerged aquatic vegetation, some presence of upland vegetation, and shallow water depths. Two subdivisions in Palm Beach County, *Jonathan's Landing* and *Admiral's Cove*, have incorporated enhancement with vegetation alongside riprap revetments and seawalls. Another approach to protect existing natural shorelines from erosion resulting from wave action is creating breakwaters at a proper distance from the shoreline. A single headland breakwater or a system of detached breakwaters strategically placed in medium and high wave energy environments can replicate the effect of "natural bars, reefs or nearshore islands" creating a sheltered area behind the breakwater where sand can accumulate. Areas with active vertical erosion near existing bulkheads and seawalls are suitable for hybrid stabilization with placement of ripraps and vegetation. Hybrid stabilization options in high wave energy environments offer numerous benefits including; reducing the scouring effect of the wave action on the hard structure and protecting the toe of the seawall, preserving the functionality of the intertidal zone, supporting natural processes, and providing habitat for aquatic flora and fauna species. Hybrid options with vegetation enhancement can reduce the erosion rates, protect and prolong the life of the hard structure, provide visual/ aesthetic value for waterfront homeowners, filter stormwater runoff, and even provide cost-effective solutions outside the traditional hard armoring approach. Figures 13 and 14 show the existing conditions and suitable shoreline enhancement options.

South Florida coastal ecosystems are highly susceptible to erosion/sedimentation, fragmentation, and habitat degradation due to dredging/ fill and land conversion to urban and housing development (FFWCC 2005). Due to Florida's history of disturbance and urbanization, many restoration sites require re-grading by scraping back nonnative soils to elevations appropriate for intertidal native plants to recruit (FWS 1999). Elevation is an important factor in species distribution of mangroves and marsh plants and must be considered when replanting restoration sites. Mangrove swamps are essential for the health of estuarine and marine environments in South Florida (FWS 1999). They provide habitat for over one thousand species of intertidal, sub-tidal, and arboreal animals (FWS 1999). They also serve as nesting sites; nurseries for fish, shellfish, and crustaceans; and are a major source of detritus which provides the basis of the marine food system (FWS 1999). Their root systems stabilize shorelines; buffer wind action; reduce turbidity and increase water clarity; and cause accretion by catching sediment and debris (Kirwan and Megonigal 2013). Red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), black needlerush (*Juncus roemerianus*), and smooth cordgrass (*Spartina spartinae*) are commonly used in wetlands and mangrove restoration projects (FWS 1999). Using the National Geodetic Vertical Datum (NGVD), red mangroves are planted in the elevation range 1.0′-1.2′, black mangrove 1.25′-1.5′, white mangrove 1.5′-2.0′, and gulf cordgrass in the range 2.1′-2.5′. Habitat may also be created by reconstruction of a more natural hydrology, such as re-establishing inter-tidal flushing creek connections.

A number of spoil island restoration projects have been successfully implemented in Miami-Dade County since the 1990s (Milano 1999, 2000). Dredged material disposal during the construction of the Atlantic Intracoastal Waterway which began in the early 1900s resulted in the creation of spoil islands (Milano 2000). They have been dominated for decades by exotic invasive species and have been known as a source of sedimentation and water quality degradation (Milano 2000). Spoil island restoration involves fill removal, clearance of exotic species, creation of flushing channels, planting mangroves and native upland species, and shoreline stabilization (Milano 2000). Rip-raps are commonly used as "a riprap revetment can be part of a "living shoreline", as a substrate for aquatic plants and animals or as part of a "planter" for vegetation" (MDC - personal communication, 2011, 2014).

Development of barrier islands in South Florida negatively affected many of the maritime hammock communities. In South Florida, maritime hammock is characterized by tropical, broadleaved hardwoods such as live oak, cabbage palmetto, red bay, silver palm, and black bead (FWS 1999). Species of concern which inhabit this habitat include the Florida panther, peregrine falcon, Florida prairie warbler, and several species of prickly apple (FWS 1999). South Florida hammock restoration projects are generally not planted as a monoculture, but rather as a mix. The most common species used in restoration are gumbo limbo (*Bursera simaruba*), buttonwood (*Conocarpus erectus*), strangler fig (*Ficus aurea*), false mastic (*Sideroxylon foetidissimum*) and Jamaican dogwood (*Piscidia piscipula*) (FWS 1999, MDC, personal communication, 2014). Freshwater wetlands are also part of ongoing restoration efforts in South Florida. These marshes consist mostly of herbaceous plants and grass of which saw grass, pickerelweed, arrowhead, and spikerush are the most abundant (MDC 2013). Many of these important ecosystems have been degraded or lost due to alteration of hydrologic conditions (MDC 2013).

Development of alternative solutions to hard armoring requires removing regulatory obstacles and establishment of a permitting system that incorporates and facilitates nature-based approaches. Best management practices indicate that permits can be sought for restoration or protection (NJDEP 2009). Planning for living shoreline also requires revision of the existing coastal management plans. Outreach and information campaigns should be put in place to engage both contractors and property owners. Currently, a failing seawall will most likely be repaired or replaced by a new hard structure. In many cases this might be the only solution. However, if it is determined that the site characteristics would not prevent the successful implementation of alternative nature-based solutions, such options should be given priority and pursued, and appropriate techniques and materials identified and included in the permitting process.

Figure 13. Results from the suitability analysis for the Oleta River State Park shoreline

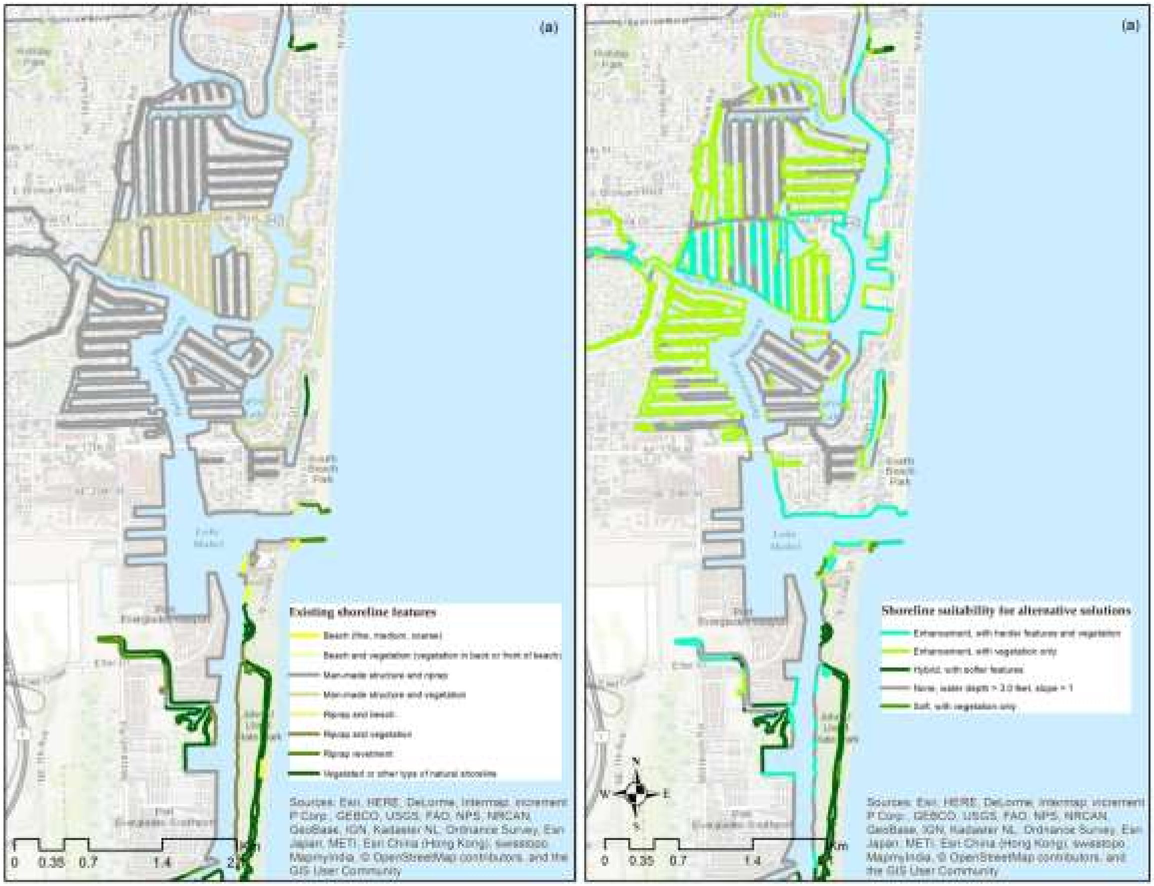


Figure 14. Shoreline type and proposed alternative stabilization options based on the results of the suitability model (City of Fort Lauderdale, FL): (a) existing shoreline features, (b) suitable alternatives.

4. Conclusion

In this study, we developed a GIS-based multi-criteria decision framework for nature-based shoreline stabilization options. Our focus is on living shorelines in estuarine and tidally-influenced environments. More specifically, we combined the tools of spatial analysis with value judgments derived from an expert opinion survey to assign weights to the model variables, The existing shoreline type derived from an updated version of the NOS Environmental Sensitivity Index was evaluated using the exposure index aggregated scores, and generic project types for each set of possible combinations of shoreline features and exposure were proposed. Although armoring of the shoreline is still the dominant trend, the results indicate that there are valuable living shoreline alternatives available in Southeast Florida. Existing coastal restoration and living shoreline projects in South Florida provide examples of successful implementation of nature-based strategies to counteract the damaging effects of erosion and extreme events.

The results from this study should be interpreted as a screening and planning tool for identification of potential sites for closer examination. In each specific case where a living shoreline is considered, further detailed site-specific analysis should be conducted. This study has been conducted on a regional scale. Its main objective was to identify potentially suitable areas for alternative shoreline stabilization options along the inland waters of Southeast Florida using the best available digital data. Site-specific implementation of living shorelines may be constrained by several factors not considered in this analysis. These factors can potentially make the implementation impossible or impractical. These additional considerations include narrow channels with high boat traffic where placement of living shorelines may obstruct navigation, areas designated for commercial vessel berthing and areas used for loading and unloading operations, areas that are easily accessible which may dramatically increase the cost of restoration, and areas with inadequate width to support soft armoring despite all other favorable conditions being present (NJDEP 2009). Site-specific analyses should also consider other physical constraints including adverse effects of tidal flushing, insufficient land area for grading and establishing suitable elevations for native species recruitment (NJDEP 2009).

Other factors to consider are land regulations and policies. In order to be successfully implemented on a larger regional scale, nature-based alternatives to hard armoring should become part of the coastal element of the county and municipal comprehensive plans. A pertinent permitting process should be put in place. As part of future research efforts, site-specific evaluation of the effectiveness of existing living shorelines should be conducted under various conditions to improve response and design requirements as their buffering properties are not as predictable as hard bulkheads and seawalls and may require lengthier planning horizons and careful design to be effective. Continued research on this topic is particularly important in the context of sea level rise as living shorelines and habitat restoration offer a host of strategies that planners, coastal resource managers, and decision-makers can use to mitigate hazards, protect property values, secure the tax base, prevent processes of shrinking and divestiture, and enhance habitat value. Examples from South Florida indicate that dune planting, coastal strand and mangrove fringes can help stabilize existing natural shorelines and enhance habitat along existing armoring structures. South Florida's coastal ecosystems offer unique opportunities to develop shoreline management techniques that can create appropriate habitat conditions and increase the resilience of the built environment to existing and future threats.

REFERENCES

Adger, W. N. 2000. Social and ecological resilience: are they related? *Progress in Human Geography* 24(3):347-364. http://dx.doi.org/10.1191/030913200701540465.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309:1036-1039. http://dx.doi.org/10.1126/science.1112122

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(3):268-281. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006

Becker, E. 2012. Social-ecological systems as epistemic objects. Pages 37-60 *in* M. Glaser, K. Gesche, B. Ratter, and M. Welp, editors. *Human-nature interactions in the Anthropocene: potentials of social-ecological systems analysis*. Routledge, London, UK.

Beichler, S. A., S. Hasibovic, B. J. Davidse, and S. Deppisch. 2014. The role played by social-ecological resilience as a method of integration in interdisciplinary research. *Ecology and Society* **19**(3): 4. http://dx.doi.org/10.5751/ES-06583-190304.

McGranahan, G., Balk, D., and Anderson, B. 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment & Urbanization, 19(1), 17–37. DOI: 10.1177/0956247807076960

Nicholls, R.J. 2004. Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios Global Environmental Change, 14, 69-86.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: current state and trends. Washington, DC: Island Press.

United Nations Environment Programme (UNEP). 2009. Ecosystem Management Programme: A New Approach to Sustainability, Division of Environmental Policy Implementation: Nairobi, Kenya

Leslie, H.M. and McLeod, K.L. 2007Confronting the challenges of implementing marine ecosystem-based management. Frontiers in Ecology and Environment 2007; 5(10): 540–548, doi:10.1890/060093

Rosenberg, A.A. and McLeod, K.L. 2005. Implementing ecosystem-based approaches to management for the conservation of ecosystem services. *Mar Ecol–Prog Ser* **300**: 270–74.

Saaty, T. 1990. How to make a decision: The Analytic Hierarchy Process, *European Journal of Operational Research*, 48, 9-26.

Florida Department of Environmental Protection (FDEP). 2011. Florida Ecological Restoration Inventory (FERI), URL: http://www.dep.state.fl.us/water/wetlands/feri/index.htm, (accessed 12/17/2014).

South Florida Water Management District (SFWMD). 2009. GIS Data Catalog (2007 Broward 10-ft DEM in NAVD 1988, Release Version 1; 2007-2008 Miami-Dade 10-ft DEM in NAVD 1988, Release Version 1; 2007-2008 Palm Beach 10-ft DEM in NAVD 1988, Release Version 1), URL: http://www.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp? (Accessed 09/12/2014).

Florida Fish and Wildlife Conservation Commission (FFWCC 2012). Environmental Sensitivity Index (ESI) for South Florida, URL: http://geodata.myfwc.com/datasets/2910418e885f4d69823021720e0156e3_24 (accessed 09/15/2015).

Gorzelany, J.F. 2009. Recreational Boating Activity in Miami-Dade County, Mote Marine Laboratory, Sarasota, FL. URL: http://www.miamidade.gov/environment/library/memos/mote-boating-study.pdf. (accessed 10/12/2015).

Gorzelany, J.F. 2005. Recreational Boating Activity in Broward County, Mote Marine Laboratory, Sarasota, FL. URL: https://www.broward.org/Manatees/Documents/recreational_boat_survey.pdf. (accessed 10/18/2015).

PBS&J (Post, Buckley, Schuh & Jernigan). 2009. Palm Beach County Vessel Traffic Study. Prepared for Florida Fish and Wildlife Conservation Commission, Division of Law Enforcement, Boating and Waterways Section, in partnership with Florida Sea Grant, URL: www.lwli.org/pdfs/.../2009PalmBeach**VesselTraffic**Study.pdf. (accessed 10/23/2015).

Lipschutz, S. 2013. Invertible Matrices. In: Lipshutz, S. and M. Lipson (Ed.) Schaum's Outline of Theory and Problems of Linear Algebra, 5th Edition, New York: McGraw-Hill, pp. 44-45.

National Oceanic and Atmospheric Administration (NOAA). 2002. *Environmental Sensitivity Index Guidelines Version 3.0*, NOAA Technical Memorandum NOS OR&R, NOAA Ocean Service, Hazardous Materials Response Division, Office of Response and Restoration: Seattle, Washington.

Fonseca, M.S. and Malhotra, A. 2010. Wave Exposure Model for use in Ecological Forecasting, Applied Ecology and Restoration Research Branch, NOAA, National Ocean Service Center for Coastal Fisheries and Habitat Research (CCFHR): Beaufort, North Carolina.

Mitsova, D., A.M. Esnard, and Y. Li. 2012. Using Enhanced Dasymetric Mapping Techniques to Improve the Spatial Accuracy of Sea Level Rise Vulnerability Assessments, *Journal of Coastal Conservation: Planning and Management,* 16(3): 355-372.

Alongi, Daniel M. 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* 76:1-13.

ArcGIS Resources. 2014. What is an OBJECTID? URL: http://resources.arcgis.com/en/help/main/10.1/index.html#//006z00000009000000, accessed 12/05/2014).

Ariza, Eduard, Kenyan C. Lindeman, Pallab Mozumber, and Daniel O. Suman. 2014. Beach management in Florida: Assessing stakeholder perceptions on governance. *Ocean & Coastal Management* 96:82-93.

Bailey, P. 2014. A Design Manual for Engineering with Nature Using Native Plant Communities, U.S. Army Engineer Research & Development Center, U.S. Army Corps of Engineers, Vicksburg, MS, URL: http://el.erdc.usace.army.mil/ewn/pdfs/EWN%20Design%20Manual.pdf, (accessed 12/18/2014).

Berman, Marcia and Harry Berquist, Julie Herman, and Karinna Nunez. 2007. *The Stability of Living Shorelines – An Evaluation*. Final Report Submitted to National Oceanic and Atmospheric Administration. Annapolis, Maryland: Chesapeake Bay Program Office.

Bilkovic, D.M., D. Stanhope and K. Angstadt. 2007. Shallow Water Fish Communities and Coastal Development Stressors in the Lynnhaven River, Final Report to U.S. Army Corps of Engineers, Virginia Institute of Marine Science, Center for Coastal Resources Management, Gloucester Point, Virginia, URL: http://ccrm.vims.edu/research/coastal_stressors/lynnhaven_fish_06/lynnhaven_habitat.pdf, (accessed 12/27/2014).

Bilkovic, D.M. and M.M. Mitchell. 2013. Ecological tradeoffs of stabilized salt marshes as a shoreline protection strategy: Effects of artificial structures on macrobenthic assemblages. *Ecological Engineering* 61:469-481.

Bradbury, H., Jennifer Corrin, Alasdair J. Edwards, David O. Obura, Yvonne J. Sadovy de Mitcheson, Melita A. Samoilys, and Charles R.C. Sheppard. 2014. Transforming management of tropical coastal seas to cope with challenges of the 21st century. *Marine Pollution Bulletin* 85:8-23.

Burke, D.G. and C.S. Hardaway. 2007. South River Shore Erosion Management and Living Shoreline Guidelines, A report prepared by the Virginia Institute of Marine Science & Burke Environmental Associates. http://web.vims.edu/physical/research/shoreline/docs/SouthRiverManagementPlan/AppendixC.pdf, (accessed 09/09/2014).

Byrne, Robert J., and Gary L. Anderson. 1979. Shoreline Erosion in Tidewater Virginia. Chesapeake Research Consortium Report No. 8.

Coasts, Oceans, Ports and Rivers Institute (COPRI). 2014. Living Shorelines Database. URL: http://mycopri.org/node/1467, (accessed 10/12/2014).

Currin, C.A., Chappell, W.S, and Deaton, A. 2010. Developing alternative shoreline armoring strategies: The living shoreline approach in North Carolina, *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and Dinicola, R.S., eds., 2010, Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254, p. 91-102.

Defeo, Omar, Anton McLachlan, David S. Schoeman, Thomas A. Schlacher, Jenifer Dugan, Alan Jones, Mariano Lastra, and Felicita Scapinil. 2009. "Threats to sandy beach ecosystems: A review." *Estuarine, Coastal and Shelf Science* 81:1-12.

Dinicola, R.S., eds., 2010, *Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop*, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254:187-194.

Dugan, J.E., and Hubbard, D.M. 2010. Ecological effects of coastal armoring: A summary of recent results for exposed sandy beaches in southern California, *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and

Evans, Rob L. 2004. Rising Sea Levels and Moving Shorelines. *Oceans* 43(1): 6-11.

Fish and Wildlife Service (FWS). 1999. *South Florida Multi-Species Recovery Plan (MSRP) - Coastal Communities*, South Florida Ecological Services Field Office, U.S. Department of the Interior. URL: http://www.fws.gov/VeroBeach/ListedSpeciesMSRP.html (accessed 10/14/2014).

Florida Department of Environmental Protection (FDEP). 2014. *Florida Coastal Management Program Guide*, Florida Coastal Management Program, URL: http://www.dep.state.fl.us/cmp/publications/FCMP_Program_Guide_2014.pdf, (accessed 10/01/2014).

Florida Department of Environmental Protection (FDEP). 2011. Florida Ecological Restoration Inventory (FERI), URL: http://www.dep.state.fl.us/water/wetlands/feri/index.htm, (accessed 12/17/2014).

Florida Department of Environmental Protection (FDEP). 2008. Living Shorelines: Natural Protection of Florida's Coasts, URL: http://www.dep.state.fl.us/coastal/news/articles/2008/0812_Shorelines.htm, (accessed 11/15/2014).

Florida Department of Transportation (FDOT). 1999. Florida Land Use, Cover and Forms Classification System (FLUCCS), third edition. Florida Department of Transportation Surveying and Mapping Office, Geographic Mapping Section, Tallahassee, Florida. URL: http://www.dot.state.fl.us/surveyingandmapping/documentsandpubs/fluccmanual1999.pdf, (accessed 12/15/2014)

Gedan, K.B., M.L. Kirwan, E. Wolanski, E.B. Barbier, and B.R. Silliman. 2011. The present and future role of coastal wetland vegetation in protection shorelines: Answering recent challenges to the paradigm. *Climatic Change* 106:7-29.

Gerstel, W.J. and J.F. Brown. 2006. *Alternative Shoreline Stabilization Evaluation Project.* Final Report Prepared for Puget Sound Action Team. URL: http://pugetsound.org/science/puget-sound-science/reports/shoreline, (accessed 09/10/2014).

Glick, P. and the Florida Coastal and Ocean Coalition. 2008. Preparing for a sea change in Florida: A strategy to cope with the impacts of global warming on the State's coastal and marine systems. 40pp. Available online DISCUSSION DRAFT – Do Not Cite 30 at: http://www.flcoastalandocean.org/PreparingforaSeaChange/Climate_Change_Guide_for_Florida_Preparing_for_a_Sea_Change.pdf.

Glick, P., J. Kostyack, J. Pittman, T. Briceno, and N. Wahlund. 2014. Natural Defenses from Hurricanes and Floods: Protecting America's Communities and Ecosystems in an Era of Extreme Weather, National Wildlife Federation & Earth Economics, URL http://www.nwf.org/news-and-magazines/media-center/news-by-topic/global-warming/2014/10-20-14-new-report-action-needed-now-to-fix-climate-change.aspx,, (accessed 11/28/2014).

Global Environmental Facility (GEF). 2012. Marine Spatial Planning in the Context of the Convention on Biological Diversity, GEF/STAP/C.43/Inf.05, URL: http://www.unep.org/dgef/Portals/43/news/GEFSTAP_C43Inf_05_MarineSPContextConvention_on_BiologicalDiversity.pdf (accessed 12/30/2014).

Gorzelany, J.F. Recreational Boating Activity in Miami-Dade County, Mote Marine Laboratory, Sarasota, FL. 2009. URL: http://www.miamidade.gov/environment/library/memos/mote-boating-study.pdf. (accessed 10/12/2015).

Gorzelany, J.F. Recreational Boating Activity in Broward County, Mote Marine Laboratory, Sarasota, FL. 2005. URL: https://www.broward.org/Manatees/Documents/recreational_boat_survey.pdf. (accessed 10/18/2015).

PBS&J (Post, Buckley, Schuh & Jernigan). Palm Beach County Vessel Traffic Study. Prepared for Florida Fish and Wildlife Conservation Commission, Division of Law Enforcement, Boating and Waterways Section, in partnership with Florida Sea Grant, 2009, URL: www.lwli.org/pdfs/.../2009PalmBeach**VesselTraffic**Study.pdf. (accessed 10/23/2015).

Hardaway, Jr., C.S. and R. J. Byrne. 1999. Shoreline Management in Chesapeake Bay. Special report in Applied Marine Science and Ocean Engineering Number 356. Virginia Sea Grant Publication VSG--11.

Hardaway, Jr., C.S., D.A. Milligan and K. Duhring. 2010. *Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments*, Special Report in Applied Marine Science and Ocean Engineering No. 421, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

Heinz Center. 2000. *Evaluation of Erosion Hazards: Summary*. Prepared for the Federal Emergency Management Agency (Contract EMW-97-CO-0375). Washington, DC: Heinz Center for Science, Economics, and the Environment.

Jancaitis, K.M. 2008. Florida on the Coast of Climate Change: Responding to Rising Seas. UC Davis Law School. *Environs Environmental Law and Policy Journal* 31(2):157-194.

Khalil, S.M., C.W. Finkl, H.H. Roberts, and R.C. Raynie. 2010. New Approaches to Sediment Management on the Inner Continental Shelf Offshore Coastal Louisiana. *Journal of Coastal Research* 26(4):591-64.

Kirwan, M.L. and J.P. Magonigal. 2013. Tidal wetland stability in the face of human impacts and sea-level rise, *Nature*, 503, 53-60.

Komar, P.D. 2000. Shore Leave. *The Sciences,* January/February, p. 20-24.

Kreeger, D. and J. Moody. 2014. A Framework for Standardized Monitoring of Living Shorelines in the Delaware Estuary and Beyond. *Partnership for the Delaware Estuary Shoreline Monitoring Framework*. Accessed September 27, 2014.
https://s3.amazonaws.com/delawareestuary/sites/default/files/PDE%20Living%20Shoreline%20Monitoring%20Framework%204-23-14%20DRAFT.pdf.

Lamont, G., Readshow, J., Robinson, C., St-Germain, P. 2014. Greening Shorelines to Enhance Resilience: An Evaluation of Approaches for Adaptation to Sea Level Rise. Guide prepared by SNC-Lavalin Inc. for the Stewardship Centre for British Columbia and submitted to Natural Resources of Canada (AP040), 46 p. URL: http://www.stewardshipcentrebc.ca/PDF_docs/reports/Greening_Shorelines_to_Enhance_Resilience.pdf, (accessed 11/05/2014).

Landry, C.J. 2002. Who Drained the Everglades? *PERC Reports* 20(5):3-6.

Leafe, R., J. Pethick, and I. Townend. 1998. Realising the benefits of shoreline management. *The Geographic Journal* 164:282-290.

Leatherman, S.P. 2003. Shoreline Change Mapping and Management along the U.S. East Coast. *Journal of Coastal Research* 38:5–13.

Miami-Dade County (MDC). 2013. Freshwater wetlands, Regulatory Economic Resources, Ecosystem Protection, URL: http://www.miamidade.gov/environment/wetlands-freshwater.asp, (accessed 12/27/2014).

Milano, G.R. 1999. Restoration of coastal wetlands in southeastern Florida. *Wetland Journal* 11(2):15-24.

Milano, G.R. 2000. Island restoration and enhancement in Biscayne Bay, Florida, 1-17. In P.J. Cannizarro (ed.). Proceedings of the 26th Annual Conference on Ecosystem Restoration and Creation, Hillsborough Community College, Tampa, Fl.

Mitsova, D. and A.M. Esnard. 2012. Holding Back the Sea: An Overview of Shore Zone Planning and Management. *Journal of Planning Literature* 27(4): 446-459.

NatureServe. 2014. Tools for Landscape-Level Assessment and Planning: A Guide for the North Pacific Landscape Conservation Cooperative, Ecosystems-Based Management Tools Network, Arlington, VA.

National Oceanic and Atmospheric Administration (NOAA). 2000. *Tide and Current Glossary*, U.S. Department of Commerce. URL: http://co-ops.nos.noaa.gov/publications/glossary2.pdf, (accessed 09/30/2014).

New Jersey Department of Environmental Protection. 2009. Mitigating Shoreline Erosion along New Jersey's Sheltered Coast: Overcoming Regulatory Obstacles to Allow for Living Shorelines, NJ Office of Coastal Management, URL: http://www.nj.gov/dep/cmp/docs/living-shorelines2011.pdf (accessed 01/29/2016).

Park, J., J. Obeysekera, M. Irizarry, J. Barnes, P. Trimble, and W. Park-Said. 2011. Storm surge projections and implications for water management in South Florida. *Climatic Change* 107:109-128. DOI 10.1007/s10584-011-0079-8.

Peterson, M.S. & M. R. Lowe. 2009. Implications of Cumulative Impacts to Estuarine and Marine Habitat Quality for Fish and Invertebrate Resources. *Reviews in Fisheries Science* 17(4):505-523. http://dx.doi.org/10.1080/10641260903171803.

Reay, W.G. and S. Lerberg. 2008. Living Shorelines: Restoring multi-function buffers on coastal shorelines. *Water Resources IMPACT* 10(3):9-11.

Rohweder, J., J. T Rogala, B. L Johnson, D. Anderson, S. Clark, F. Chamberlin, D. Potter, and K. Runyon. 2012. Application of Wind Fetch and Wave Models for Habitat Rehabilitation and Enhancement Projects – 2012 Update. Contract report prepared for U.S. Army Corps of Engineers Upper Mississippi River Restoration – Environmental Management Program. 52 p.

Ruppert, T.K. 2008. Eroding Long-Term Prospects for Florida Beaches: Florida's Coastal Construction Control Line Program. Sea Grant Law and Policy 1(1): 65–98, http://nsglc.olemiss.edu/SGLPJ/Vol1No1/4Ruppert.pdf, (accessed 09/10/2014).

Sale, P.F., T. Agardy, C.H. Ainsworth, B.E. Feist, J.D. Bell, P. Christie, O. Hoegh-Guldberg, P.J. Mumby, D.A. Feary, M.I. Saunders, T.M. Daw, S.J. Foale, P.S. Levin, K.C. Lindeman, K. Lorenzen, R.S. Pomeroy, E.H. Allison, R. H. Bradbury, J. Corrin, A.J. Edwards, D.O. Obura, Y.J. Sadovy de Mitcheson, M.A. Samoilys, and C.R. Sheppard. 2014. Transforming management of tropical coastal seas to cope with challenges of the 21st century. *Marine Pollution Bulletin* 85:8-23.

Sargent, F.E. 1988. Case Histories of Corps Breakwater and Jetty Structures - South Atlantic Division - Report 2- *Technical Report REMR-CO-3*, U.S. Army Corps of Engineers South Atlantic Division.

Scyphers, S.B., Powers S.P., Heck K.L. Jr., Byron D. 2011. Oyster Reefs as Natural Breakwaters Mitigate Shoreline Loss and Facilitate Fisheries. *PLoS ONE* 6(8):e22396. DOI:10.1371/journal.pone.0022396.

Southeast Florida Regional Climate Change Compact (SEFL-CCC). 2012a. Inundation Mapping and Vulnerability Assessment Work Group. Analysis of the Vulnerability of Southeast Florida to Sea Level Rise. p. 103, URL: http://www.southeastfloridaclimatecompact.org//wp-content/uploads/2014/09/vulnerability-assessment.pdf, (accessed 11/25/2014).

Southeast Florida Regional Climate Change Compact (SEFL-CCC). 2012b. A Region Responds to a Changing Climate: Regional Climate Action Plan, URL: http://www.southeastfloridaclimatecompact.org//wp-content/uploads/2014/09/regional-climate-action-plan-final-ada-compliant.pdf, (accessed 01/19/2015).

South Florida Water Management District (SFWMD). 2002. FLUCCS Codes Modified for SFWMD, URL: http://www.evergladesplan.org/pm/projects/project_docs/pdp_08_eaa_store/111303_docs_08_socio_fluccs.pdf, (accessed 12/10/2014).

South Florida Water Management District (SFWMD). 2013. Basin Metadata, URL: http://www.sfwmd.gov/gisapps/sfwmdxwebdc/openxml.asp?file=metadata/meta_xml1963.xml&xsl=FGDCESRI.xsl, (accessed 12/07/2014).

South Florida Water Management District (SFWMD). 2015. Coastal Watersheds. URL: http://my.sfwmd.gov/portal/page/portal/xweb%20protecting%20and%20restoring/coastal%20watersheds (accessed 01/23/2015)

Stauble, Donald K. 2003. The Use of Shoreline Change Mapping in Coastal Engineering Project Assessment. *Journal of Coastal Research* 38:178-206.

Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535, DOI:10.1017/CBO9781107415324.

Strauss, B.H, R. Ziemlinski, J.L Weiss and J.T Overpeck. 2012. Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States, *Environmental Research Letters*, 7(1), 1-12.

Subramanian, Bhaskaran, Gene Slear, Kevin M. Smith, and Karen A. Duhring. 2006. Current Understanding of the Effectiveness of Nonstructural and Marsh Sill Approaches. Paper presented at *The Living Shorelines Summit: Evaluation of Living Shoreline Techniques*, William and Mary Virginia Institute of Marine Science, Williamsburg, Virginia, p.35-40. http://www.vims.edu/cbnerr/coastal_training/recent_workshops/ls_summit.php, (accessed 09/10/2014).

Swann, LaDon. 2008. The Use of Living Shorelines to Mitigate the Effects of Storm Events on Dauphin Island, Alabama, USA. *American Fisheries Society Symposium* 64:47–57.

U.S. Army Corps of Engineers (USACE). 1971. *Report of the National Shoreline Study*. Washington, DC: U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers (USACE). 1984. *Shore Protection Manual*, *Volume 1 and Volume 2*. Department. of the Army, Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, Mississippi; Washington, DC.

U.S. Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS).2014. Soil Survey Geographic (SSURGO) Database. USDA-NRCS Soil Survey Staff, Available online at http://sdmdataaccess.nrcs.usda.gov/, (accessed 10/25/2014).

U.S. Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS). 2014. National Soil Survey Handbook, USDA-NRCS Soil Survey Staff, Available online at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054242, (accessed 12/15/2014).

U.S. Department of Transportation -**Federal Highway Administration (FDOT-FHA). 2011.** Highways in the Coastal Environment, Second Edition, Chapter 4 – Waves (4.4 Wave Generation), URL: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/4.cfm, (accessed 12/05/2014).

Van der Westhuysen, Andre J. 2012. Modeling nearshore wave processes UCAR Visiting Scientist at NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch, ECMWF Workshop on Ocean Waves, 25 - 27 June 2012.

Virginia Institute of Marine Science – Center for Coastal Resources Management (VIMS-CCRM). 2012. Living Shorelines Policy: The Integration of Shoreline Management and Planning, *Rivers and Coasts*, 7 (1), 1-8, URL: http://ccrm.vims.edu/publications/pubs/rivers&coast/vol7_no1LSPolicy.pdf, (accessed 10/23/2014).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, **9**(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5/

Walker, R., B. Bendell, and L. Wallendorf. 2011. Defining Engineering Guidelines for Living Shoreline Projects. *Coastal Engineering Practice* ASCE 1064-1077.

Whalen, L., D. Kreeger, D. Bushek, and J. Moody. 2012. Strategic Planning for Living Shorelines in the Delaware Estuary. *National Wetlands Newsletter* 34(6):14-19. Washington, DC: Environmental Law Institute.

Whalen, L., D. Kreeger, D. Bushek, J. Moody, and A. Padeletti. 2011. Practitioner's Guide: Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic. *Partnership for the Delaware Estuary Report* 11-04, URL: https://s3.amazonaws.com/delawareestuary/pdf/Living%20Shorelines/DELSI%20Practitioners%20Guide%20v9.7.11.pdf, (accessed 09/28/2014).

The Nature Conservancy (TNC). 2014. Nature-based Coastal Defenses in Southeast Florida. A collaborative publication of The Nature Conservancy and the Southeast Florida Regional Climate Change Compact Shoreline Resilience Working Group, URL: http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/florida/explore/nature-based-coastal-defenses-in-southeast-florida.xml, (accessed 12/29/2014).

The White House, Office of the Press Secretary. 2014. FACT SHEET: What Climate Change Means for Florida and the Southeast and Caribbean [Press Release]. http://www.whitehouse.gov/sites/default/files/docs/state-reports/FLORIDA_NCA_2014.pdf, (accessed 09/28/2014).

World Meteorological Organization (WMO). 1998. *Guide to Wave Analysis and Forecasting*, 2nd edition, WMO-No. 702, URL: http://www.wmo.int/pages/prog/amp/mmop/documents/WMO%20No%20702/WMO702.pdf, (accessed 12/15/2014).

Appendix 1. Study area shorelines types and proposed stabilization options

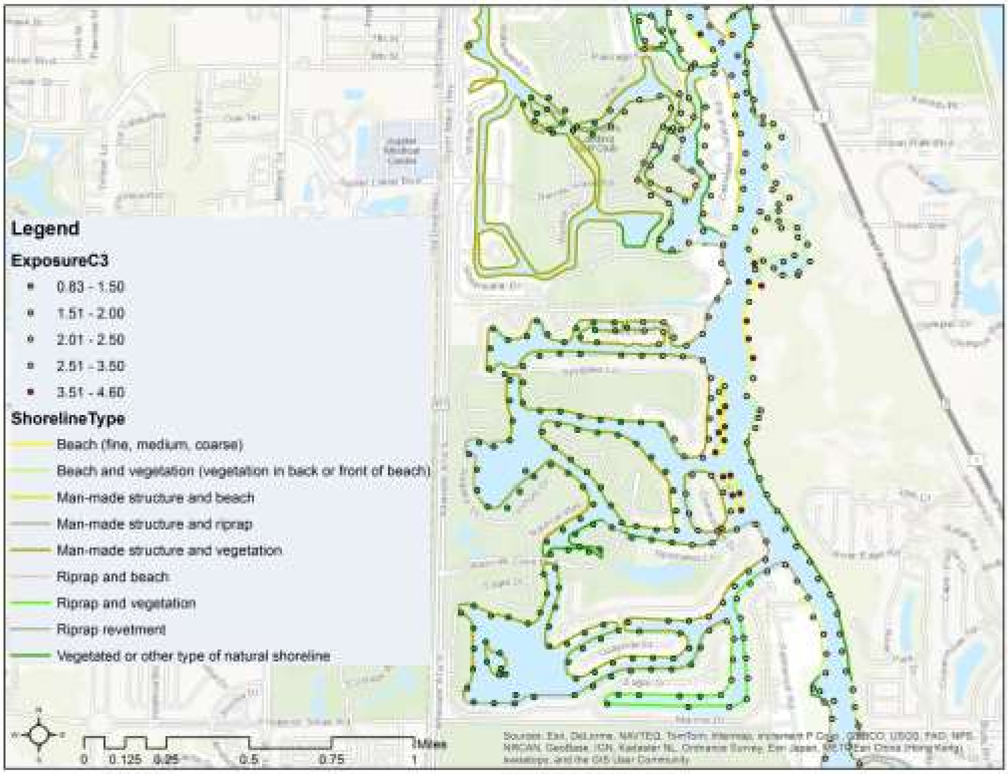
Landward *Seaward*

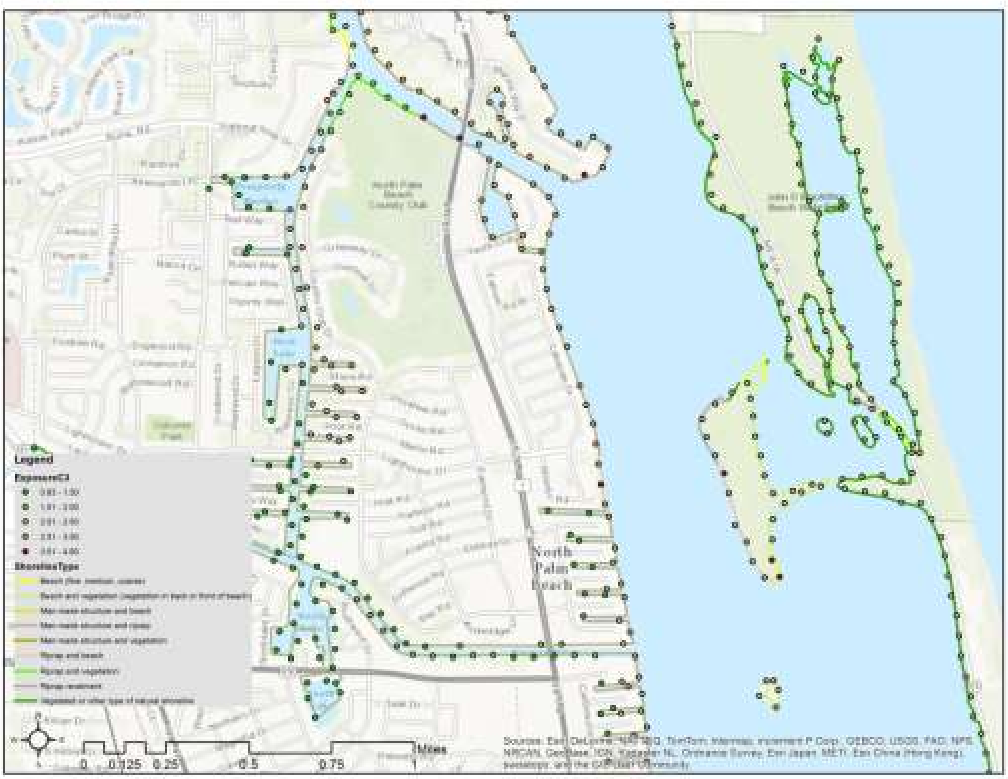
Shoreline Code	Shoreline Type	Category	Stabilization Type
10A/10D/9A	Salt- and Brackish-water Marshes/ Scrub-shrub Wetlands/ Sheltered Tidal Flats	Natural	None
10A/10D	Salt- and Brackish-water Marshes/ Scrub-shrub Wetlands	Natural	None
10A/4	Salt- and Brackish-water Marshes/ Coarse-grained Sand Beaches	Natural	Soft
10A/5	Salt- and Brackish-water Marshes/ Mixed Sand and Gravel Beaches	Natural	Soft
10A/8B	Salt- and Brackish-water Marshes/ Sheltered, Solid Man-made Structures	Man-made	Hybrid/ Soft (enhancement)
10A/9A	Salt- and Brackish-water Marshes/ Sheltered Tidal Flats	Natural	None
10A	Salt- and Brackish-water Marshes	Natural	None
10B/10D	Freshwater Marshes/ Scrub-shrub Wetlands	Natural	None
10B	Freshwater Marshes	Natural	Soft
10C/10D	Swamps/ Scrub-shrub Wetlands	Natural	None/Soft
10C/8A	Swamps/ Sheltered Rocky Shores and Sheltered Scarps in Bedrock, Mud, or Clay	Natural	None/ Soft
10C	Swamps	Natural	None
10D/1B	Scrub-shrub Wetlands / Exposed, Solid Man-made Structures	Man-made	Armored/ Hybrid
10D/2A	Scrub-shrub Wetlands/ Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Natural	None
10D/2B	Scrub-shrub Wetlands / Exposed Scarps and Steep Slopes in Clay	Natural	None
10D/3A	Scrub-shrub Wetlands/ Fine- to Medium-grained Sand Beaches	Natural	None/ Soft
10D/3B	Scrub-shrub Wetlands/ Scarps and Steep Slopes in Sand	Natural	None/Soft
10D/4/7	Scrub-shrub Wetlands/ Coarse-grained Sand Beaches/ Exposed Tidal Flats	Natural	None/Soft
10D/4	Scrub-shrub Wetlands/ Coarse-grained Sand Beaches	Natural	None/ Soft
10D/5	Scrub-shrub Wetlands/ Mixed Sand and Gravel Beaches	Natural	None/ Soft
10D/6B	Scrub-shrub Wetlands/ Riprap	Man-made	Soft/ Hybrid
10D/7	Scrub-shrub Wetlands/ Exposed Tidal Flats	Natural	None
10D/8A	Scrub-shrub Wetlands/ Sheltered Rocky Shores and Sheltered Scarps in Bedrock, Mud, or Clay	Natural	None
10D/8B	Scrub-shrub Wetlands/ Sheltered, Solid Man-made Structures	Man-made	Soft/ Hybrid (enhancement)
10D/8C	Scrub-shrub Wetlands/ Sheltered Riprap	Man-made	Soft/ Hybrid

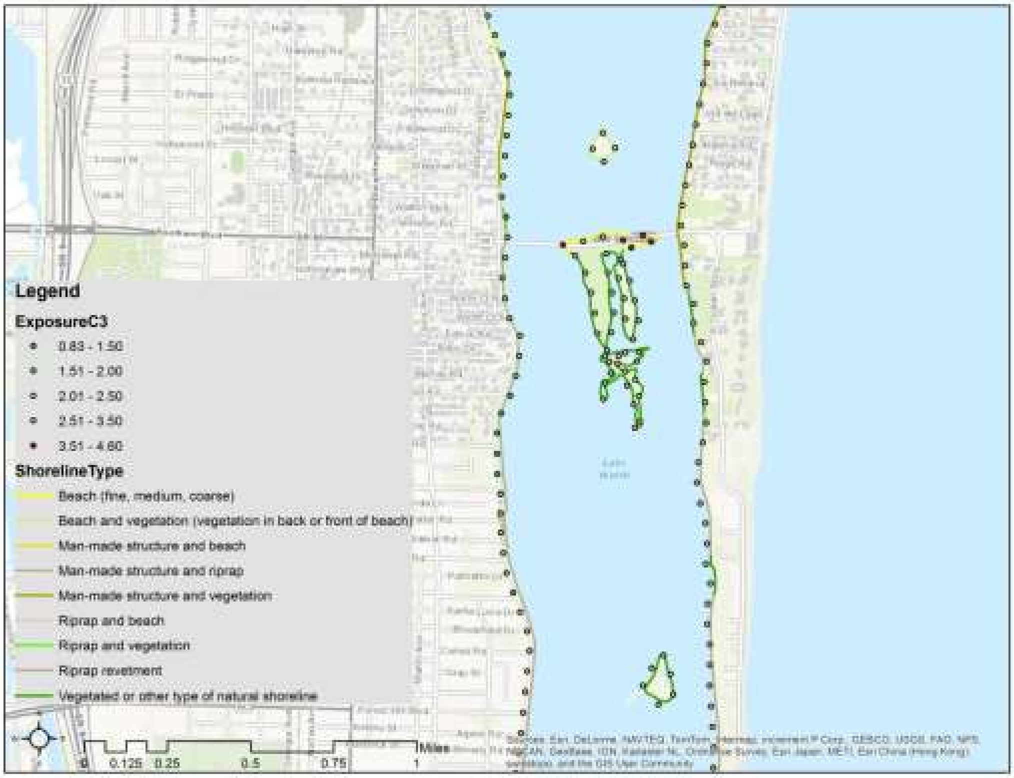
10D/2B	Scrub-shrub Wetlands/ Exposed Scarps and Steep Slopes in Clay	Natural	None
1B/10D	Exposed, Solid Man-made Structures /Scrub-shrub Wetlands	Man-made	Soft/ Hybrid
10D/2A	Scrub-shrub Wetlands/ Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Natural	None
1B/2A	Exposed, Solid Man-made Structures / Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Man-made	Hybrid/None
2B/3A	Exposed Scarps and Steep Slopes in Clay / Fine- to Medium-grained Sand Beaches	Natural	None/ Soft
3A/1B	Fine- to Medium-grained Sand Beaches / Exposed, Solid Man-made Structures		Soft/ Armored/ Hybrid (enhancement)
3A/2A	Fine- to Medium-grained Sand Beaches / Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Natural	None
3A/6B	Fine- to Medium-grained Sand Beaches / Exposed riprap	Man-made	Soft/ Hybrid
3A/7	Fine- to Medium-grained Sand Beaches / Exposed Tidal Flats	Natural	None/ Soft
3A	Fine- to Medium-grained Sand Beaches	Natural	None/ Soft
3B	Scarps and Steep Slopes in Sand	Natural	None/ Soft
4/1B	Coarse-grained Sand Beaches/ Exposed, Solid Man-made Structures	Man-made	Hybrid
4/2A	Coarse-grained Sand Beaches / Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Natural	None
4/6B	Coarse-grained Sand Beaches / Exposed riprap	Man-made	Hybrid
4/7	Coarse-grained Sand Beaches / Exposed Tidal Flats	Natural	None/ Soft
4/8C	Coarse-grained Sand Beaches/ Sheltered Riprap	Man-made	Soft/ Hybrid
4	Coarse-grained Sand Beaches	Natural	None/ Soft
5/10D	Mixed Sand and Gravel Beaches /Scrub-shrub Wetlands	Natural	None/ Soft
5/6B	Mixed Sand and Gravel Beaches / Exposed riprap	Man-made	Soft/ Hybrid
5/7	Mixed Sand and Gravel Beaches/ Exposed Tidal Flats	Natural	None
5	Mixed Sand and Gravel Beaches	Natural	None/ Soft
6B/10A	Exposed riprap/ Salt- and Brackish-water Marshes	Man-made	Hybrid/ Soft
6B/10D	Exposed riprap / Scrub-shrub Wetlands	Man-made	Hybrid/ Soft
6B/2A	Exposed riprap/ Exposed Wave-cut Platforms in Bedrock, Mud, or Clay	Man-made	Hybrid
6B/3A	Exposed riprap/ Fine- to Medium-grained Sand Beaches	Man-made	Hybrid/ Soft
6B/4	Exposed riprap/ Coarse-grained Sand Beaches	Man-made	Hybrid/ Soft
6B/5	Exposed riprap/ Mixed Sand and Gravel Beaches	Man-made	Hybrid/ Soft
6B/7	Exposed riprap / Exposed Tidal Flats	Man-made	Hybrid/ Soft
6B	Exposed riprap	Man-made	Hybrid/ Soft
8A/10D	Sheltered Rocky Shores and Sheltered Scarps in Bedrock, Mud, or Clay /Scrub-shrub Wetlands	Natural	None
8A	Sheltered Rocky Shores and Sheltered Scarps in	Natural	None

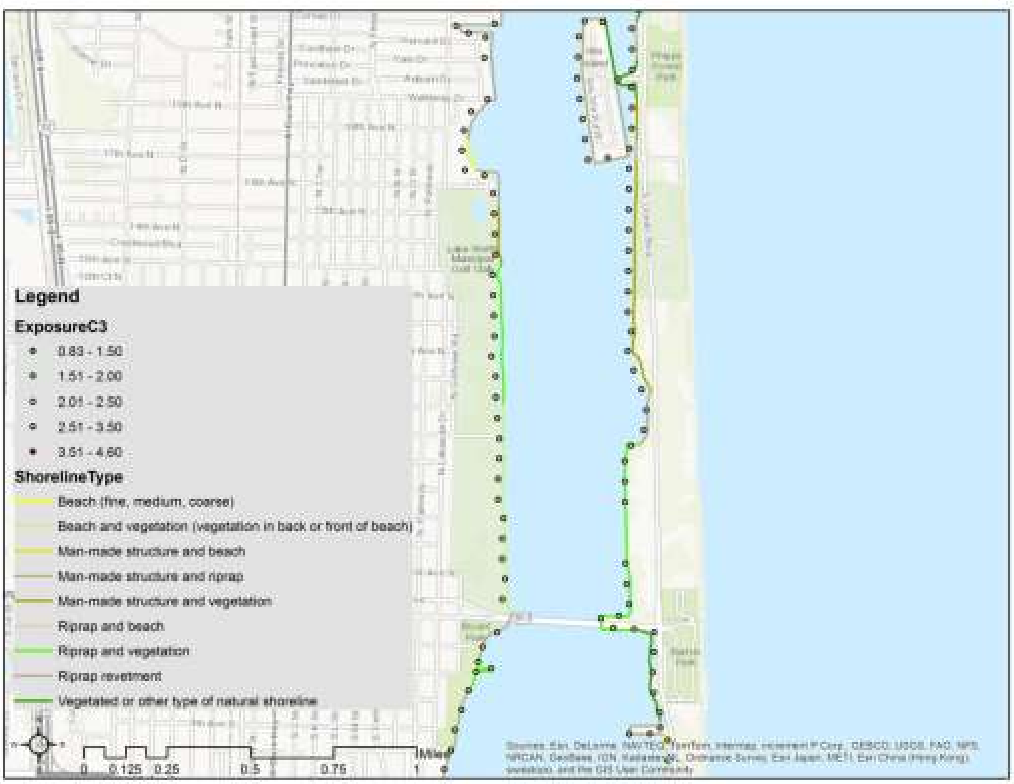
	Bedrock, Mud, or Clay		
8B/10D	Sheltered, Solid Man-made Structures/ Sheltered Rocky Shores and Sheltered Scarps in Bedrock, Mud, or Clay	Man-made	Hybrid
8B/3A	Sheltered, Solid Man-made Structures/ Fine- to Medium-grained Sand Beaches	Man-made	Hybrid/ Soft
8B/4	Sheltered, Solid Man-made Structures/ Coarse-grained Sand Beaches	Man-made	Hybrid/ Soft
8B/6B	Sheltered, Solid Man-made Structures / Exposed rip-rap	Man-made	Hybrid (enhancement)
8B/7	Sheltered, Solid Man-made Structures / Exposed Tidal Flats	Man-made	Hybrid/ Soft
8B/8C	Sheltered, Solid Man-made Structures/ Sheltered Riprap	Man-made	Hybrid/ Soft
8B/9A	Sheltered, Solid Man-made Structures/ Sheltered Tidal Flats	Man-made	Hybrid/ Soft
8B/9B	Sheltered, Solid Man-made Structures/ Vegetated Low Banks	Man-made	Hybrid/ Soft
8B	Sheltered, Solid Man-made Structures	Man-made	Hybrid
8C/10D	Sheltered Riprap/ Sheltered Rocky Shores and Sheltered Scarps in Bedrock, Mud, or Clay	Man-made	Hybrid/ None
8C/3A	Sheltered Riprap/ Fine- to Medium-grained Sand Beaches	Man-made	Hybrid/ Soft
8C/4	Sheltered Riprap / Coarse-grained Sand Beaches	Man-made	Hybrid/ Soft
8C/5	Sheltered Riprap / Mixed Sand and Gravel Beaches	Man-made	Hybrid/ Soft
8C	Sheltered riprap	Man-made	Hybrid/ Soft
9B/3A	Vegetated Low Banks/ Fine- to Medium-grained Sand Beaches	Natural	None/ Soft
9B/4	Vegetated Low Banks / Coarse-grained Sand Beaches	Natural	None/ Soft
9B/5	Vegetated Low Banks / Mixed Sand and Gravel Beaches	Natural	None/ Soft
9B/6B	Vegetated Low Banks / Exposed rip-rap	Man-made	Hybrid/ Soft
9B/5	Vegetated Low Banks / Mixed Sand and Gravel Beaches	Natural	Hybrid/ Soft
9B/6B	Vegetated Low Banks/ Exposed riprap	Man-made	Hybrid
9B/8C	Vegetated Low Banks / Sheltered Riprap	Man-made	Hybrid
9B	Vegetated Low Banks	Natural	None/ Soft
9C	Hypersaline Tidal Flats	Natural	None

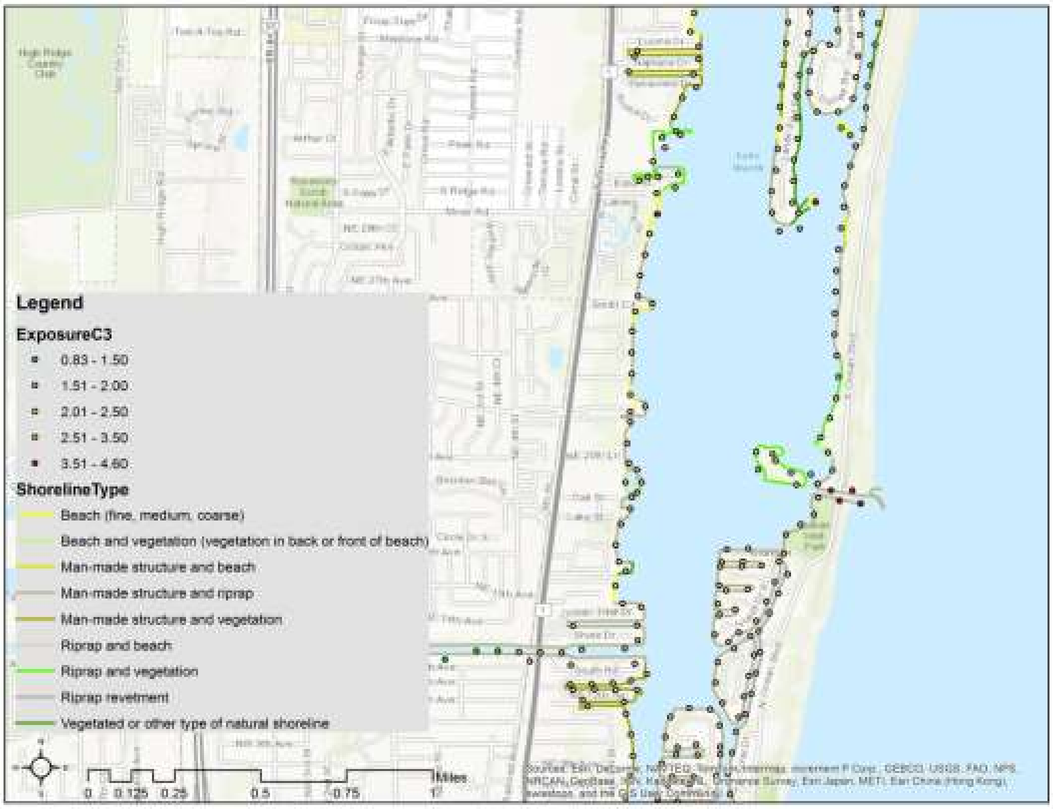
Appendix 2. Examples of potential sites to consider for soft and hybrid stabilization

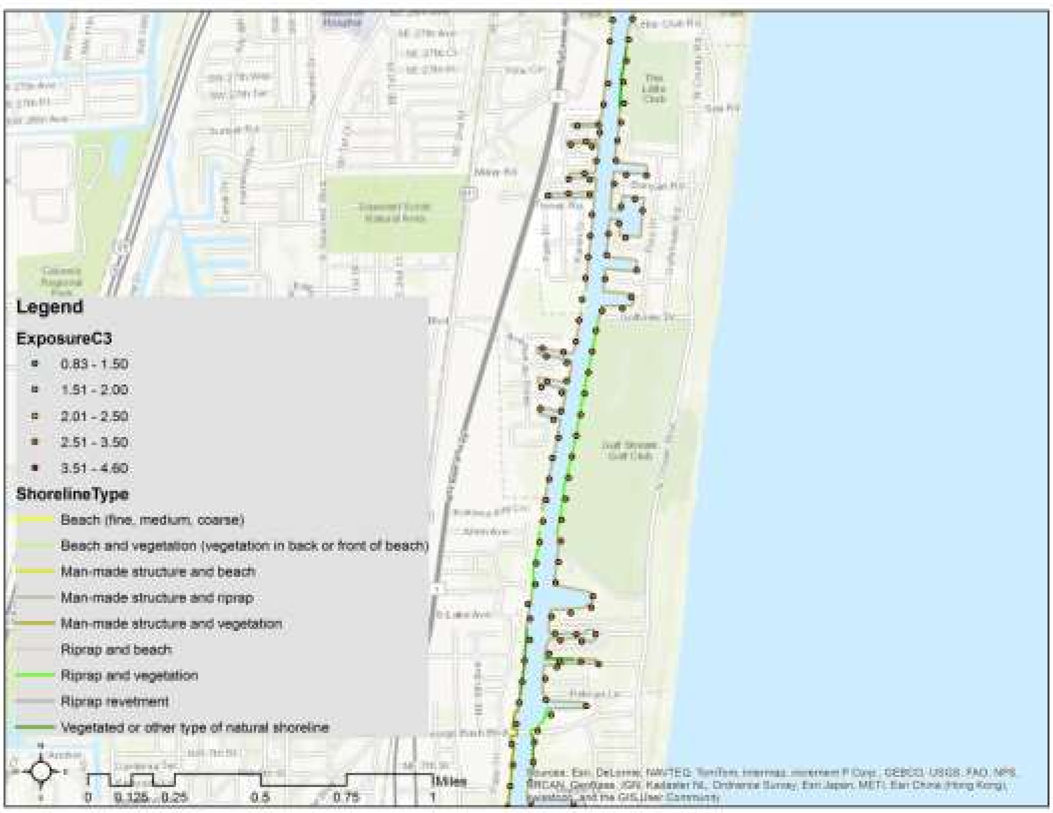


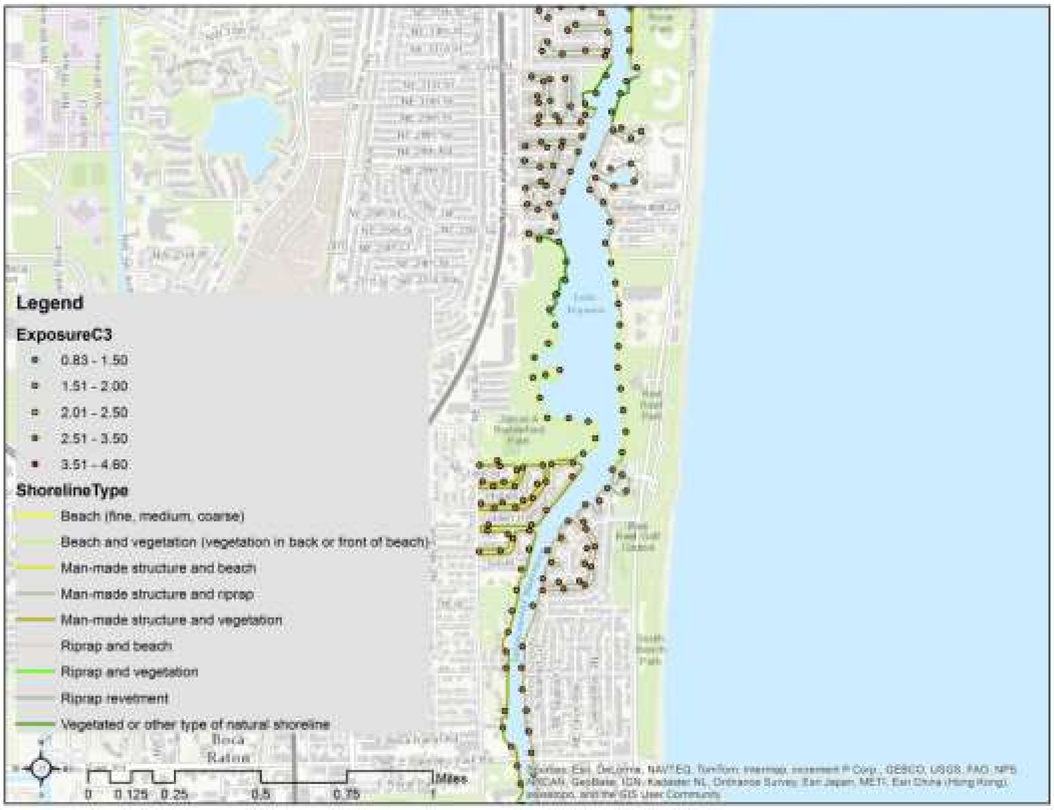



Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles

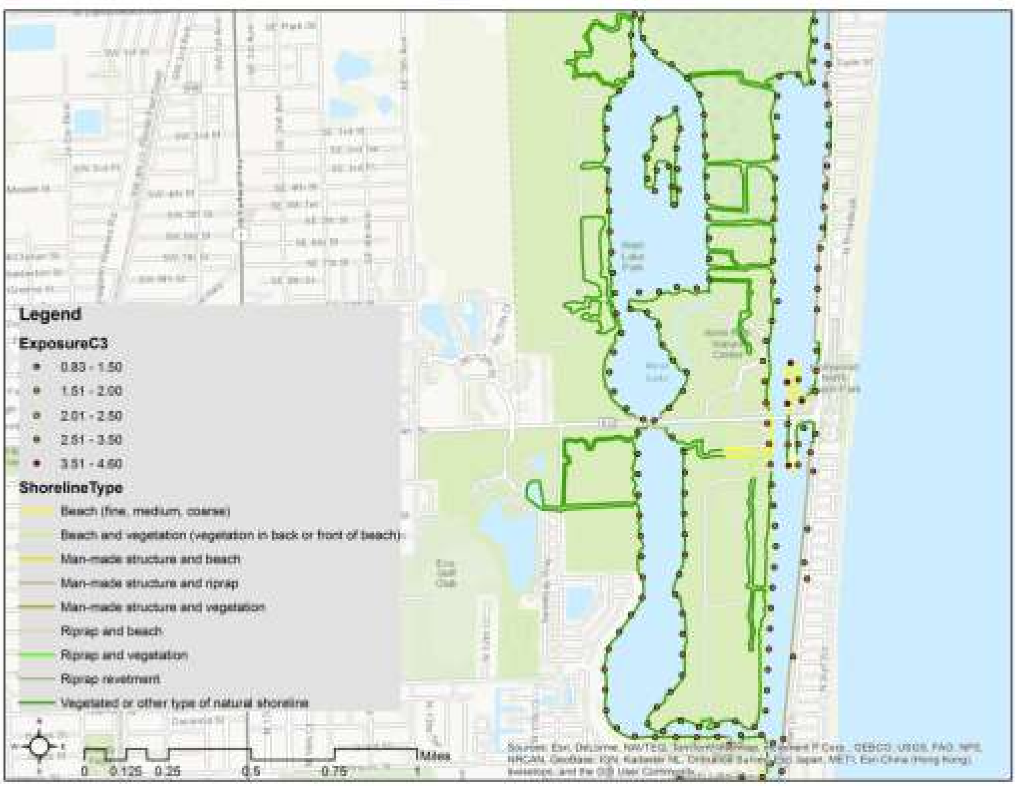

Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles
Boca Raton


Fort Lauderdale
Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
Dania Beach
0 0.125 0.25 0.5 0.75 1
Miles

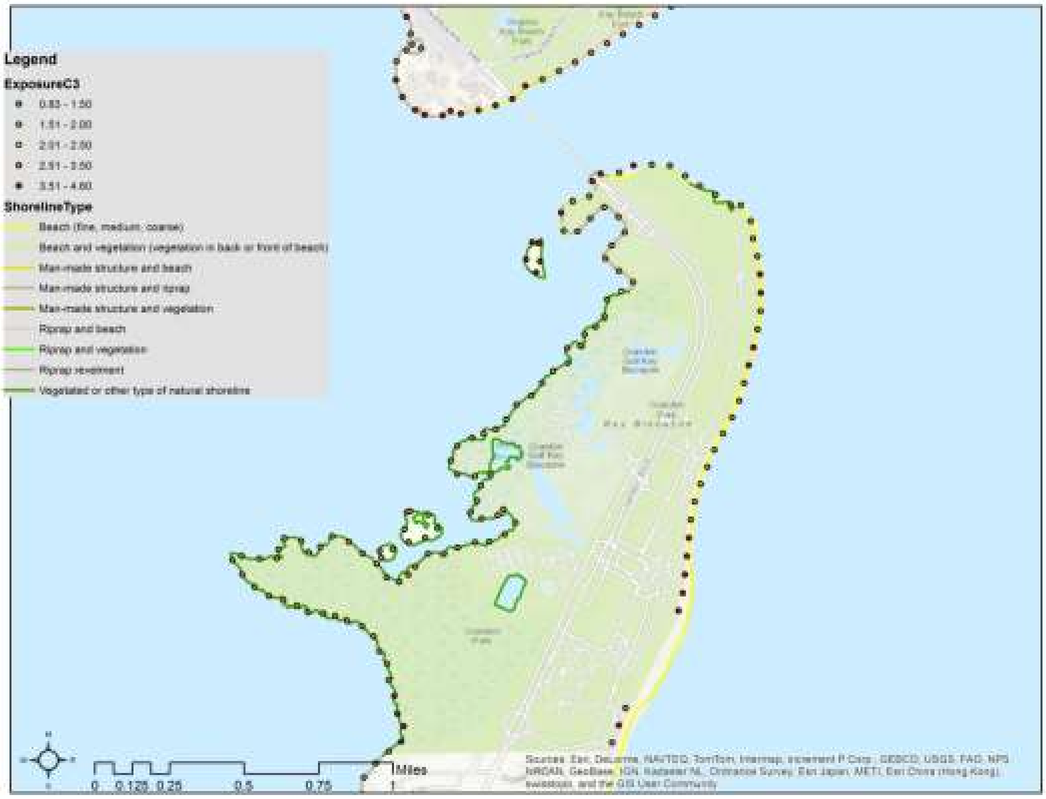

Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
ShorelineType
Ojus
Sunny Isles Beach
Miles
0 0.125 0.25 0.5 0.75


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
Miles
0 0.075 0.15 0.3 0.45 0.6


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.075 0.15 0.3 0.45 0.6
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.125 0.25 0.5 0.75 1
Miles


Key Biscayne
W Mashta Dr
E Mashta Dr
Island Dr
Cape Florida Dr
Bill Baggs Cape Florida State Park
Legend
ExposureC3
0.83 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.50
3.51 - 4.60
ShorelineType
Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Man-made structure and beach
Man-made structure and riprap
Man-made structure and vegetation
Riprap and beach
Riprap and vegetation
Riprap revetment
Vegetated or other type of natural shoreline
0 0.1 0.2 0.4 0.6 0.8
Miles

Appendix 3. Attribute label, attribute type, attribute definition and attribute definition source

Attribute Label	**Attribute Type**	**Attribute Definition**	**Attribute Definition Source**
OBJECTID	OID	Internal feature number	ESRI
Shape	String	Feature type	ESRI
S_NEAR_DIS	Double	Distance between the shoreline point and the water/ landward point (in meters)	generated by ArcGIS **Near** function , used to calculate slope
S_NEAR_X	Double	X-coordinate	ESRI
S_NEAR_Y	String	Y-coordinate	ESRI
S_Z_M	Double	Elevation for the shoreline point feature (in meters)	Data sources: ***Layer Name:*** Broward_10ft (2007 Broward 10-ft DEM in NAVD 1988, Release Version 1) ***Originators:*** South Florida Water Management District (SFWMD) ***Publication date:*** November 23, 2009 ***Data type:*** Fgdb raster digital data ***Data location:*** \\ad.sfwmd.gov\dfsroot\data\elevation\lidar\2007_FDEM\DEM_Releases\Broward\ReleaseV1\merged\fgdb\Broward_Merged_10ft.gdb ***Layer Name:*** MiamiDade_10ft (2007-08 Miami-Dade 5-ft DEM in NAVD 1988, Release Version 1) ***Originators:*** South Florida Water Management District (SFWMD) ***Publication date:*** November 23, 2009 ***Data type:*** Fgdb raster digital data ***Data location:*** http://www.sfwmd.gov ***Layer Name:*** PBEast_10ft Broward_10ft (2007-08 Palm Beach East 10-ft DEM in NAVD 1988, Release Version 1) ***Originators:*** South Florida Water Management District (SFWMD) ***Publication date:*** May 14, 2010 ***Data type:*** Fgdb raster digital data ***Data location:*** \\ad.sfwmd.gov\dfsroot\data\elevation\lidar\2007_FDEM\DEM_Releases\PalmBeachEast\ReleaseV1\merged\fgdb\PBEast_Merged_10ft.gdb
S_Z_FT	Double	Mean elevation for each shoreline feature	Data sources (see S_Z_M field entry)
L_Z_M	Double	Mean elevation for a point ~ 10 m landward from the shoreline feature	Data sources (see S_Z_M field entry)
L_Z_FT	Double	Mean elevation for a point ~ 10 m landward from the shoreline feature	Data sources (see S_Z_M field entry)
W_Z_M	Double	Mean elevation for a point ~ 10 m seaward from the shoreline feature	Data sources (see S_Z_M field entry)
W_Z_FT	Double	Mean elevation for a point ~ 10 m seaward from the	Data sources (see S_Z_M field entry)

		shoreline feature	
LS_PC	Double	Landward slope in percent	Calculated field
WS_PC	Double	Seaward slope	Calculated field
SeagrassDE	String	Description, presence/absence of seagrasses	***Layer Name***: SEAGRS_2011, FLORIDA'S STATEWIDE SEAGRASS – 2011 ***Originators:*** Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute ***Publication date:*** October 21, 2011 ***Data type:*** vector digital data ***Data location:*** http://www.fgdl.org/metadataexplorer/explorer.jsp
MOST_SENS	String	Environmental Sensitivity Index (NOAA 2012) code of the most sensitive plant community	***Layer Name***: SENSHR_2013, FLORIDA'S ENVIRONMENTALLY SENSITIVE SHORELINES - 2013 ***Originators:*** Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute ***Publication date:*** August 1, 2014 ***Data type:*** vector digital data ***Data location:*** http://www.fgdl.org/metadataexplorer/explorer.jsp
Descript2	String	Environmental Sensitivity Index (NOAA 2012) code of the most sensitive plant community	Data source (see above)
W_Z_feet	Double	Water depth 10 m from the shoreline	Derived from topobathymetric LiDAR using the Value to Point function in ArcGIS.
BoatWake	String	Describes three categories of boat wake influence – no wake, medium and high boat wake	***Layer Name:*** State_Boating_Safety_Zones_Florida, This data set represents the FWC Boating Restricted Areas as described in Florida Administrative Code Chapter 68D-24. ***Originators:*** Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute ***Publication date:*** January 1, 2011; updated 2015 ***Data type:*** vector digital data ***Data location:*** http://geodata.myfwc.com/datasets/663fd68e205445da97800b5a5f9ae561_13
SpeedRule	String	Boating safety speed rule	***Layer Name:*** State_Boating_Safety_Zones_Florida, This data set represents the FWC Boating Restricted Areas as described in Florida Administrative Code Chapter 68D-24. ***Originators:*** Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute ***Publication date:*** January 1, 2011; updated 2015 ***Data type:*** vector digital data ***Data location:*** http://geodata.myfwc.com/datasets/663fd68e205445da97800b5a5f9ae561_13 Gorzelany 2005, 2009; PBS&J 2009
DistInlt3mi	String	Binary variable (Yes/No) to	Calculated

		indicate if a shoreline point is within 3 miles from an inlet	
Fetch_cat	String	Very low < 0.25 mi; Low 0.25 to 0.5mi; Medium 0.5 to 1.0 mi; High 1.0 mi to 3.0 mi; Unbounded	The average fetch in miles was calculated using the *Application of Wind Fetch and Wave Models for Habitat Rehabilitation and Enhancement Projects* (Rohweder et al. 2012). The application *Waves2012.tbx* is a toolbox for ©ArcGIS 10.0/10.1 based on the methodology described in the *USACE Shore Protection Manual* (USACE 1984).
Poly_ID	String	SLOSH model output	Available reports, permits and other documents, expert knowledge
i_index	Short integer	A free text field to place general comments	Available reports, permits and other documents, expert knowledge
c1_mean	Double	Modeled height of storm surge	SLOSH
c1_high	Double	Modeled height of storm surge	SLOSH
c2_mean	Double	Modeled height of storm surge	SLOSH
c2_high	Double	Modeled height of storm surge	SLOSH
c3_mean	Double	Modeled height of storm surge	SLOSH
c3_high	Double	Modeled height of storm surge	SLOSH
c4_mean	Double	Modeled height of storm surge	SLOSH
c4_high	Double	Modeled height of storm surge	SLOSH
c5_mean	Double	Modeled height of storm surge	SLOSH
c5_high	Double	Modeled height of storm surge	SLOSH
ShorelineType	String	Environmental Sensitivity Index (NOAA 2012) code of the most sensitive plant community	UPDATED
REI	Double	InVEST output	InVEST outout
Wave_Exp	Double	InVEST output	InVEST output
ExposureX	Double	Exposure Index	Calculated
ExposureC3	Double	Exposure Index + exposure to storm surge for category 3 hurricane (mean)	Calculated
ExposureC5	Double	Exposure Index + exposure to storm surge for category 5 hurricane (high)	Calculated
SuitabilityX	String	Alternative shoreline stabilization options	Based on the decision tree analysis

Appendix 4. Research Participation Invitation

To: dmitsova@fau.edu; cbergh@tnc.org

BCC: email addresses from the expert list (to avoid disclosing the email addresses of potential research subjects to others, it is an IRB requirement)

From: dmitsova@fau.edu; cbergh@tnc.org

Subject: Research Participation Invitation – Living Shorelines Suitability Analysis for Estuarine Systems

You have been asked to complete this survey as part of a research project conducted by FAU with support from The Nature Conservancy. This email message is an approved request for participation in research titled ***SUITABILITY ANALYSIS FOR LIVING SHORELINES IN SOUTHEAST FLORIDA ESTUARINE SYSTEMS*** which has been declared exempt or non-human subjects research by the Florida Atlantic University Institutional Review Board. We conduct a Multi-objective / Multi-criteria suitability analysis. A common concern in multi-criteria evaluation is to measure the relative importance of each criterion. This questionnaire is intended to provide insight and input to the prioritization and assignment of weights to the suitability criteria.

The survey will take about 10 minutes to complete. Your responses are entirely voluntary, and you may refuse to complete any part or all of this survey, by skipping a question or checking "I prefer not to answer." This survey is designed to be anonymous, meaning that there should be no way to connect your responses with you. Toward that end, please do not sign your name to the survey or include any information in your responses that makes it easy to identify you. By completing and submitting the survey, you affirm that you are at least 18 years old and that you give your consent for the Principal Investigator to use your answers as part of this research. If you have any questions about this research before or after you complete the survey, please contact the principal investigator Diana Mitsova at dmitsova@fau.edu or (561) 297-4279. If you have any concerns or questions about your rights as a participant in this research, please contact the Florida Atlantic University Division of Research at (561) 297-0777.

The survey can be accessed through the link below:

http://faucdsi.az1.qualtrics.com/jfe/form/SV_eKYZwTTvVEWYnqZ

Thank you for your participation.

Diana Mitsova, PhD

Associate Professor
School of Urban & Regional Planning
Florida Atlantic University
Phone: 561-297-4285

Chris Bergh

South Florida Conservation Director
The Nature Conservancy
Chair, Shoreline Resilience Working Group
SE FL Regional Climate Compact

Appendix 5. Survey instrument

Questionnaire

In response to the erosion of shorelines, as well as potentially more intense storm damage and flooding as a result of sea level rise and climate change, armoring of shorelines is likely to increase using traditional engineered approaches and structures. This hard-armoring approach is known to reduce sediment sources by interrupting natural sediment transport, affect water quality and reduce habitat in adjacent water bodies, and fundamentally disrupt the connection between coastal and offshore ecosystems. Alternative and viable approaches to shoreline stabilization techniques and land use practices that minimize structural and environmental problems associated with hard-armored shorelines are becoming an accepted practice in shore zone management. Alternative stabilization techniques have been shown to provide comparable protection under suitable landscape and environmental conditions. These approaches allow for the long-term protection, restoration and/or enhancement of vegetated shoreline habitats, even during tropical storms. We conduct a Multi-objective / Multi-criteria suitability analysis and mapping for such alternative approaches: A common concern in multi-criteria evaluation is to measure the relative importance of each criterion. This questionnaire is intended to provide insight and input to the prioritization and assignment of weights to the suitability criteria (see pp. 3-4 of this questionnaire).

The survey will take about 10 minutes to complete. Your participation to this survey is voluntary. You may skip any question that makes you uncomfortable by checking "I prefer not to answer." The risks involved with participation in this study are no more than one would experience in regular daily activities since your survey responses are anonymous (i.e. there are no personal identifiers). For other questions about the study, contact the principal investigator Diana Mitsova at dmitsova@fau.edu or (561) 297-4279.

==

1. County________________________

2. How many years of experience do you have in the field? I prefer not to answer___

3. Which sector have you worked for? I prefer not to answer___
   a. Public
   b. Private
   c. Both
4. What is your area of expertise? I prefer not to answer___

   ____

5. What is your educational background?
   a. Coastal Engineering ____
   b. Geoscience and GIS ____
   c. Environmental science ____
   d. Urban Planning ____
   e. Architecture/ Design ____
   f. Social science ____
   g. Business ____
   h. Other (please specify) ____

6. Have you been involved in coastal management projects?
   a. Yes b. No
   If yes, for how many years? ______________________________

7. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 5 years? I prefer not to answer___
   a. No
   b. Yes
   If yes, what type of hazard? __________________________________

8. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 10 years? I prefer not to answer___
   a. No
   b. Yes
   If yes, what type of hazard? __________________________________

9. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 25 years? I prefer not to answer___
   a. No
   b. Yes
   If yes, what type of hazard? __________________________________

10. One of the parameters included in the living shoreline suitability analysis for SE FL estuarine environments is "Distance to inlet." This parameter will be used as a proxy for currents and salinity conditions within a specified shoreline feature. To this respect , which of the following should be the maximum distance to inlet to be considered in the analysis (please circle one):
    a. 0.25 mi
    b. 0.5 mi
    c. 1.0 mi
    d. 2.0 mi
    e. 3.0 mi
    f. Other (please specify) ___________________________________
    g. I don't know

11. Listed on the next page are various land use categories. Some uses such as publicly-owned parks or golfcourses are known to allow easier access and implementation of various restoration and stabilization projects. Others tend to be more cautious in their approach. For example, public lands, public parks and conservation areas are more likely to facilitate soft stabilization while private property owners may be more inclined to support hard armoring or hybrid shoreline stabilization. The scale below indicates the perceived ease of action regarding the establishment of project types other than traditional armoring. On a scale of 1 to 5, please indicate how easy you think it will be to implement nature-based approaches (where 1 indicates a very low chance of implementing a project type other than traditional armoring, while 5 indicates a very high chance of implementing such a project, all other favorable conditions being present):

	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Public lands (Recreation/ Conservation	1	2	3	4	5
Education	1	2	3	4	5
Marina	1	2	3	4	5
Transportation	1	2	3	4	5
Recreation private Golfcourse	1	2	3	4	5
Commercial Hotel/Timeshare	1	2	3	4	5
Industrial	1	2	3	4	5
Mixed Use	1	2	3	4	5
Office / Commercial	1	2	3	4	5
Residential High Density	1	2	3	4	5
Residential Low Density	1	2	3	4	5
Residential Multifamily/ Condos	1	2	3	4	5

12. Suitability analysis usually relies on multiple factors. Some of these factors are more important for the proposed action than others, therefore they carry more weight. The next few questions are intended to elicit your expert opinion on the importance of some of the factors included in the suitability analysis for living shorelines in SE FL estuarine environments. We will use pairwise comparisons to gain an insight of which factor is considered more important and thus having higher weight. Weights will be extracted on the basis of these pairwise comparisons.

    a. Wind/Wave Exposure (WWE) vs. Boat wake exposure (BWE)

WWE ___ BWE ______ Both ______

    b. Boat wake exposure (BWE) vs. Distance to inlet (DI)

BWE ____ DI _____ Both ______

    c. Nearshore slope vs. Shoreline Type (ST) (natural, armored, hybrid)

Nearshore slope _____ ST _____ Both ______

    d. Nearshore slope vs. Distance to inlet (DI)

Nearshore slope _____ DI _____ Both ______

    e. Shoreline type (ST) (natural, armored, hybrid) vs. Nearshore habitat (NH)

ST _____ Nearshore habitat _____ Both ______

f. Nearshore slope vs. Nearshore habitat (NH)

Nearshore slope _____ Nearshore habitat _____ Both ______

g. Presence of upland natural habitat (PNH) vs. Shoreline Type (ST) (natural, armored, hybrid)

Upland NH _______ ST ______ Both ______

h. Nearshore habitat (NH) vs. Wind/Wave Exposure (WWE))

Nearshore habitat _______ WWE _____ Both ______

i. Wind/Wave Exposure (WWE) vs. Presence of upland natural habitat (Upland NH)

WWE ______ Upland NH _____ Both ______

j. Ownership (public or private) vs. Land use (LU)

Ownership ______ LU ______ Both _______

Appendix 6. Qualtrics initial report

Last Modified: 11/01/2015

#	Answer		Response	%
1	I consent to participate in this study		33	100%
2	I do not consent to participate in this study		0	0%
	Total		33	100%

Statistic	Value
Min Value	1
Max Value	1
Mean	1.00
Variance	0.00
Standard Deviation	0.00
Total Responses	33

2. County (enter the name of the County where you are employed)
Text Response
Santa Barbara
Dade
Miami Dade
Miami-Dade
Monroe
Miami - Dade
Miami-Dade
USA
Leon
United States
broward
Indian River
santa cruz, CA
Monroe
Leon
Miami-Dade
Miami-Dade County
Palm Beach
Volusia
Broward
Broward
Palm Beach
Palm Beach
Broward
Miami-Dade
Palm Beach
Palm Beach
Broward
Monroe
Miami-Dade
Martin

Statistic	Value
Total Responses	31

1. What is your area of expertise?

Text Response
Coastal engineering
Coastal science
Planning
Ecology
land conservation - sustainability
Marine Biology
Systems Ecology
Community Resilience Building
Marine habitat restoration
Design / Planning / Art
environmental restoration and education
Biology
coastal engineering
wetland ecology
Marine Habitat Restoration
Environmental Science
Restoration Specialist
Environmental Restoration
Coastal hydrology
Restoration
Environmental Science and Coastal Policy
Coastal Dune
Coastal Ecology
Urban Planning, Sustainability, Environmental Engineering
Coastal Science
Stormwater Management and Drainage
Natural Area Management
Restoration Ecology
Coastal restoration and invasion biologist

Statistic	Value
Total Responses	29

4. Which sector have you worked for?

#	Answer		Response	%
1	Public		10	30%
2	Private		3	9%
3	Both		20	61%
4	I prefer not to answer		0	0%
	Total		33	100%

Statistic	Value
Min Value	1
Max Value	3
Mean	2.30
Variance	0.84
Standard Deviation	0.92
Total Responses	33

5. What is your educational background?

#	Answer		Response	%
1	Coastal Engineering		3	9%
2	Geoscience and GIS		1	3%
3	Environmental science		14	42%
4	Urban Planning		1	3%
5	Architecture/ Design		2	6%
6	Social science		0	0%
7	Business		1	3%
8	Other (please specify)		11	33%
	Total		33	100%

Other (please specify)
Regional & urban planning
Biology
ecology
Limnology
Ecology/Biology
Coastal Zone Management
Marine Biology and Coastal Zone Mgmt
Civil ad Environmental Engineering
Biology
plant biologist

Statistic	Value
Min Value	1
Max Value	8
Mean	4.73
Variance	6.70
Standard Deviation	2.59
Total Responses	33

6. How many years of experience do you have in the field?
Text Response
7
35
17
15
20
11
42
25
25
15
27
33
8
30
20
10+
37
32
30+
10
4
40
5
23
8
10 plus
35
14
30 plus
20
12
25

Statistic	Value
Total Responses	32

7. Have you been involved in coastal management projects?				
#	Answer		Response	%
1	No		6	19%
2	Yes		26	81%
	Total		32	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.81
Variance	0.16
Standard Deviation	0.40
Total Responses	32

8. If yes, for how many years:

Text Response
30
10
15
3
5
25
25
12
5
13
4
15
8
32
27
20
40
10 plus
25
5
10 plus
20
7
20

Statistic	Value
Total Responses	24

9. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 5 years?

#	Answer		Response	%
1	No		19	61%
2	Yes		12	39%
	Total		31	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.39
Variance	0.25
Standard Deviation	0.50
Total Responses	31

10. If yes, what type of hazard?

Text Response
Flooding, sea level rise
storm surge, wind/ice/snow, tornado, sea level rise, inland flooding
Flooding
Storm Events
Flooding
SLR, Tidal
Flooding and Erosion
TS Isaac Flood Response and Emergency Ops Center response
Oil Spill, Storm
Shoreline erosion

Statistic	Value
Total Responses	10

11. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 10 years?

#	Answer		Response	%
1	No		17	53%
2	Yes		15	47%
	Total		32	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.47
Variance	0.26
Standard Deviation	0.51
Total Responses	32

12. If yes, what type of hazard?

Text Response
Flooding, sea level rise
same as above for 5 years
Hurricane
hurricanes
Flooding
Storm Events
Flooding from Isaac
Hurricanes in 2004 - work extended through 2006
Flooding
But involved in USCG regional hazard prep efforts for wildlife protection
Flooding and Erosion
Coastal erosion, emergency response and long term planning, and restoration projects
Storm
Past Hurricane Damage Assessments
Shoreline erosion

Statistic	Value
Total Responses	15

13. Have you been part of a response effort to a coastal flooding event or other coastal hazards in your community in the past 25 years?

#	Answer		Response	%
1	No		19	66%
2	Yes		10	34%
	Total		29	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.34
Variance	0.23
Standard Deviation	0.48
Total Responses	29

14. If yes, what type of hazard?

Text Response
Flooding & storm surge
storm surge, inland flooding
Hurricane
Storm Events
coastal flooding due to tropical storm (unnamed)
Same as 7 and 8
Storm
Past Hurricane Damage Assessments
Coastal flooding, saltwater intrusion

Statistic	Value
Total Responses	9

15. One of the parameters included in the living shoreline suitability analysis for SE FL estuarine environments is "Distance to inlet." This parameter will be used as a proxy for boat traffic and circulation conditions within a specified distance from a shoreline feature. To your knowledge, which of the following should be the maximum distance to inlet to be considered in the analysis (please check one):

#	Answer		Response	%
1	0.25 mi		3	17%
2	0.5 mi		0	0%
3	1.0 mi		1	6%
4	2.0 mi		1	6%
5	3.0 mi		5	28%
6	Other		8	44%
	Total		18	100%

Other
This is inlet-dependent
if possible otherwise 0.25mi - more is better to minimize wake but properly designed living shorelines can reduce wake in very close proximity however, they then may cause navigational hazards which are not to cool
depends on floodplain....consider floodplain maps
Distance should be based on historical information on erosion in a particular system. However for planning purposes, in south Florida tidal influence in the estuarine waters can be considered to be within 3 miles.
Not Applicable
Depends on type of shoreline and purpose of project. Could be a variable or not.
10 miles
Varies depending on location and other factors

Statistic	Value
Min Value	1
Max Value	6
Mean	4.61
Variance	3.43
Standard Deviation	1.85
Total Responses	18

16. Listed below are various land use categories. Some uses such as publicly-owned parks or golfcourses are known to allow easier access and implementation of various restoration and stabilization projects. Others tend to be more cautious in their approach. For example, public lands, public parks and conservation areas are more likely to facilitate soft stabilization while private property owners may be more inclined to support hard armoring or hybrid shoreline stabilization. The scale below indicates the perceived ease of action regarding the establishment of project types other than traditional armoring. On a scale of 1 to 5, please indicate how easy you think it will be to implement nature-based approaches (where 1 indicates a very low chance of implementing a project type other than traditional armoring, while 5 indicates a very high chance of implementing such a project, all other favorable conditions being present):

#	Question	Very Low [1]	Low [2]	Medium [3]	High [4]	Very High [5]	Total Responses	Mean
1	Public lands (recreation, conservation)	0	0	3	5	23	31	4.65
2	Education	0	0	7	10	14	31	4.23
3	Marina	8	8	14	1	0	31	2.26
4	Transportation	5	7	12	6	1	31	2.71
5	Recreation Private Golfcourse	1	3	12	11	3	30	3.40
6	Commercial Office	6	7	16	2	0	31	2.45
7	Commercial Hotel/ Timeshare	6	9	13	3	0	31	2.42
8	Mixed use	1	6	23	1	0	31	2.77
9	Industrial	12	9	9	0	1	31	2.00
10	Residential Low Density	1	6	18	3	3	31	3.03
11	Residential High Density	4	14	10	2	1	31	2.42
12	Residential Multi-familiy/ Condos	1	14	13	2	1	31	2.61

Statistic	Public lands (recreation, conservation)	Education	Marina	Transportation	Recreation Private Golfcourse	Commercial Office	Commercial Hotel / Timeshare	Mixed use	Industrial	Residential Low Density	Residential High Density	Residential Multi-family/ Condos
Min Value	3	3	1	1	1	1	1	1	1	1	1	1
Max Value	5	5	4	5	5	4	4	4	5	5	5	5
Mean	4.65	4.23	2.26	2.71	3.40	2.45	2.42	2.77	2.00	3.03	2.42	2.61
Variance	0.44	0.65	0.80	1.15	0.87	0.79	0.85	0.31	1.00	0.83	0.85	0.65
Standard Deviation	0.66	0.80	0.89	1.07	0.93	0.89	0.92	0.56	1.00	0.91	0.92	0.80
Total Responses	31	31	31	31	30	31	31	31	31	31	31	31

17. Suitability analysis usually relies on multiple factors. Some of these factors are more important for the proposed action than others, therefore they carry more weight. The next few questions are intended to elicit your expert opinion on the importance of the factors included in the suitability analysis. We will use pairwise comparisons to gain an insight of which factor is considered more important and thus having higher weight. Weights will be extracted on the basis of these pairwise comparisons. Consider the first statement " Wind/Wave Exposure (WWE) vs. Boat wake exposure (BWE)." In this statement, WWE is Parameter 1 while BWE is Parameter 2. Check the radio button to indicate whether you consider WWE having more influence than BWE, BWE having more influence than WWE, or both being equally important.

#	Question	Parameter 1	Parameter 2	Both	Total Responses	Mean
1	Wind/Wave Exposure (WWE) vs. Boat wake exposure (BWE)	12	2	15	29	2.10
2	Boat wake exposure (BWE) vs. Distance to inlet (DI)	15	6	5	26	1.62
3	Nearshore slope (NS) vs. Shoreline Type (ST) (natural, armored, hybrid)	5	11	11	27	2.22
4	Nearshore slope (NS) vs. Distance to inlet (DI)	17	5	4	26	1.50
5	Shoreline type (ST) (natural, armored, hybrid) vs. Nearshore habitat (NH)	13	5	9	27	1.85
6	Nearshore slope vs. Nearshore	9	5	12	26	2.12

	habitat (NH)					
7	Presence of upland natural habitat (PNH) vs. Shoreline Type (ST) (natural, armored, hybrid)	7	16	4	27	1.89
8	Nearshore habitat (NH) vs. Wind/Wave Exposure (WWE)	3	15	8	26	2.19
9	Wind/Wave Exposure (WWE) vs. Presence of upland natural habitat (Upland NH)	20	3	3	26	1.35
10	Ownership (public or private) vs. Land use (LU)	7	4	15	26	2.31

Statistic	Wind/ Wave Exposure (WWE) vs. Boat wake exposure (BWE)	Boat wake exposure (BWE) vs. Distance to inlet (DI)	Nearshore slope (NS) vs. Shoreline Type (ST) (natural, armored, hybrid)	Nearshore slope (NS) vs. Distance to inlet (DI)	Shoreline type (ST) (natural, armored, hybrid) vs. Nearshore habitat (NH)	Nearshore slope vs. Nearshore habitat (NH)	Presence of upland natural habitat (PNH) vs. Shore line Type (ST) (natural, armored, hybrid)	Nearshore habitat (NH) vs. Wind/ Wave Exposure (WWE)	Wind/ Wave Exposure (WWE) vs. Presence of upland natural habitat (Upland NH)	Ownership (public or private) vs. Land use (LU)
Min Value	1	1	1	1	1	1	1	1	1	1
Max Value	3	3	3	3	3	3	3	3	3	3
Mean	2.10	1.62	2.22	1.50	1.85	2.12	1.89	2.19	1.35	2.31
Variance	0.95	0.65	0.56	0.58	0.82	0.83	0.41	0.40	0.48	0.78
Standard Deviation	0.98	0.80	0.75	0.76	0.91	0.91	0.64	0.63	0.69	0.88
Total Responses	29	26	27	26	27	26	27	26	26	26

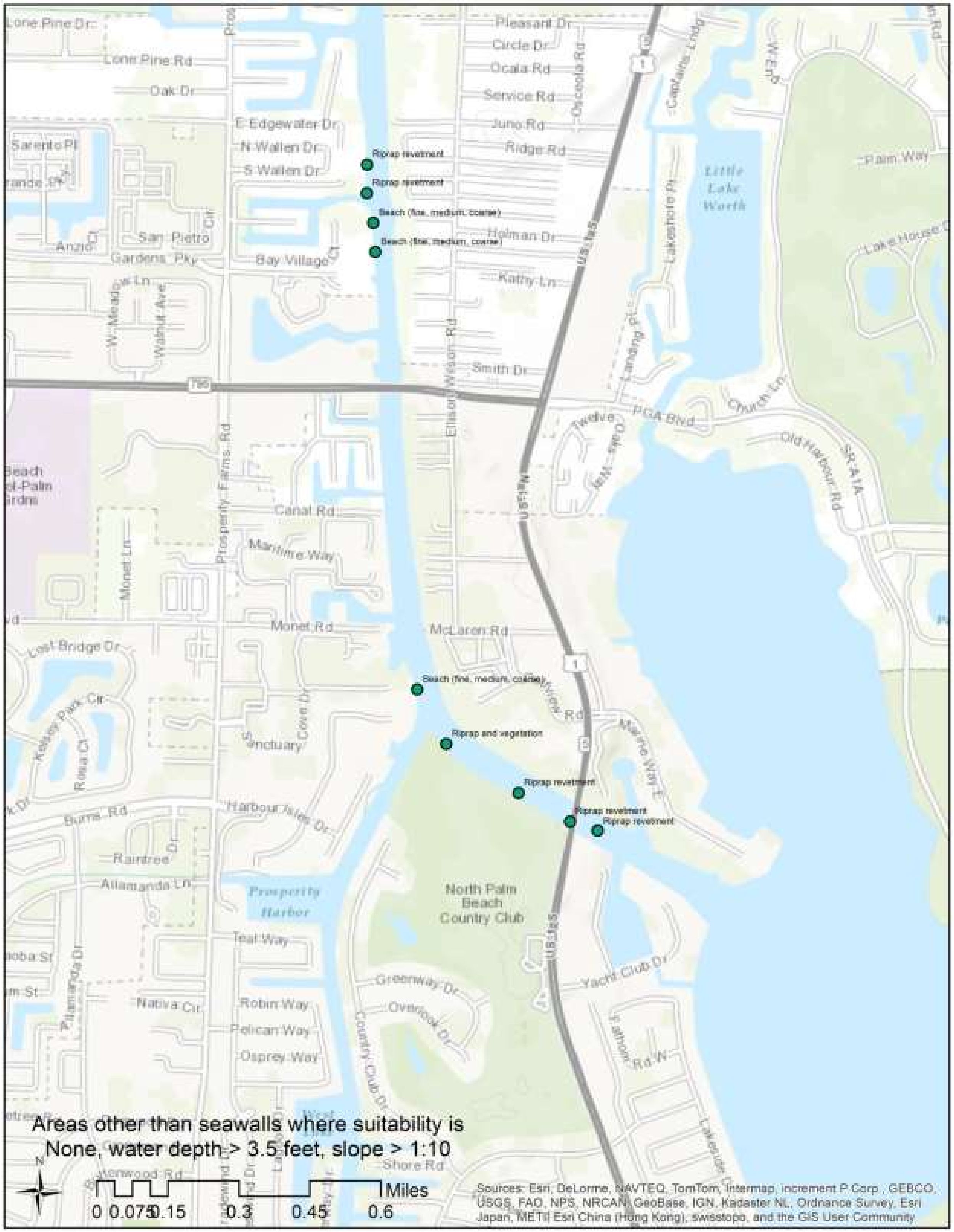
18. In this section, we will give you the opportunity to share comments and suggestions.
Text Response
If you have good policy, all can be easier.
I did not understand the last question....consider natural floodplain in the analysis, education is necessary as the way to disseminate information to landowners so they understand how living shorelines will protect their assets....also consider plants and pruning that will not impact view too much, that will help.
The selections in the previous section depend on the circumstances. For example, wind/wave exposure is more important in open areas exposed to wind but not as important in a protected narrow channel setting. In the narrow channel setting, boat wakes play a bigger role.
After reading through and answering the questions I realized that (I think) we are not talking about beach erosion. A living shoreline on an ocean beach can be effective for erosion control but I assumed oceanfront projects are not the subject of this survey.
Answers came from hard copy of the survey
Answers came from hard copy of the survey. Pair-wise comparisons were noted to be site dependent and boat wake exposure and distance to inlet was said to not be a logical factor. All land use categories were also said by the respondent to be possible in today's regulatory world.

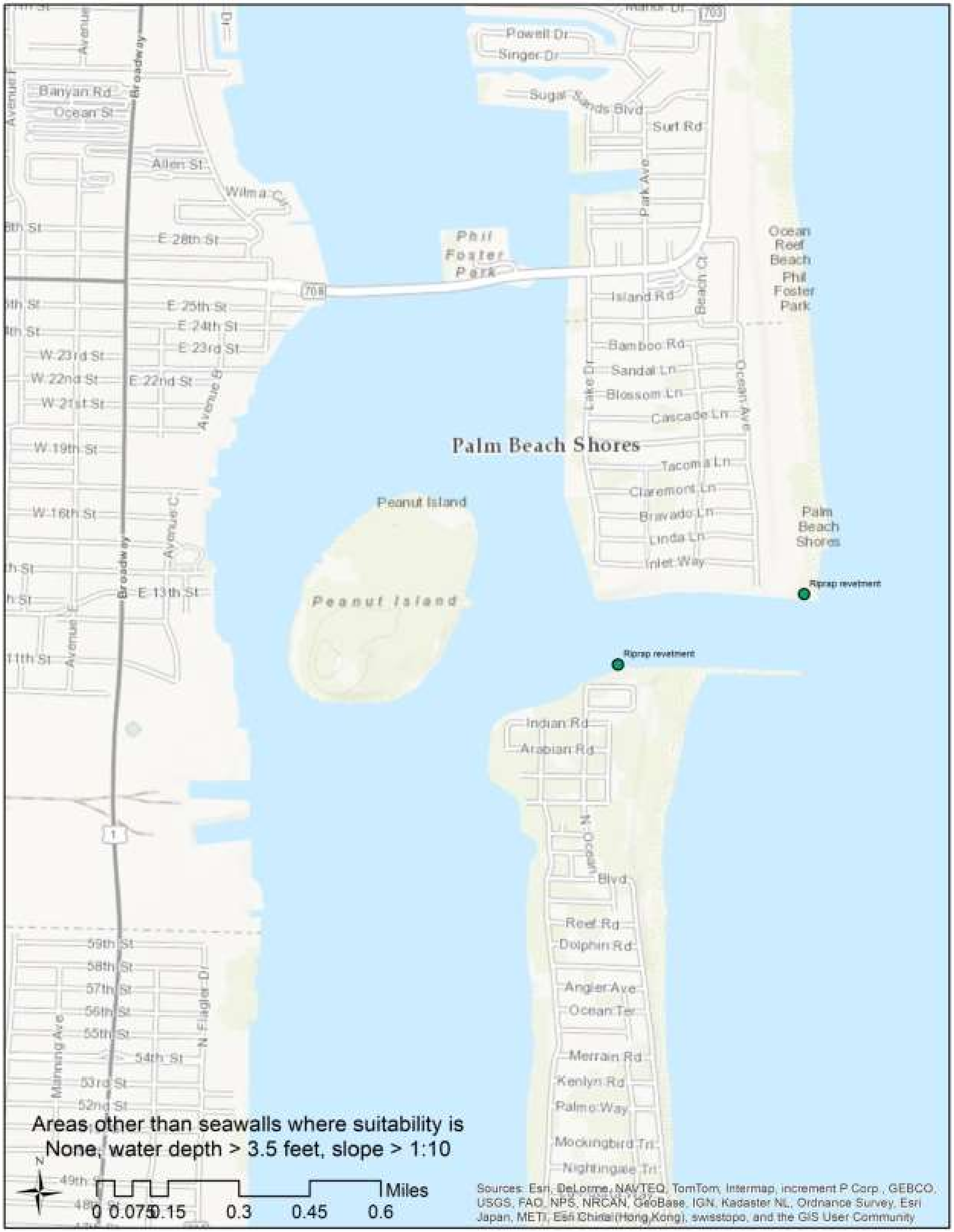
Appendix 7. Areas with a natural or hybrid type of shoreline where suitability for nature-based stabilization options is considered "none" due to greater water depths and steeper gradients

NOTE: Due to sediment movement caused by currents, storms, boat traffic, and construction activities, changes in sediment erosion and deposition rates may occur at the specified locations over time.

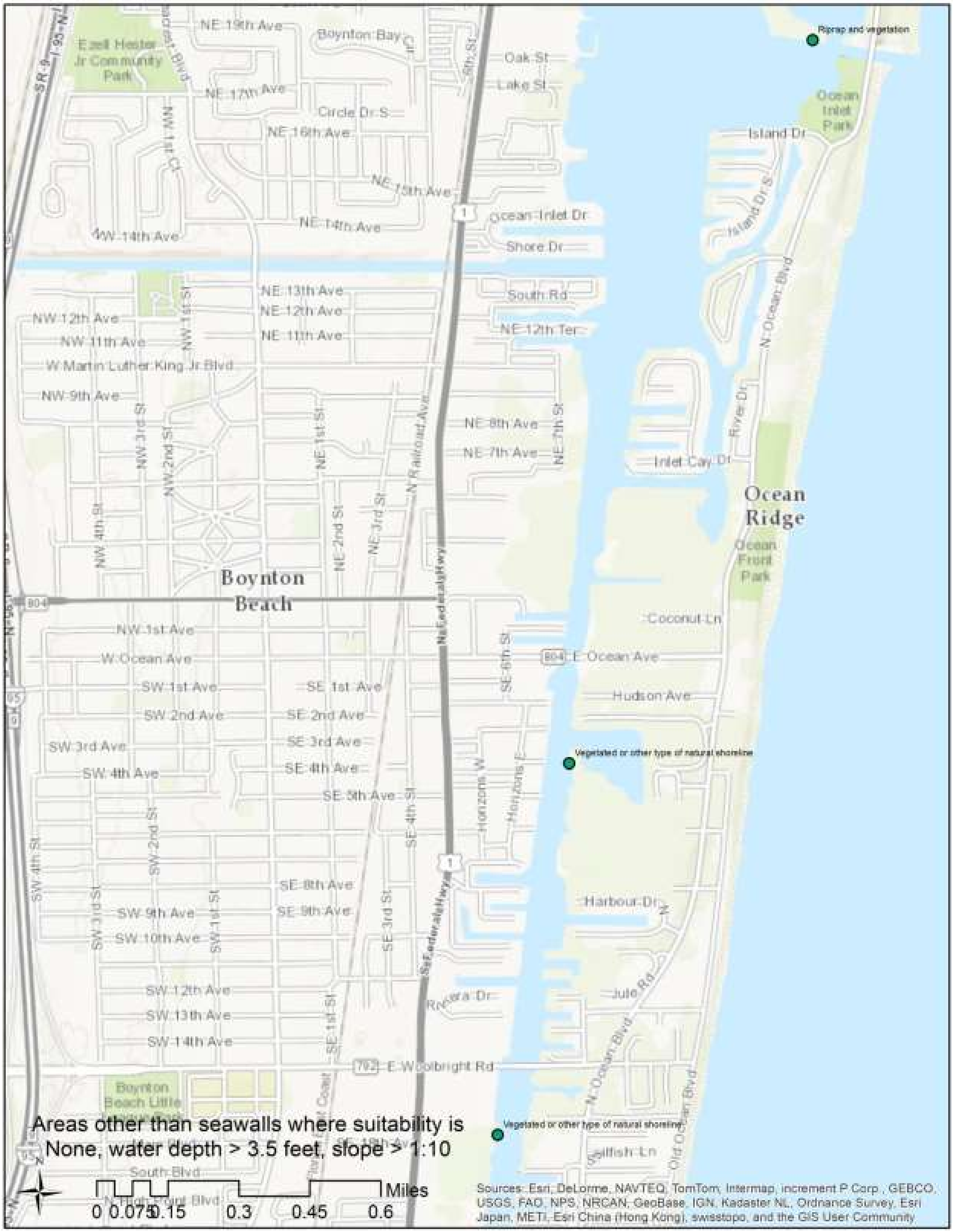
Jupiter Inlet Colony
Jupiter Inlet Lighthouse & Museum
Beach Rd
Burt Reynolds Park
Dubois Park
Jupiter Beach County Park
Saturn St
Elsa Rd
The Shoppes of Jupiter
Indiantown Rd
Dickinson Rd
Carlin Park
Jonathan's Landing Golf Club
Water Hazard
Xanadu Pl
Ocean Walk Blvd
Ocean Way
Beach and vegetation (vegetation in back or front of beach)
Vegetated or other type of natural shoreline
Riprap revetment
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


Beach (fine, medium, coarse)
Beach and vegetation (vegetation in back or front of beach)
Beach and vegetation (vegetation in back or front of beach)
Beach and vegetation (vegetation in back or front of beach)
Beach and vegetation (vegetation in back or front of beach)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
N
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community
Bear's Club
Ocean City Park
Juno Beach Park
Donald Ross Rd
Frenchmans Creek Dr
Water Hazard


Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
Riprap revetment
Riprap revetment
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Beach (fine, medium, coarse)
Riprap and vegetation
Riprap revetment
Riprap revetment
Riprap revetment
Little Lake Worth
Prosperity Harbor
North Palm Beach Country Club
PGA Blvd
Prosperity Farms Rd
Ellison Wilson Rd
US Hwy 1
0 0.075 0.15 0.3 0.45 0.6
Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

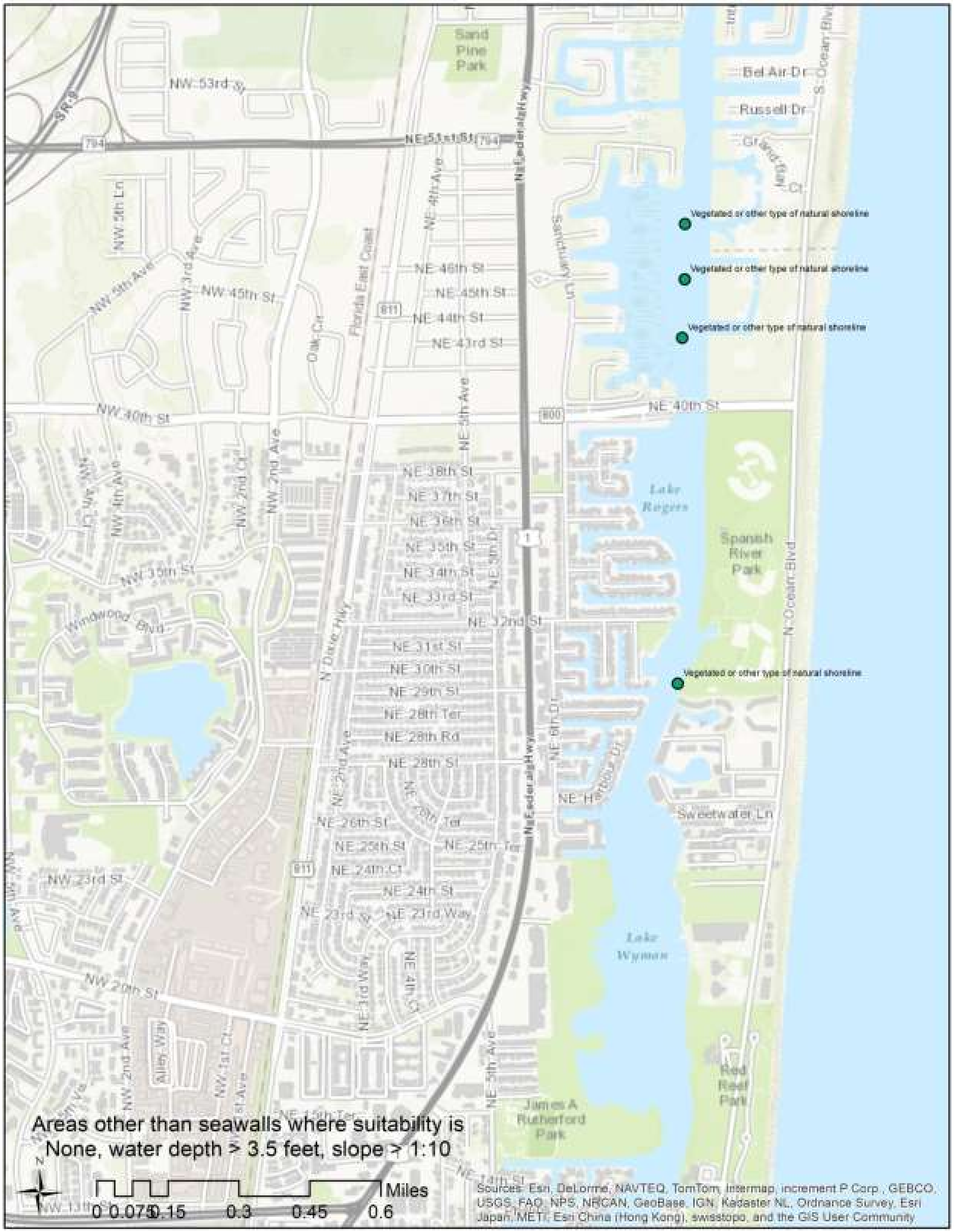


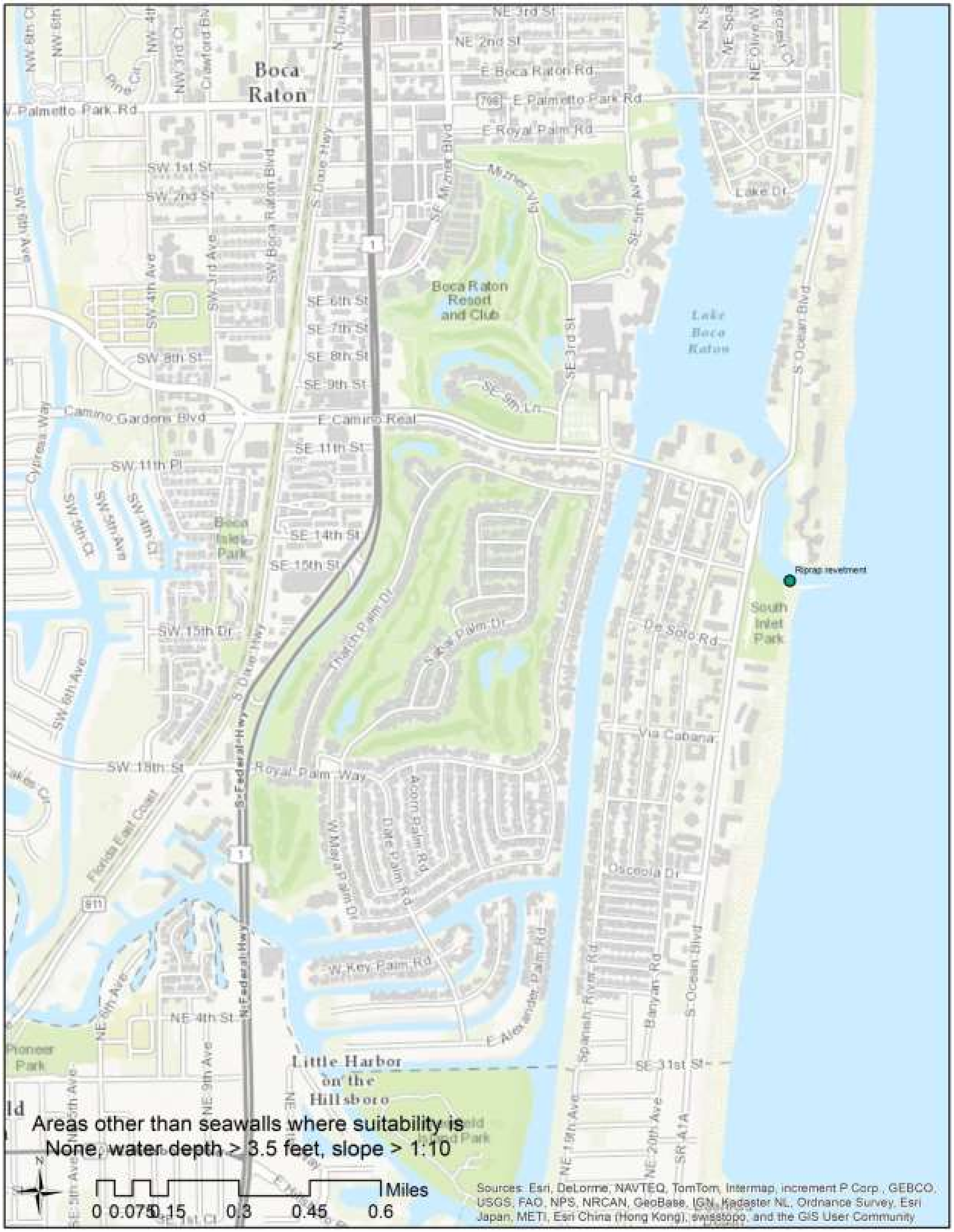
Palm Beach Shores
Peanut Island
Phil Foster Park
Ocean Reef Beach
Riprap revetment
Riprap revetment
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6
Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

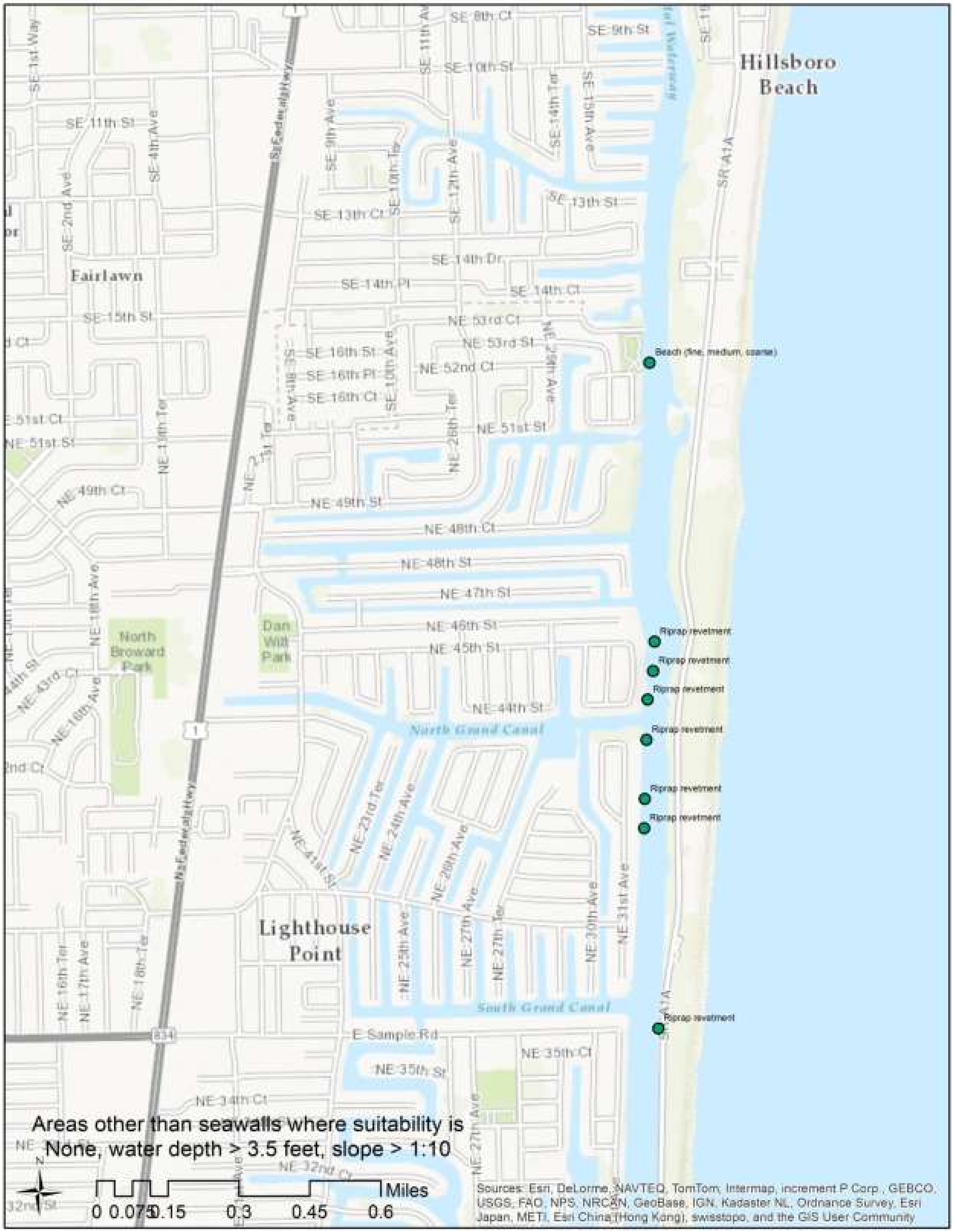

Riprap and vegetation
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Boynton Beach
Ocean Ridge
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6
Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

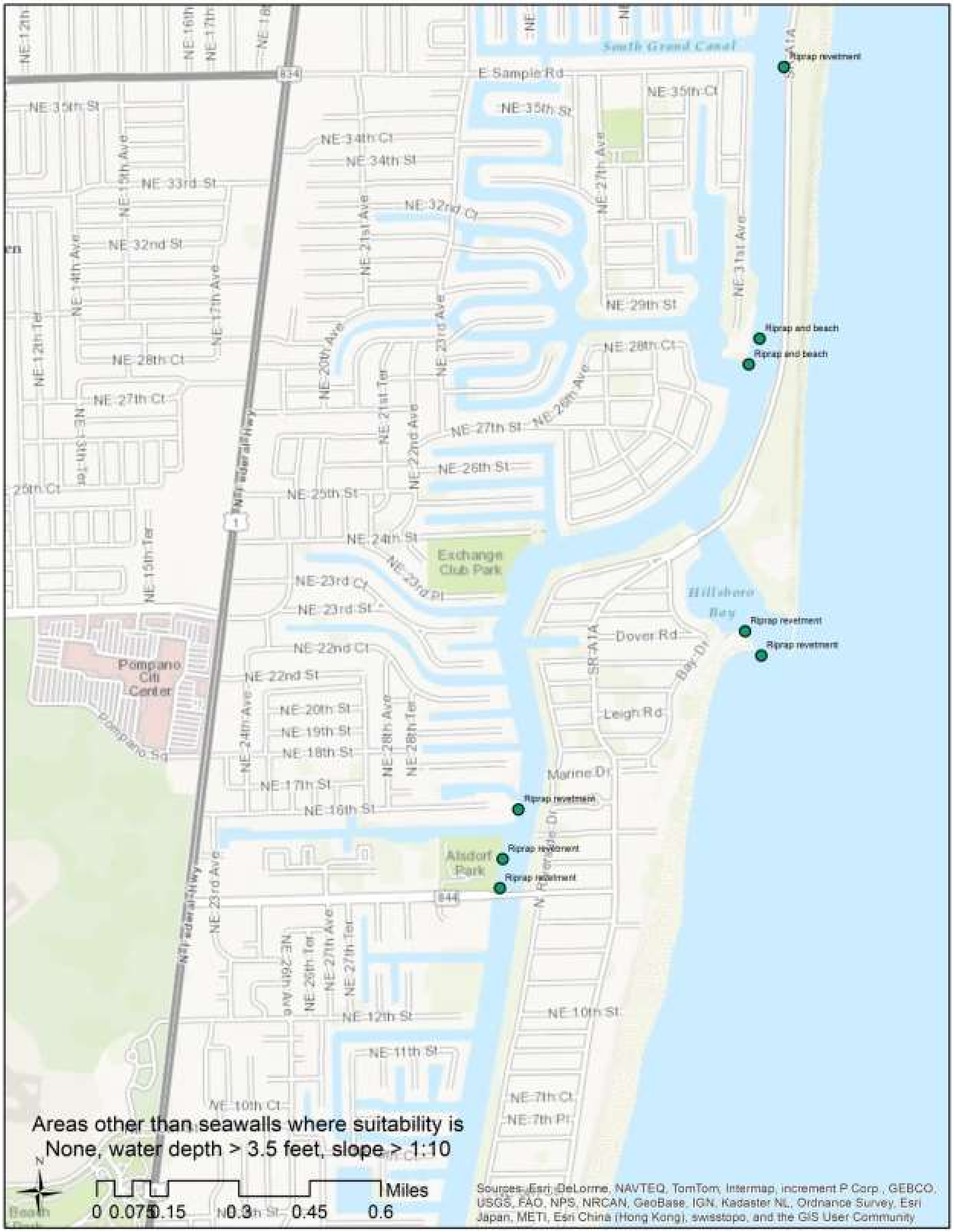

Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Riprap revetment
Riprap revetment
Riprap revetment
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Riprap revetment
Riprap revetment
Riprap revetment
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
0 0.075 0.15 0.3 0.45 0.6
Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community
Ocean Breeze Golf & Country Club

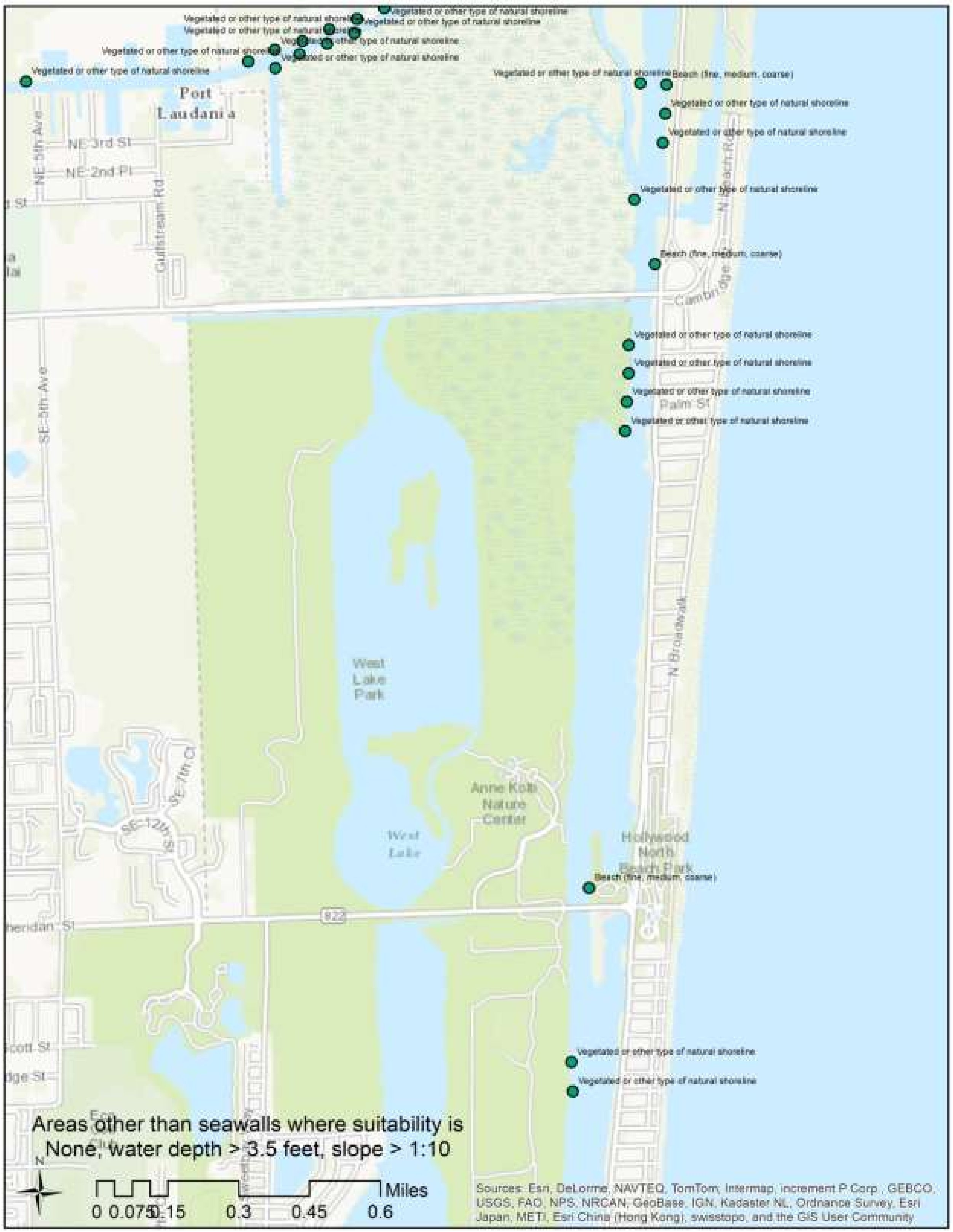

Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6
Miles
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community
Sand Pine Park
Lake Rogers
Spanish River Park
Lake Wyman
Red Reef Park
James A Rutherford Park
NE 40th St
NW 40th St
N Ocean Blvd
N Federal Hwy

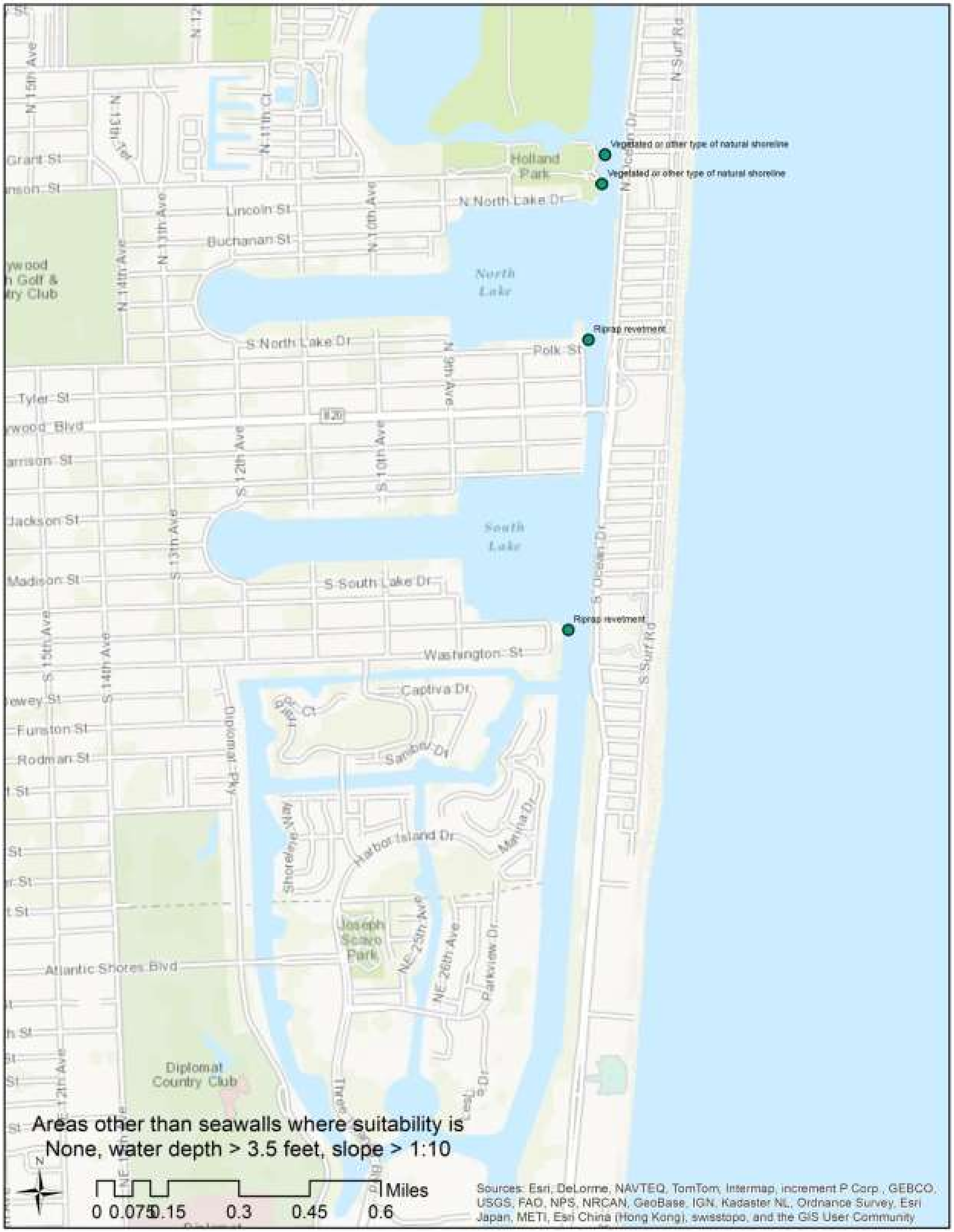

Boca Raton
Boca Raton Resort and Club
Lake Boca Raton
South Inlet Park
Riprap revetment
Little Harbor on the Hillsboro
Areas other than seawalls where suitability is None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
Hillsboro
Beach
Fairlawn
Lighthouse
Point
North
Broward
Park
Dan
Witt
Park
North Grand Canal
South Grand Canal
Beach (fine, medium, coarse)
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
SE 8th Ct
SE 9th St
SE 10th St
SE 11th St
SE 13th Ct
SE 13th St
SE 14th Dr
SE 14th Pl
SE 14th Ct
SE 15th St
NE 53rd Ct
NE 53rd St
SE 16th St
SE 16th Pl
SE 16th Ct
NE 52nd Ct
NE 51st Ct
NE 51st St
NE 49th Ct
NE 49th St
NE 48th Ct
NE 48th St
NE 47th St
NE 46th St
NE 45th St
NE 43rd Ct
NE 44th St
NE 41st St
E Sample Rd
NE 35th Ct
NE 35th St
NE 34th Ct
NE 32nd Ct
SR A1A
S Federal Hwy
N Federal Hwy
N
0 0.075 0.15 0.3 0.45 0.6
Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

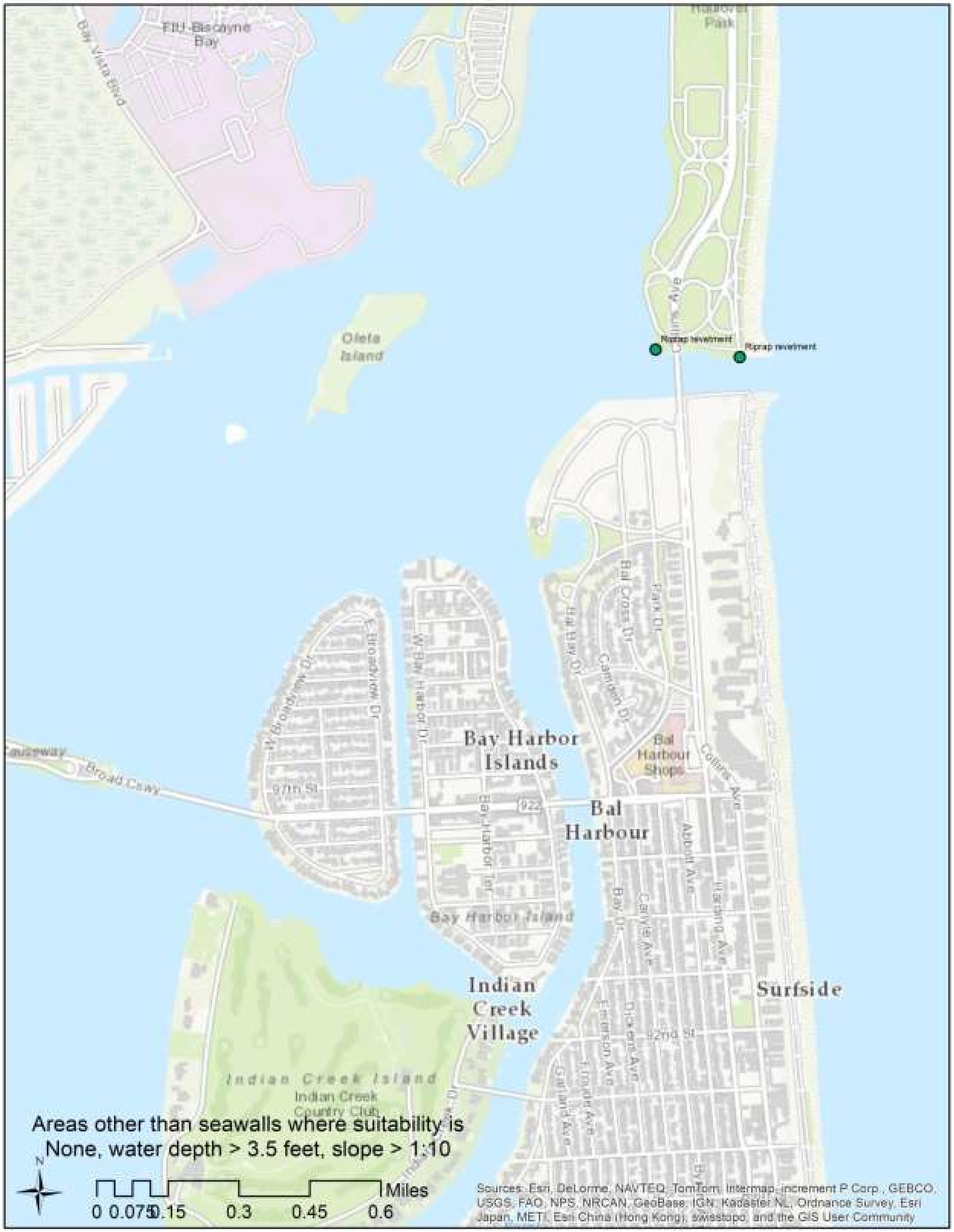

Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
Riprap revetment
Riprap and beach
Riprap and beach
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
Riprap revetment
South Grand Canal
E Sample Rd
NE 35th St
NE 35th Ct
NE 34th Ct
NE 34th St
NE 33rd St
NE 32nd St
NE 32nd Ct
NE 29th St
NE 28th Ct
NE 27th Ct
NE 27th St
NE 26th St
NE 25th St
NE 24th St
NE 23rd Ct
NE 23rd St
NE 23rd Pl
NE 22nd Ct
NE 22nd St
NE 20th St
NE 19th St
NE 18th St
NE 17th St
NE 16th St
NE 12th St
NE 11th St
NE 10th St
NE 10th Ct
NE 7th Ct
NE 7th Pl
NE 14th Ave
NE 15th Ave
NE 17th Ave
NE 20th Ave
NE 21st Ave
NE 21st Ter
NE 22nd Ave
NE 23rd Ave
NE 24th Ave
NE 26th Ave
NE 26th Ter
NE 27th Ave
NE 27th Ter
NE 28th Ave
NE 28th Ter
NE 31st Ave
NE 15th Ter
N Federal Hwy
SR-A1A
Exchange Club Park
Hillsboro Bay
Dover Rd
Leigh Rd
Bay Dr
Marine Dr
Alsdorf Park
Pompano Citi Center
Pompano Sq
Miles
0 0.075 0.15 0.3 0.45 0.6
N
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
Miles
0 0.075 0.15 0.3 0.45 0.6
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community
Riprap revetment
Vegetated or other type of natural shoreline
Riprap and vegetation
Beach (fine, medium, coarse)
Port Everglades-Midport
Port Everglades-Southport
John U Lloyd State Park
Navsea Warfare Center Ft Lauderdale
Lake Mabel
SR-84 W
SE 28th St
SE 32nd St
SE 14th Ave
NE 7th Ave
McIntosh Rd
Eller Dr
N Ocean Dr
Intracoastal Waterway


Vegetated or other type of natural shoreline
Beach (fine, medium, coarse)
Port Laudania
NE 3rd St
NE 2nd Pl
NE 5th Ave
Gulfstream Rd
SE 5th Ave
N Beach Rd
Cambridge St
Palm St
N Broadwalk
West Lake Park
West Lake
Anne Kolb Nature Center
Hollywood North Beach Park
Sheridan St
822
Areas other than seawalls where suitability is None, water depth > 3.5 feet, slope > 1:10
N
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community



Vegetated or other type of natural shoreline
Vegetated or other type of natural shoreline
Riprap revetment
Riprap revetment
Holland Park
North Lake
South Lake
Joseph Scavo Park
Diplomat Country Club
Areas other than seawalls where suitability is
None, water depth > 3.5 feet, slope > 1:10
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


FIU-Biscayne Bay
Haulover Park
Oleta Island
Riprap revetment
Riprap revetment
Collins Ave
Bal Cross Dr
Park Dr
Camden Dr
Bay Harbor Islands
Bal Harbour Shops
Broad Cswy
97th St
Bal Harbour
Abbott Ave
Harding Ave
Bay Harbor Island
Indian Creek Village
Surfside
92nd St
Indian Creek Island
Indian Creek Country Club
Areas other than seawalls where suitability is None, water depth > 3.5 feet, slope > 1:10
N
0 0.075 0.15 0.3 0.45 0.6 Miles
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community