ENVIRONMENTAL SITING SUITABILITY ANALYSIS FOR COMMERCIAL SCALE OCEAN RENEWABLE ENERGY:

A SOUTHEAST FLORIDA CASE STUDY

by

Amanda Mulcan

A Thesis Submitted to the Faculty of

The Charles E. Schmidt College of Science

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

Florida Atlantic University

Boca Raton, FL

August 2014

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

ENVIRONMENTAL SITING SUITABILITY ANALYSIS FOR COMMERCIAL SCALE OCEAN RENEWABLE ENERGY: A SOUTHEAST FLORIDA CASE STUDY

by

Amanda Mulcan

This thesis was prepared under the direction of the candidate's thesis co-advisors, Dr. Howard Hanson and Dr. Tobin Hindle, Department of Geosciences, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

SUPERVISORY COMMITTEE:

Howard Hanson
Howard P. Hanson, Ph.D.
Thesis Co-Advisor

Tobin K. Hindle, Ph.D.
Thesis Co-Advisor

D Mitsova
Diana Mitsova-Boneva, Ph.D.

Camille Coley, J.D.

Dale Gawlik
Dale E. Gawlik, Ph.D.
Director, Environmental Sciences Program

Russell L. Ivy, Ph.D.
Interim Dean, The Charles E. Schmidt College of Science

Deborah L. Floyd, Ed.D.
Interim Dean, Graduate College

07/14/2014
Date

ACKNOWLEDGEMENTS

I would like to thank my committee members, Camille Coley, Dr. Howard Hanson, Dr. Tobin Hindle, and Dr. Diana Mitsova-Boneva, for their patience and guidance in the process of this thesis. I would especially like to thank Dr. Howard Hanson for his willingness to serve as a long distance advisor and Dr. Mitsova-Boneva for her close supervision and assistance with my research. I am deeply grateful for the love, encouragement, and guidance of my parents, to whom I attribute the majority of my success. And lastly, I appreciate the support of Chris Mulcan and Fabian Lopez who have helped reduce the stress of completing this project.

ABSTRACT

Author:	Amanda Mulcan
Title:	Environmental Siting Suitability Analysis for Commercial Scale Ocean Renewable Energy: A Southeast Florida Case Study
Institution:	Florida Atlantic University
Thesis Co-Advisors:	Dr. Howard Hanson Dr. Tobin Hindle
Degree:	Master of Science
Year:	2014

This thesis aims to facilitate the siting and implementation of Florida Atlantic University Southeast National Marine Renewable Energy Center (FAU SNMREC) ocean current energy (OCE) projects offshore southeastern Florida through the analysis of benthic anchoring conditions. Specifically, a suitability analysis considering all presently available biologic and geologic datasets within the legal framework of OCE policy and regulation was done. OCE related literature sources were consulted to assign suitability levels to each dataset, ArcGIS interpolations generated seafloor substrate maps, and existing submarine cable pathways were considered for OCE power cables. The finalized suitability map highlights the eastern study area as most suitable for OCE siting due to its abundance of sand/sediment substrate, existing underwater cable route access, and minimal biologic presence. Higher resolution datasets are necessary to locate specific OCE development locales, better understand their benthic conditions, and minimize potentially negative OCE environmental impacts.

ENVIRONMENTAL SITING SUITABILITY ANALYSIS FOR COMMERCIAL SCALE OCEAN RENEWABLE ENERGY: A SOUTHEAST FLORIDA CASE STUDY

TABLES

FIGURES

1. INTRODUCTION

With rising greenhouse gas emissions and climate change, the demand for efficient, clean, renewable energy sources has grown. One such energy source is ocean current energy (OCE), a type of marine renewable energy (MRE), which harnesses power from ocean currents using hydrokinetic turbines. Despite the fact that the Florida Current generally flows at low speeds (an order of magnitude slower than wind), it possesses the power of a gale force wind because the density of water is much heavier than air (Hanson et al., 2011). This suggests that capturing and converting that energy has the same potential as wind energy conversion. This thesis is focused on the OCE project that occurs offshore Southeast Florida, in the channel between Florida and the Bahamas (approximately 35 kilometers offshore Palm Beach, Broward and Miami-Dade Counties). Here, the marine hydrokinetic energy of open-ocean Florida Current (part of the Gulf Stream) can be accessed. The main goal of this study is to facilitate the siting and implementation of Florida Atlantic University's Southeast National Marine Renewable Energy Center (FAU SNMREC) OCE projects as well as other future ocean projects offshore southeastern Florida through the analysis of benthic anchoring conditions.

The feasibility and siting of OCE systems is being studied at FAU SNMREC for use in the Florida Current. A typical OCE installation will possess a hydrokinetic turbine placed in range of the Florida Current that is anchored to the seabed (Hanson et al., 2010). Future installations by commercial energy developers will also include power transmission cables running along the seabed to an onshore power grid for large-scale power supply. As the experiences of other marine renewable energy project (i.e. tidal energy) have shown, a firm understanding of both the seafloor geology and benthic communities of an area allows for better, more environmentally-sound MRE siting decisions (Fader, 2009; Fader, 2011; Stewart, 2010; Keenan et al., 2011). This is no different in the case of Florida OCE. To meet the goal of this thesis, the following objectives will be addressed: 1) Assemble a comprehensive database of geologic and benthic parameters relevant to offshore southeast Florida OCE siting 2) Analyze seafloor geology core sample data to locate suitable substrate for OCE anchoring 3) Analyze benthic biologic data to identify biologically sensitive areas which should be avoided in OCE siting 4) Determine pathways for power transmission cables that avoid biologically sensitive areas 5) Create a finalized spatial layer identifying most suitable areas for Florida OCE based on objectives 2-4 and 6) Discern what additional datasets are required to address offshore southeast Florida OCE.

2. BACKGROUND

2.1 OCE Siting

While OCE is still in its infancy, other MREs forms such as tidal, wave, offshore wind, and ocean thermal energy conversion (OTEC) are further developed. All MRE devices share some basic infrastructure similarities: anchors, moors, and/or cables that are either grounded into the seafloor or rest atop it. Soft bottom habitats typically consist of unconsolidated sediment and un-vegetated areas (Street et al., 2005), while hard bottom habitat refers to coral reef communities, consolidated sediments and manmade reefs. Hard bottoms may also be referred to as "live rock" or "live bottom" due to the presence of living plants and invertebra (i.e. echinoderms, bryozoans, sponges) and fish nearby or within the physical hard bottoms. Additionally, areas of compacted mud and sediment can also qualify as a form of hard bottom (Peterson et al., 2000). The likelihood of OCE devices (anchors, moors, cables) significantly impacting the surrounding marine environment increases in hard bottom habitats due to their high concentrations of biologic activity (Vinick et al., 2012). In this setting, it is vital that soft bottom habitat be distinguished from hard bottom habitat in order to site OCE devices with minimal environmental impact. Because of these infrastructure (cables, anchors, and moors) similarities, OTEC, tidal, wave, and offshore wind energy can be used as proxies in the siting of OCE. Specifically, siting studies, pre-installation baseline environmental assessments, and post-installation environmental monitoring studies from other MREs will give insight into the process of OCE devices.

2.2 MRE Siting – General Data Collection Practices

Bathymetric (notably multibeam and side-scan sonar) data and sediment core data (physical samples taken directly from the seabed) are associated with distinguishing soft bottom from hard bottom substrate. Generally, cores provide description of the seafloor substrate at the sampled location, however they can be subjected to more detailed stratigraphic analysis (i.e. studying subsurface seabed lithology and stratigraphy) depending on the specific project requirements. A multibeam echosounder device is typically used to determine both water depth, or “distance to the bottom.” These devices work by emitting a wide acoustic fan-shaped pulse from a transducer across the full swath across-track accompanied by a narrow along-track, which forms multiple receive beams (“beamforming”) that is much narrower (almost one degree depending on the system) in the across-track. From this narrow beam, the acoustic pulse’s two-way travel time is then ascertained using a bottom detection algorithm. Once the speed of sound of the full water column profile water is known, the depth and position of the return signal can be computed from the receive angle and the previously found two-way travel time. Also, it is important a multibeam echosounder take precise measurement of the motion of the sonar relative to a Cartesian coordinate system in order to determine the transmit and receive angle of each incoming beam (“Multibeam echosounders,” 2013).

Side-scan is a type of sonar system employed to construct an image of large areas of the seafloor in an efficient manner. Combined with seafloor samples (i.e. sediment cores) it is able to expose the differences in material and texture type of the seabed. This method utilizes a sonar device (towed from a surface vessel or submarine or mounted on a ship's hull) that discharges conical or fan-shaped pulses downward to the seafloor across a broad angle perpendicular to the sensor path through the water. The beam’s acoustic reflection intensity from the seafloor is noted in a sequence of cross-track slices. When put together along the direction of motion, these slices form an image of the seafloor within the swath of the beam. Side-scan sonar frequencies ordinarily range from 100 to 500 kHz with higher frequencies producing better resolution but less range. Most side-scan units possess fan-shaped beams, or transducers, placed in a "towfish" and pulled by a "tow cable" which allow the device to get closer to the bottom in deep water and yield a better sonar image (U.S. Patent No. 4197591 A, 1958).

2.3 Differences between Florida OCE and other MREs

OCE devices are sited to be deployed further offshore than other MREs, which will result in longer cable transmission lines and require more extensive offshore benthic surveys to properly accommodate the OCE structures. With respect to Florida OCE there are three major differences from other MRE projects. First, and most obviously, the OCE siting offshore southeast Florida must adapt to the Florida’s distinct environmental setting, particularly the prominent coral reef ecosystems that reside in the study area. Second, the Naval Surface Warfare Center, Carderock Division and its South Florida Testing Facility (SFTF) – which extends offshore south of Port Everglades over an 18 nautical mile cross-shelf by 4 nautical mile along-shelf region, encompassing water depth of up to over 700m – is located near Dania Beach, Florida. This poses a unique regulatory and user conflict issue for any future OCE projects in this specific area of southeastern Florida, which will have to consider the facility’s coastal jurisdiction and any special regulations. And third, most fully operational MRE stations are tidal power stations that exist outside of the U.S. where different regulations and policy govern. This means that Florida OCE will abide by different U.S.-specific operational procedures, which will shape the overall outcome of OCE. Florida-based OCE falls under the jurisdiction of Federal Energy Regulatory Commission (FERC), the Bureau of Ocean Energy Management (BOEM), and the State of Florida whose responsibility is to enforce U.S. environmental laws like the National Environmental Policy Act (NEPA), Clean Water Act (CWA), Coastal Zone Management Act (CZMA), Marine Mammal Protection Act (MMPA), and Endangered Species Act (ESA). In the case of Florida's OCE, the NEPA requires that a detailed environmental review be done before any OCE deployments occur on the OCS, whether small or large-scale. To this end, BOEM released a preliminary environmental assessment in January 2012, which was open for public comment, and a final environmental assessment for southeast Florida OCE in August 2013 (discussed below). Although NEPA has no fundamental outcome mandates, the requirement of generating environmental planning documentation provides an opportunity for stakeholder involvement and examination of the environmental impact of a given project as well as the viability of other alternatives that may have less environmental impact (Salcido, 2011).

2.4 Florida OCE Laws, Policy, and Regulation

Due to fact that OCE devices must be attached to the seafloor and reside in the water column, it is critical to carefully site OCE installations such that their presence complies with existing U.S. environmental law and inflicts minimal adverse impact on the surrounding benthic marine environment. The continuing evolution of state and federal agency requirements makes it challenging to attain permits for open ocean deployment, even for simpler experimental test systems. Pursuing OCE research and development on the Outer Continental Shelf (OCS) must comply with the federal Outer Continental Shelf Lands Act (OCSLA), which gives BOEM jurisdiction and regulatory responsibility over the federal offshore lands; for example, the southeastern Florida areas proposed for OCE installations. As such, BOEM is charged with enforcing ocean energy related environmental laws like National Environmental Policy Act of 1970 (NEPA), the Clean Water Act of 1972 (CWA), the Coastal Zone Management Act of 1972 (CZMA, reauthorized in 1990), Marine Mammal Protection Act of 1972 as Amended in (2007), and the Endangered Species Act of 1973 (ESA), which explicitly authorize state involvement in decision-making and enforcement of the federal law (Portman, 2010). Additionally, FERC possesses authority to regulate hydroelectric projects located on navigable waters, federal lands (including reservations) or constructed after 1935 on commerce clause waters and affecting the interests of interstate commerce. When FERC considers issuing a license, as in the case of Florida OCE, it considers not only power production, but also non-power resources and environmental impacts. As part of this, specific provisions for marine protection require coordination with both local and federal fish and wildlife agencies (Salcido, 2011).

With respect to potential future commercial OCE development offshore southeastern Florida, activities located farther than 3 miles offshore (aka. activities outside Florida state waters including turbine and anchor deployment) will be supervised by the Florida Fish and Wildlife Commission (FFWC) due to its agreements with the U.S. Fish Wildlife Service (USFWS). Shore-side activities (onshore cabling to a land-based power grid) will be conducted within Florida state waters and consequently they will be under the purview of the Florida Department of Environmental Protection (FDEP). As mentioned previously, OCE development offshore southeastern Florida will occur on the OCS (further than 3 miles offshore), meaning that it must comply with OCSLA overseen by BOEM.

Overall, BOEM is charged with regulating renewable energy activities on the OCS under the authorization of Section 388 of the Energy Policy Act of 2005 (EPA) and codified in subsection 8(p) of OCSLA. As part of their enforcement, OCE reviews done by BOEM require that an applicant comply with the following conditions: "operations must result in the diligent development and efficient recovery of resources, all activities must comply with applicable federal, state and local laws and regulations applicable to federal leases including the Coastal Zone Management Act (CZMA) and the Endangered Species Act (ESA), all activities must include adequate safeguards to protect the environment, disturbed lands must be properly reclaimed, and all activities must protect public health and safety" (SNMREC, 2012). BOEM also enforces the CWA, which strives to ensure minimal water pollution in the U.S. by requiring that a federal agency must first acquire a Florida state waiver prior to issuing a federal permit to any Florida OCE project that may result in a release into navigable waters of the U.S. (CWA 1972). Once again, FERC is responsible for the issuance of licenses for the construction of any new OCE project connecting to a power grid. In this case, FERC and BOEM have agreed that offshore OCE is BOEM's responsibility up to the point of grid connections (SNMREC, 2012).

The U.S. Army Corps of Engineers (USACE), U.S. Coast Guard (USCG), National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (USEPA) and USFWS are the other federal agencies that will be directly involved with offshore southeastern Florida OCE. Under Section 318 of the Clean Air Act the USEPA has the jurisdiction to require point source pollution discharge permits for projects in the open ocean, specific regulations can be seen in Code of Florida Regulations (CFR) in the National Pollutant Discharge Elimination System (NPDES). Additionally, the Ocean Dumping Act of 1972 within the United States Code (USC) grants authority to the USEPA to permit the discarding of material into U.S. waters when such unloading will not unreasonably degrade or endanger human health, the marine environment, ecological systems, or economic potentialities. Reviewing such permits include considering the need for the proposed dumping, the effects of dumping on human health and welfare (including economic, aesthetic and recreational values), effects on fisheries resources, plankton, fish, shellfish, wildlife, shorelines and beaches, and effects on marine ecosystems (33 USC § 1412 (1999)). Furthermore, OCS air permit regulations must comply with all applicable Florida state air requirements (40 CFR 55.13-14). For OCE, the permit would only be necessary for the air quality aspects of project installations because air emissions will mostly come from the vessels used to install OCE structures (SNMREC, 2012).

The USACE supervises any discharge of dredged and fill material into U.S. waters, including wetlands and structures in, of affecting, navigable waters in order to preserve unhindered navigational access of the nation’s waters. They have authority under Section 10 of the Rivers and Harbors Act of 1899, as extended by OCSLA. As such, the USACE requires a permit for the erection of “any obstruction” in federal waters to preserve unhindered navigational access of the nation’s waters (SNMREC, 2012). OCSLA extended the USACE Section 10 authority into the exclusive economic zone (EEZ), allowing them to also regulate “installations and other devices permanently or temporarily attached to the seabed, which may be erected thereon for the purpose of exploring for, developing or producing resources from [the outer continental shelf]” including CZMA and ESA (43 U.S.C. § 1333(a), (e) (1999)). As such, offshore southeastern Florida OCE requires a Section 10 permit from the USACE. However, it is important to note that before issuing or denying a Section 10 permit the USACE deeply considers a broad range of potential environmental and other impacts (SNMREC, 2012).

NOAA supplies consultation under the ESA with the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) for any OCE the effects on Essential Fish Habitat and Habitat Areas of Particular Concern, effects to threatened or endangered species, or effects regarding the protection of marine mammal species and their habitats in an effort to maintain sustainable marine mammal populations (50 CFR 600.905-930). Under the ESA, NOAA provides consultation regarding effects to threatened or endangered species (16 USC 1531-1543) and, under the MMPA, NOAA lends advice regarding the protection of marine mammal species and their habitats in an effort to maintain sustainable marine mammal populations (16 USC Chapter 31). Lastly, the MSFCMA gives the National Marine Fisheries Service (NMFS) regulatory responsibilities that will affect ocean energy development in the EEZ. In the instance of OCE offshore southeastern Florida, the NMFS requires the applicant to apply for a Letter of Acknowledgement in order to do scientific research and subsequently informs the other agencies (the U.S. Coast Guard and state agencies, if necessary) that OCE activity is occurring in federal waters.

Issuance of a Title XI right-of-way permit for construction of a transportation or utility system across refuge lands (43 CFR 36) falls under the authority of the USFWS. The USFWS also offers consultation regarding effects to threatened or endangered species under the ESA (16 USC 1531-1543) as well as issues permitting for the "construction of a transportation or utility system across refuge lands" (SNMREC, 2012). The USCG is generally responsible for the regulation and enforcement of various activities in the navigable waters of the U.S. As part of this, the USCG stipulates research-related projects, like OCE, be marked with lights and signals in order to ensure safe passage of vessels. Additionally, the installation and maintenance of the markers must be done by the engineers as long as the structures are located in navigable waters (SNMREC, 2012).

On the state level, FDEP is in charge of issuing a Certificate of Reasonable Assurance for discharge of dredged and fill material into U.S. waters under Section 401, Federal Water Pollution Control Act of 1972 (FWPCA), as amended in 1977. They also issue a Certificate of Reasonable Assurance/NPDES and Mixing Zone Approval for wastewater disposal into all state waters under Section 402 of the FWPCA and a Title V Operating Permit and a Prevention of Significant Deterioration permit for air pollutant emissions from construction and operation activities, and approving domestic wastewater collection, treatment, and disposal plans for domestic wastewaters under the Florida Administrative Code (FAC) Chapter 62-212.400 (SNMREC, 2012). Furthermore, the FDEP executes domestic wastewater collection, treatment, and disposal plans for domestic wastewaters (FAC Chapter 62-604) and approves Coastal Zone Management Act Federal Consistency Program, Chapter 380, Part II, Florida Statutes (FS) (SNMREC, 2012).

The FFWC directs activities involving marine turtles in Florida under authority granted to the state through a Cooperative Agreement with the USFWS under Section 6 of the ESA. Generally, all activities related to marine turtles need to be approved under subsection 370.10 of the FS. This includes the restriction of the speed and operation of vessels where necessary in order to protect manatees from harmful collisions with vessels as part of the Manatee Sanctuary Act (SNMREC, 2012). THE FFWC also deals with issuing Fish Habitat Permits per Florida Statute 379 for activities within fish-bearing streams that may hinder fish passage. OCE activities that may involve stream diversion, gravel removal, water withdrawal etc. usually demand a Florida Fish and Wildlife Conservation Permit (SNMREC, 2012).

In this way, federal entities play a significant role in the OCE process, making it somewhat cumbersome, yet thorough, with the aim of promoting orderly, safe, and environmentally responsible ocean energy development (Salcido, 2011). It is important to remember that offshore OCE development comes with onshore impacts. In the example of southeastern Florida OCE, commercial arrays will be physically located beyond state authority, however the connections to a power grid will happen under state jurisdiction, cables will need to run across the seabed to shore, and new onshore facilities may have to be constructed to support the offshore equipment. This poses another separate issue to be considered when siting OCE projects in Florida (Salcido, 2011). For this reason, and the several others mentioned above, MRE proxies can be useful for informing the overall scientific siting process of OCE siting in Florida, however it is not advisable that they be exactly followed due to site-specific differences between in each MRE case.

2.5 Existing Florida OCE Siting Research

In August of 2011, FAU SNRMEC filed an application with BOEM for a 5-year Interim Policy lease of OCS blocks 7003, 7053, and 7054 for OCE testing (Figure 1). The proposed lease area provides adequate access to the Florida Current and is approximately 16.7 to 27.8 kilometers (9 to 15 nautical miles) offshore of Fort Lauderdale, Florida and ranges in depth from 262 meters (859.6 feet) in OCS Block 7053 to 366 meters (1,200 feet) in the southern half of OCS Block 7054. Under the proposed action, FAU SNMREC would first deploy a single-anchor mooring attached to a Mooring and Telemetry Buoy (MTB) and test the marine hydrokinetic (MHK) equipment for the potential to generate electricity from the Florida Current. The MTB is designed similar to the Navy Oceanographic Meteorological Automatic Device (NOMAD) and has a history of long-term survivability in severe seas. It would remain deployed at variable intervals throughout the year and throughout the 5-year lease period (USDOC, NOAA, NBDC, 2012). Additionally, FAU SNMREC intends to deploy two more MTBs at a later time during the lease period. These additional MTBs would be operational simultaneously with the first MTB, resulting in up to three total technology testing facilities operating on the leasehold (SNMREC, 2012).

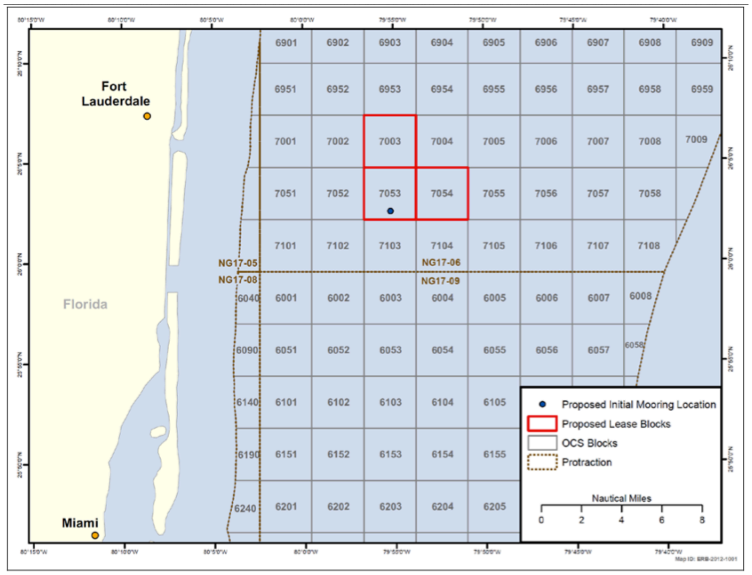


Figure 1. Locations of OCS Blocks 7003, 7053, and 7054 and proposed MTB location (BOEM Office of Renewable Energy Programs, 2012)

BOEM, in conjunction with the United States Department of the Interior (DOI), prepared an environmental assessment (EA) to determine whether the issuance of a lease authorizing OCE technology testing offshore southeast Florida would result in a significant effect on the environment and whether or not an environmental impact statement (EIS) must subsequently be prepared. BOEM conducted its analysis as part of complying with the NEPA, 42 U.S.C. §§ 4321-4370f, the Council on Environmental Quality (CEQ) regulations at 40 CFR 1501.3(b) and 1508.9, DOI regulations implementing NEPA at 43 CFR 46, and USDOI Manual (DM) Chapter 15 (516 DM 15). In April 2012, BOEM made a Notice of Availability (NOA) of the Outer Continental Shelf (OCS) Renewable Energy Program Leasing for Marine Hydrokinetic Technology Testing Offshore Florida Environmental Assessment (2012 EA) (77 FR 24734) available for a 30-day comment period. Next, in May 2012, a public information meeting was held in Fort Lauderdale, Florida, giving stakeholders an opportunity to comment on the EA. BOEM then used the comments received and the new information and additional activities associated with the proposed OCE actions to revise the 2012 EA and released a finalized EA in August 2013 (U.S. DOI, BOEM, 2013b).

Most notably, BOEM's 2013 final EA further addressed potential environmental impacts of offshore southeastern Florida OCE (not solely benthic habitat impacts) and resulted in a Finding of No Significant Impact (FONSI). This finding delineates that potential southeastern Florida OCE deployments are expected to possess negligible, insignificant or no impact on the surrounding environment which includes air quality, water quality, biological resources (i.e. beaches), marine mammals, sea turtles, benthic habitats, avian communities, bats, fish and essential fish habitat (including electromagnetic fields and Habitat Areas of Particular Concern). Despite the FONSI, BOEM still requires FAU SNMREC provide additional site-specific acoustic and remotely operated vehicle (ROV) surveys be conducted in order to ensure consistency of BOEM's compliance with the NEPA, and the Essential Fish Habitat provisions of the MSFCMA. To characterize surface sediments, seafloor morphology, and potential surface obstructions, an acoustic survey system (i.e. side-scan sonar) would be employed. Specifically, BOEM protocols for conducting acoustic surveys stipulate that:

> The Lessee [in this case FAU SNMREC] shall conduct high-resolution multibeam or side-scan sonar geophysical survey (HRG Survey) to assist with site selection in order to avoid or minimize impact to possible hard-bottom habitat. Such surveys will provide data to eliminate unsuitable areas, such as obvious high-relief features, from consideration and permit focusing on areas potentially suitable for the deployment of the MTB…Surveys should collect both bathymetry and backscatter information. The bathymetry will provide depth information, whereas the backscatter will provide some indication of seafloor hardness. This may be helpful in distinguishing low-relief hard-bottom from unconsolidated sediments in some cases…The results will be used to verify sediment thickness at the proposed mooring site prior to deployment of the mooring system. (BOEM, 2013b)

BOEM will also require site-specific videographic and/or photographic surveys be done for the proposed anchor locations before OCE structure deployment. These surveys would serve to identify any potential deepwater coral habitat, verify bottom types, and aid in the assessment of impacts to essential fish habitats as defined under the MSFCMA. A submersible, for instance a ROV, fitted with ultra-short baseline (USBL) positioning is recommended to record and typify the benthic habitat and biota at all OCE mooring locations for the surveys. Specifically, BOEM requires:

> The biological resources shall be identified and characterized within a minimum of 126,025 m^2 (126.0 hectares) for each mooring location; Seafloor video imagery should be continuous along each transect and be taken from no more than 1-2 meters off the seafloor; Seafloor imagery shall include still imagery of at least 1 MB in quality of biological targets…Images should be analyzed in greater detail to determine faunal composition and organism densities in areas of biological interest…Observers must report any observations concerning impacts on Endangered Species Act listed marine mammals, sea turtles, or smalltooth sawfish to the Lessor and NMFS within 48 hours. Any observed takes of listed marine mammals, sea turtles, or smalltooth sawfish resulting in injury or mortality must be reported within 24 hours to the Lessor and NMFS; The Lessee [in this case FAU SNMREC] must ensure that sightings of any injured or dead protected species (e.g., marine mammals, sea turtles, or smalltooth sawfish) are reported to the NMFS Southeast Region's Stranding Hotline (877-433-8299 or current) within 24 hours of sighting. (BOEM, 2013a)

These extensive survey stipulations, detailed survey requirements and careful regulatory compliance clearly show the government's (BOEM's) concerns about possible OCE environmental impacts. Thus, revealing how important and necessary continued siting research is for future large-scale southeastern Florida OCE to translate from idea to reality.

2.6 Florida OCE Public Perceptions

In addition to satisfying regulatory requirements, future commercial OCE installations in south Florida will contend with local opinion. In 2011 and in 2012 BOEM released public commentary in response to FAU SNMREC efforts to deploy OCE testing devices. Comments from public individuals showed favor, and even enthusiasm, for OCE development offshore southeast Florida, while comments from individuals belonging to federal and state entities (i.e. Department of Defense) reacted cautiously to the idea and pushed for strong environmental assessment background studies to be done prior to any OCE installations (Croom, 2011; Muench, 2011; DiGiovanni, 2011; Tucker, 2011; Westbury, 2012). For example, in response to a FAU SNMREC Lecture Series open to the public on southeastern Florida OCE, audience members commented, “It seems the only way you can find out how the device interacts with the marine life is with long-term 24/7 deployment on the bottom” and “Have you done any testing to see what kind of fish life you have in that section of ocean before you put your buoy there?” (public commentary in response to Skemp, 2012). Such reactions reveal that there is a general support for OCE in southeast Florida waters, however stakeholders desire robust environmental and safety baseline research be done in order to guarantee the well-being of existing biologic conditions and not disrupt industry and commerce in the area.

Existing regulations and the general public perception of offshore OCE in southeast Florida display how important environmental studies are when considering commercial OCE installations. In this way, environmental baseline studies are a key facet in siting OCE. For offshore southeast Florida, areas consisting of loose sand substrate (aka. soft bottom) with limited biologic productivity will be promising for OCE structures (anchoring, cabling, etc.) because the area’s biologic sparseness will reduce the likelihood of negative environmental encounters (i.e. an OCE anchor hitting or disturbing a coral reef community). Whereas, substrate with hard bottom (containing coral, sponges, crinoids, etc.) habitat will be unfavorable due to their high amounts of biologic productivity and subsequent increased chance of negative environmental impact (Vinick et al., 2012).

3. LITERATURE REVIEW

3.1 MRE Siting

MREs like tidal, wave, offshore wind, and OTEC are further developed than OCE. Because these MREs share infrastructure similarities on the form of anchors, moors, and/or cables that are either grounded into the seafloor or rest atop it, they can act as proxies in the siting of OCE. Specifically, siting studies, pre-installation baseline environmental assessments, and post-installation environmental monitoring studies from other MREs give insight into the process of siting OCE devices.

3.2 Tidal Energy Siting

The Minas Basin located within Nova Scotia's Bay of Fundy lays claim to some the highest tides in the world; therefore it serves as a hotspot for tidal energy exploration. In 2008, Minas Basin Pulp and Power Co. Ltd. (based in Nova Scotia, Canada) was cleared to construct a tidal power demonstration and research facility. Subsequently, they carried out a baseline environmental assessment report, which employed multibeam bathymetry, seabed samples and photographs in tandem with biologic studies to isolate candidate tidal energy siting locations. Upon analysis of the collected data, turbines were installed atop a hard, exposed basalt platform with minor regions of gravel and no significant benthic habitat community. After installation, Nova Scotia Power Inc./Open Hydro (NSPI/OH) enacted a five-year monitoring initiative for the installation that included the use of a towed side-scan sonar system, a towed video camera, and the previous multibeam bathymetry data. At the end of the five-year period there was a finding of no detectable change to the seabed or its surroundings due to the turbines over the operation time period (Fader, 2011; Stewart, 2010).

The United Kingdom's SeaGen in-stream tidal energy project is similar to the tidal power research in the Bay of Fundy. Once given the green light to install tidal turbines in the Narrows of Strangford Lough, Northern Ireland, Marine Current Turbines Ltd. (MCT) established an Environmental Monitoring Plan (EMP). Pre-installation data collection began in April 2005 and formed the basis of an Environmental Baseline Report, against which all future monitoring during installation, commissioning and decommissioning could be compared. Pre-installation data included a shore based survey, passive acoustic monitoring (T-PODs), carcass post mortem, an aerial survey, harbor seal telemetry, underwater noise monitoring and active sonar. Post installation data focused on marine mammals, benthic ecology, and tidal flow (Keenan et al., 2011). Specifically, the benthic habitats were monitored using diver survey. Results from each of the monitoring strands of the EMP (i.e. benthic ecology, marine mammals) were evaluated regularly to ensure that any impact of SeaGen turbines on the marine environment in Strangford Lough would be detected at an early stage (Keenan et al., 2011). After a three-year period of environmental monitoring (photographic and videographic surveys executed by divers), it was concluded that SeaGen turbines inflicted no significant impacts on the surrounding marine environment (Keenan et al., 2011). In the cases of the Northern Ireland and the Bay of Fundy incorporating detailed seafloor geology, along with the appropriate biologic data, into the OCE process was key in mitigating and minimizing potential environmental impacts as neither project witnessed adverse environmental impacts in response to tidal energy installation.

3.3 Wave Energy Siting

On the west coast of Sweden, the Lysekil wave energy research site (a temporary, pilot experimental research facility) was established to test the potential of sea waves to generate electricity via wave energy converters (WEC) under realistic circumstances and over an extended period of time. Before construction, geophysical surveys were undertaken by the Geological Survey of Sweden (SGU) in order to characterize the seabed (Leijon et al., 2008). Upper seabed sediment layers were typified by means of sub-bottom profiling (echo sounding), side-scan sonar, and “clamshell snapper” and “orange peel bucket” bottom sediment samples (Cato & Kjellin, 2008). The raw data was collected in digital format SEG-Y (geophysical data format developed by the Society of Geophysicists) and the sonar pictures were slant-range-corrected and geo-rectified to a sonar mosaic in geo-Tiff format and pixel size 10x10 cm in allowing areas of mainly sandy silt and no major benthic assemblages to be identified, which became the designated test site. At the site after installation and during operation, assessment of environmental impacts focused on interactions between bottom dwelling marine organisms, biofoulers, and vertebrates. In one soft-bottom macrofaunal study, results indicated that the deployment of WECs at the Lysekil research site would have only minor direct ecological impact beyond the natural level of variation, while future large-scale deployments of WECs will require continuous long term monitoring (Langhamer, 2010).

In the United States, Oregon State University's (OSU) Northwest National Marine Center (NNMREC) is in the process of developing WEC test facilities. In order to establish a test site, a baseline environmental assessment was released in 2011 that chronicled the details of the Oregon's offshore seafloor geology and benthic habitats (Henkel, 2011). For their analysis, box coring, trawling and videographic surveys supplied descriptions of the benthic environment and sediment characteristics at points on the seafloor. Sediment samples were sieved (1 millimeter) in the field to collect organisms greater than 1 millimeter. The grain sizes of the sediment samples were analyzed using a Beckman Coulter Laser Diffraction Particle Size Analyzer (LD-PSA) to establish the percent of silt/clay. In the laboratory, the benthic fauna (after being preserved in buffered formalin, stained with rose Bengal, and transferred to ethanol) were sorted and identified by staff personnel. Principal component analysis (PCA) was done for the percentage of silt/clay in the box care samples to examine the physical variability between sampling stations. For species assemblages Shannon-Weaver diversity, two-way ANOVAs, cluster analysis ad multidimensional scaling were completed. Lastly, the videographic surveys were used to estimate encounter/capture rates for the studied species (Henkel, 2011). The survey results allowed OSU/NNMREC to distinguish and avoid unfavorable areas containing reefs or hard bottom, and then nominate potential test deployment areas with minimal ecological complications ("Oregon State University and Northwest National Marine Renewable Energy Center Wave Energy Test Project Final Environmental Assessment DOE/EA-1917," 2012). From this point, OSU/NNMREC stands to move forward with its WEC test facility.

3.4 Offshore Wind Energy Siting

The Cape Wind project in Nantucket Sound, Massachusetts aims to be the first offshore wind energy farm in the United States. In December of 2012, the United States Department of Energy (DOE) released a full-fledged baseline environmental impact assessment for the Cape Wind project. As part of the siting process the DOE performed field studies to further refine the understanding of the proposed action site as it relates to the seafloor, sub-seafloor and onshore cable routes. The project consulted United States Geological Survey (USGS) substrate data from the Gulf of Maine that included digitized NOAA nautical charts and surficial sediment data from geological reports unrelated to the Cape Wind project in addition to side-scan sonar, vibracores, and borings data to target surface sediment types and seafloor morphology. Seagrass communities were identified using preexisting maps from the Massachusetts Department of Environmental Protection. Benthic community assemblages were determined by means of a literature review, side-scan sonar, vibracores, and marine borings data analysis. With the geological and biological environmental assessment completed, construction for the Cape Wind project is slated to begin at the end of this year with the project being partially commissioned by 2015 and fully commissioned by 2016 ("Final environmental impact statement for the proposed cape wind energy project, Nantucket Sound, Massachusetts (adopted) DOE/EIS-0470," 2009).

3.5 OTEC Siting

In the 1980's, major research was done on the use of OTEC in Kahe Point, Oahu, Hawaii (Harrison, 2009), which resulted in publications characterizing the area's biota, geology, water quality etc. To better understand Kahe Point's seabed, the University of

Hawaii partnered with the USGS to execute high-resolution seismic-reflection and acoustic profiling surveys (using the near bottom SeaMARC II towed swath bathymetric side-scan sonar system operating at 12 kHz, a 3.5 kHz profiling system, and a mini-sparker profiling system provided by the USGS) and collect sediment samples via gravity cores. Duplicates of the seismic reflection records were made and spliced together to create the figures (maps) in the final report. Analysis of this data resulted in detailed bathymetric and seafloor geology maps of Kahe Point which, in combination with additional ecological data, facilitated the OTEC siting process at Kahe Point (Normark et al., 1982). In recent years, the Hawaii National Marine Renewable Energy Center (HINMREC) has taken over and continues to pioneer Hawaiian OTEC research.

3.6 Existing offshore southeast Florida OCE Siting Research

In 2012 Vinick et al., in cooperation with Nova Southeastern University Oceanographic Center (NSU-OC) and FAU/SNMREC, published an offshore southeastern Florida OCE siting study as part of BOEM's Environmental Assessment (EA) process (see below). Researchers in the report first conducted a geophysical survey (using the data collection methods outlined in Section 2.2) of pre-selected areas with subsequent post-processing and expert data interpretation by geophysicists and experienced marine biologists knowledgeable about the general project area. The geophysical survey was completed using a sweep multibeam backscatter and bathymetry system. To validate the benthic habitat types interpreted from the geophysical data the researchers conducted benthic video and photographic field surveys of selected habitat types, this included spot-checking selected habitat types rather than comprehensive evaluation of the entire area covered by the geophysical survey. After the field surveys the original field documentation was summarized and video data reviewed in the laboratory to define benthic habitats. Each image from the photographic surveys was viewed and edited in Photoshop to better ensure photo quality, and then each image was analyzed using Coral Point Count with Microsoft Excel extensions (CPCe) to determine benthic habitat cover and area analysis. The CPCe analysis of each image yielded 1) raw percent composition and 2) percent composition per area data for each photo site which was saved into an Excel database. The percent cover data derived from the CPCe analysis was then analyzed using a multivariate approach including cluster analysis and corresponding non-metric multi-dimensional scaling to address the statistical connections between sites. Overall, this study approached portions offshore southeast Florida from a strong biological perspective, paying particular attention to the area's benthic communities. As such it will provide the backdrop for the benthic habitat and seafloor geology suitability analyses carried out in this thesis (Vinick et al., 2012).

3.7 MRE Siting Suitability Analysis

"Geospatial Analysis of Technical and Economic Suitability for Renewable Ocean Energy Development on Washington's Outer Coast" by Van Cleve et al. (2013) is the only known publication to address MRE siting using a suitability approach. The report focuses on siting tidal, wave and offshore wind energy projects on the Pacific Coast of Washington state. As the report's title suggests, it explores siting suitability considering only geospatial and technical aspects of siting such as site quality, grid-connection, and shore-side support. To create a scale of suitability Van Cleve et al. (2013) compiled attributes relevant to siting MRE (energy resource potential, depth, seafloor substrate, distance to shore, etc.) from the pertinent documents, presented them to industry professionals for review, and refined them to cater to technical and economic considerations. The suitability scaling and weights (scored attribute classes ranging from 0 to 10, with 0 meaning no potential for development and 10 designating conditions that are favorable for development) were decided as a result of incorporating relevant literature sources and in-depth industry professional feedback. Van Cleve et al. (2013) then developed a geospatial database containing GIS (geographic information systems) datasets of their identified important attributes (i.e. bottom sediment type, distance to shore, transmission lines). Based on the suitability weights, the geospatial datasets were subjected to eight algorithms describing the relative suitability of sites for each MRE type. When run, each of the eight algorithms created a different siting suitability model. From there, Van Cleve et al. (2013) focused on evaluating the results generated by the eight models. Aside from this report, no other documented research that employs a suitability scale or GIS suitability approach to siting a MRE project was found.

3.7a Florida OCE Siting Suitability Analysis – Suitability Scale Attributes

Vinick et al. (2012), Dubbs et al. (2013), Orth et al. (2006), and BOEM's 2013 "Guidelines for providing benthic habitat survey information for renewable energy development on the Atlantic outer continental shelf pursuant to 30 CFR part 585" were consulted to glean the biologic factors involved with siting Florida OCE. These documents reassert the OCE laws, policy and regulation chronicled in Section 2.4, which call for the protection of "environmentally sensitive habitats" (i.e. coral reefs, essential fish habitats, marine protected areas) located in and around the any proposed OCE development area. As highlighted earlier, Vinick et al. (2012) specifically catered to the south Florida OCE in their siting study. For their purposes, Vinick et al. (2013)

focused on adhering to the MSFCMA overseen by NMFS, SAFMC, and NOAA that strongly emphasizes the protection of marine resources such as EFH and coral reefs (Vinick et al., 2012). Dubbs et al. (2013) reinforce the importance of safeguarding the marine environment in their assessment of MHK permitting and risk. They profile the overarching laws and regulations essential to making MRE, and by extension OCE, development feasible. Overall, this piece presents a very similar outline of MRE policies akin to the detailed discussion found in Section 2.4. Orth et al. (2006) echoes the sentiments found in Vinick et al. (2012), Dubbs et al. (2013) and BOEM guidelines, while highlighting the ecological importance of seagrass. Orth et al. (2006) presents a collectivized argument for the protection of seagrass communities due to their ability to act as carbon sinks, nutrient filters, biodiversity hotspots, and nursery grounds. Further, they warn, "changes in seagrass distribution…signal important losses of [these] ecosystem services".

In terms of seafloor geology, Vinick et al. (2012) directly discusses the link between substrate type and OCE development. The report designates boulders, rubble, cobble, etc. as generally unfavorable for OCE devices and offer sand or unconsolidated sediment areas as best for OCE (Vinick et al., 2012). MRE anchoring studies (Valent et al., 1976; Taylor, 1982; Sound and Sea Technology, 2009; VanZwieten, et al., 2012) denote clays, mud, sand, and glacial till as functional for many MRE anchor types. However, these studies consistently highlight sand over mud/clay/etc. as most favorable for anchors (Valent et al., 1976; Taylor, 1982; Sound and Sea Technology, 2009; VanZwieten, et al., 2012; Vinick et al., 2012). Generally, sedimentology research (Bennett & Glasser, 2009; Foley, 2009; Peterson et al., 2000; Kukal, 1971) supports the distinction of sand from fine-grained sediments (e.g. mud or clay) and large-grained (e.g. gravel or glacial till) for their varying compatibility with OCE anchoring (Sound and Sea Technology, 2009; VanZwieten, et al., 2012). The biologic and geologic sources explored here collectively suggest that biologic areas should be given low suitability values (i.e. less suitable, least suitable) when considering OCE placement offshore Florida, while seafloor substrate suitability values will vary based on their physical properties (i.e. grain size).

3.7b Florida OCE Siting Suitability Analysis – Core Interpolation Methods

Marine geology data for offshore south Florida is primarily available in the form of seafloor core and grab samples. Spatial analysis of this sample type has been explored in GIS literature (categorical data interpolation methods) and academic literature (seafloor sediment studies). These documents are used to support potential methods for spatial investigation of marine geology data with respect to siting OCE offshore southeastern Florida.

GIS literature

Seafloor core data is largely categorical in nature (each data point corresponds to a discrete text description). Spatial interpolation methods for seabed point data have been explored in the literature, however no solid census has been reached (Li & Heap, 2008; Verfaillie et al., 2006; Goff et al., 2008; Li et al., 2013). Thiessen Polygon Analysis (TPA), Inverse Weighted Distance (IDW), Bayesian methods (Bayesian Maximum Entropy), and Kriging methods have been suggested by the GIS literature to generate seafloor substrate maps useful for assessing OCE suitability (Hengl, 2007; Knotters et al., 2010). TPA is a deterministic method, in which Thiessen polygons are essentially a set of areal units around data point objects. They contain a single point input feature and assign an interpolated value equal to the value found at the nearest sample location (i.e. nearest neighbor). As such, any location inside a Thiessen polygon is closer to its associated point than to any other point input feature. This method allows for a heterogenic, checkerboard view of the input variable across an area (Tchoukanski, 2013).

IDW interpolation is deterministic and can be thought of as an intermediary step between the TPA and EBK methods. It operates under the conjecture that points that are close together are more alike than points that are farther apart. IDW utilizes discrete point measurements around the prediction site to estimate a value for any unmeasured location. The closest known values to the prediction site will have more influence on the predicted value than other known values located those farther away (or in other words, IDW weights the points closer to the prediction location greater than those farther away). In this way, IDW adopts the assumption that each known point has a local influence that reduces as distance increases ("How Inverse Distance Weighted Interpolation Works," 2007).

In 2013 the Empirical Bayesian Kriging (EBK), a probabilistic method, was created. This tool incorporates the Bayesian and kriging methods proposed by Hengl (2007) and Knotters et al. (2010). It needs little interactive modeling and its standard errors of prediction are more accurate than in other kriging models (Krivoruchko & Butler, 2013). This is because general kriging methods utilize a semivariogram (a function of the distance and direction separating two locations) to measure the spatial dependence in the data whereas EBK offers a more sophisticated kriging approach that accounts for the error introduced by estimating the semivariogram model in standard kriging. This involves approximating, and then implementing, several semivariogram models instead of a single semivariogram throughout the interpolation process (Krivoruchko, 2012).

Academic literature

Verfaillie et al. (2006) compared linear regression, ordinary kriging (OK) and kriging with an external drift (KED – incorporates secondary information to help the interpolation) to assess median grain-size distribution of the sand fraction at the Belgian Continental Shelf. The linear regression interpolated map did not honor the original data points (because the original measurements are used only to compute a linear regression function), therefore it was ruled out as a viable technique. The OK interpolation produced a relatively accurate map of grain size, but did not possess a correlation between bathymetry and median grain-size. The KED interpolation results conveyed a clear linear correlation between the median grain-size and the bathymetry (i.e. the median grain-size varied in proportion to the depth) that allowed more detailed map of the median grain-size to be constructed. Verfaillie et al. (2006) concluded that general kriging methods, specifically a more sophisticated kriging like KED, are best for interpolating seabed data.

Goff et al. (2008) also implemented OK measures to interpolate randomly sampled sediment point data (mean grain size records) from the U.S. continental shelf areas in the usSEABED database. The dataset held both numerical and textual data types, the word-based descriptions were analyzed (subjected to an algorithm that parses and comprehends text descriptions then constructs an estimated grain size) separate from the numeric data. Isotropic, binned semivariograms were established from the data and inverted to get approximations of noise and field variance, and decorrelation distance. Due to the fact textual (parsed) and numerical semivariograms were quite alike, Goff et al. combined the two for the interpolation using a ‘‘bias-correction proxy’’ to accommodate differences in the mean. The resulting mean grain size interpolated map was qualitatively verified by comparing it to existing USGS 100–105kHz backscatter data for the Long Island shelf data set suggesting the usSEABED data can be processed to make interpolated maps of mean grain size and possibly other sediment characteristics in a region. The limitations of this approach include the need for data filtering or other noise reduction algorithm to reduce noise in the data before map generation and that the bias-correction proxy should be assessed separately for each region.

In 2013 Li et al. attempted to identify the best technique for spatial prediction of seabed gravel content in the northwest Australian Exclusive Economic Zone using a hybrid approach combining Random Forest (RF) with IDW or OK (i.e. RFOK or RFIDW). The predictive accuracy of each method was evaluated “in terms of relative mean absolute error (RMAE) and relative root mean squared error (RRMSE) based on the average of 100 iterations of 10-fold cross-validation” (Lin et al., 2013). When it came to RMAE and RRMSE, the RFIDW was significantly less accurate than RF and RFOK based on paired t-test (p value less than 0.0001). And in the context of RMAE, the RF was notably less accurate than RFOK based on paired t-test (p value less than 0.0001). These results establish RFOK as preferable over the other RF hybrid approaches in this case, although all RF hybrid methods yielded considerable potential for predicting environmental properties. Lin et al. (2013) suggest additional testing for spatial predictions in environmental sciences and assert that individual studies must determine which technique is best based on the dataset and intended application. As a side note, all relevant academic literature studies were executed prior to the full-scale release of the ArcGIS 10.1 EBK tool in 2013, consequently there are no academic sources exploring the use of this particular method for interpolating seafloor point data.

Bathymetry

Bathymetry can be useful in guiding seafloor core data interpolations as well as constraining benthic community locations. Biologically, water depth is a limiting factor for benthic communities like seagrass and corals (Sumner-Fromeyer, 1999; Nybakken, 2001; Cole, 2007; Nelson, 2009). Consequently, consulting bathymetric data allows biologic factors to be more realistically accounted for when interpolating seabed data. In terms of marine sediment dynamics, ocean current and wave parameters (direction, speed, etc.) primarily determine seafloor sediment distribution, while bathymetry is secondarily related to sediment distribution on the ocean floor (Karl, 2006; "Oceanography: 7 The type of sediment on the ocean floor varies," 2008). In calm deepwater (i.e. no strong currents) finer grained particles like silt/clay will settle out of the water column and become deposited on the seafloor. Conversely, finer grained sediments will remain in suspension (in the water column) in turbulent deepwater. To this effect, Verfaillie et al. (2006) employed bathymetry as a secondary variable in their KED interpolation to produce detailed grain-size maps. Verfaillie et al. (2006) is example of one possibility for water depth information to be incorporated in interpolation analysis; however further exploration on a case-by-case basis is required for future research in this area.

4. METHODS

ArcGIS, a commercial software package distributed by Esri, of Redlands, CA (Law & Collins, 2013), consists of a series of software programs and tools that are applicable for a variety of professional GIS projects (e.g. urban planning, business location analytics). Shapefiles are primarily used in GIS and ArcGIS applications. Shapefiles stores non-topological geometry and corresponding attribute information for the spatial features in a dataset ("Esri Shapefile Technical Description," 1998). They retain geometry features as shapes (point, line, and area features) comprising a set of vector coordinates and each attribute record possesses a one-to-one relationship with its associated shape record ("Esri Shapefile Technical Description," 1998). OCE relevant biologic and geologic datasets were largely available and acquired in shapefile format making them highly ArcGIS compatible. Additionally, ArcGIS 10.1 (most recent version) contains tools for executing a range of geospatial analysis including the aforementioned TPA, IDW and EBK spatial interpolation techniques. For these reasons ArcGIS 10.1 was selected as the main data analysis apparatus in this thesis.

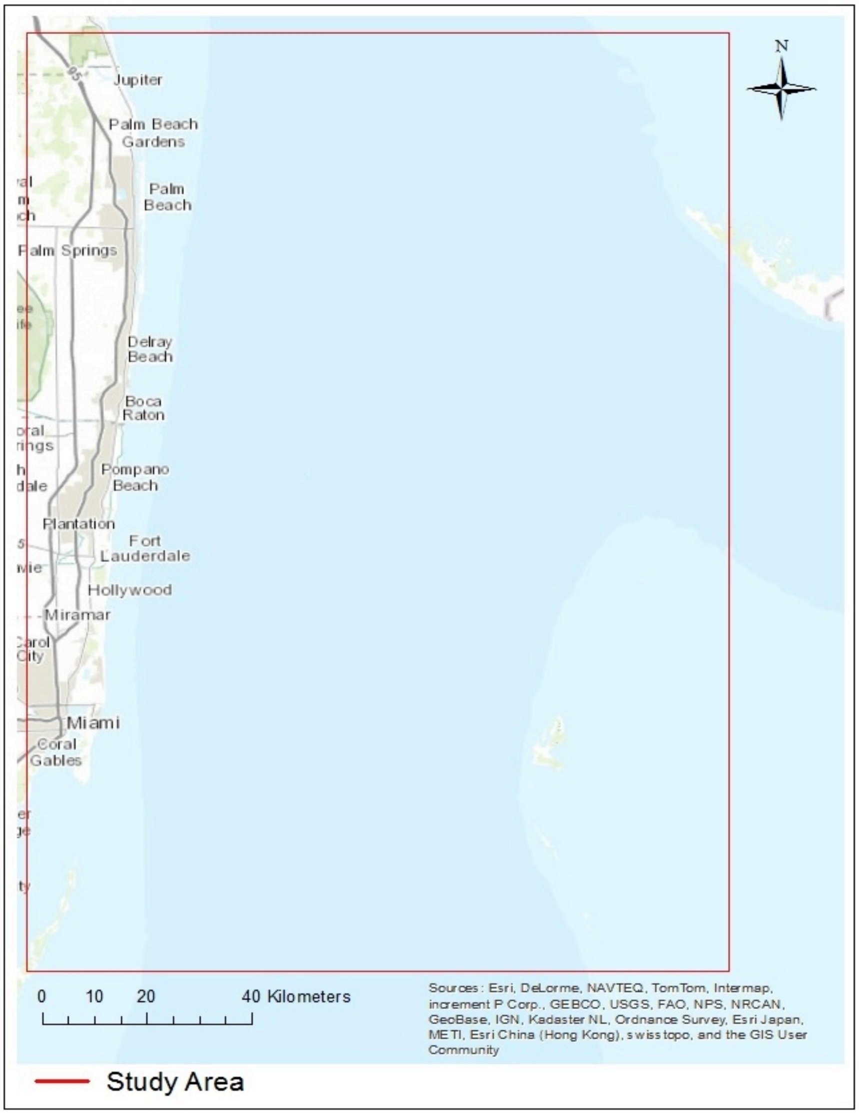
4.1 Study Area

The area spanning roughly 35 kilometers off the coast of southeast Florida from West Palm Beach County southward down to Miami-Dade County has been suggested for OCE deployments (Hanson et al., 2010) and will serve as a study area of interest in this thesis. Water depths between 250 and 400 meters are said to be workable for OCE projects in the study area which is known to contain soft bottom and hard bottom habitats (Vinick et al., 2012). The continental shelf offshore southeastern Florida is home to a tropical coral reef system (shallow-water) and relatively uncharted deep-water coral populations in the deep outer continental shelf waters (Reed et al., 2012; Walker et al., 2008).

4.1a Shallow-water and deep-water environments

Coastal reefs make up linear, almost continuous, near shore (<30 meter water depth) features that are barriers to OCE cable transmission lines. A set of reefs parallel to shore and a sequence of shallow, near shore ridges (“nearshore ridge complex”) located inshore of the reef network compose the shallow-water reef system. This shallow-water system falls in state waters (roughly 3 miles offshore of the coastline) and plays host to standard Caribbean coral reef fauna in varying composition and density (Walker et al., 2008; Walker et al., 2009).

A ridge parallel to shore (70-90 meter depth), the Miami Terrace (65 kilometer north-south stretch of deep-water terrace and escarpment with depths ranging between 200-700 meters that is about 5-15 miles offshore from Palm Beach, Broward and Miami-Dade Counties), and deep-sea coral mounds in excess of 700 meters depth make up the deeper water ecosystems and support a high diversity of deep-water fish and invertebrates including many commercially valuable and ecologically sensitive species (Reed et al. 2006; Reed et al., 2012). In 2010 NOAA designated five deep-water coral Habitat Areas of Particular Concern (HAPC) covering roughly 63,000 square kilometers from south Florida up to North Carolina. The HAPCs span a variety of habitats, some of which are typified by protected species (i.e. deep-water mound-building corals), and are intended to protect most of the known deep-sea corals in the area, including sections of the Miami Terrace. The primary area of interest for siting OCE projects is well offshore of the shallow-water reef system (within the deeper water environments), while OCE cables connecting to an onshore electrical transmission grid will need to carefully traverse the shallow-water habitats (Vinick et al., 2012).



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

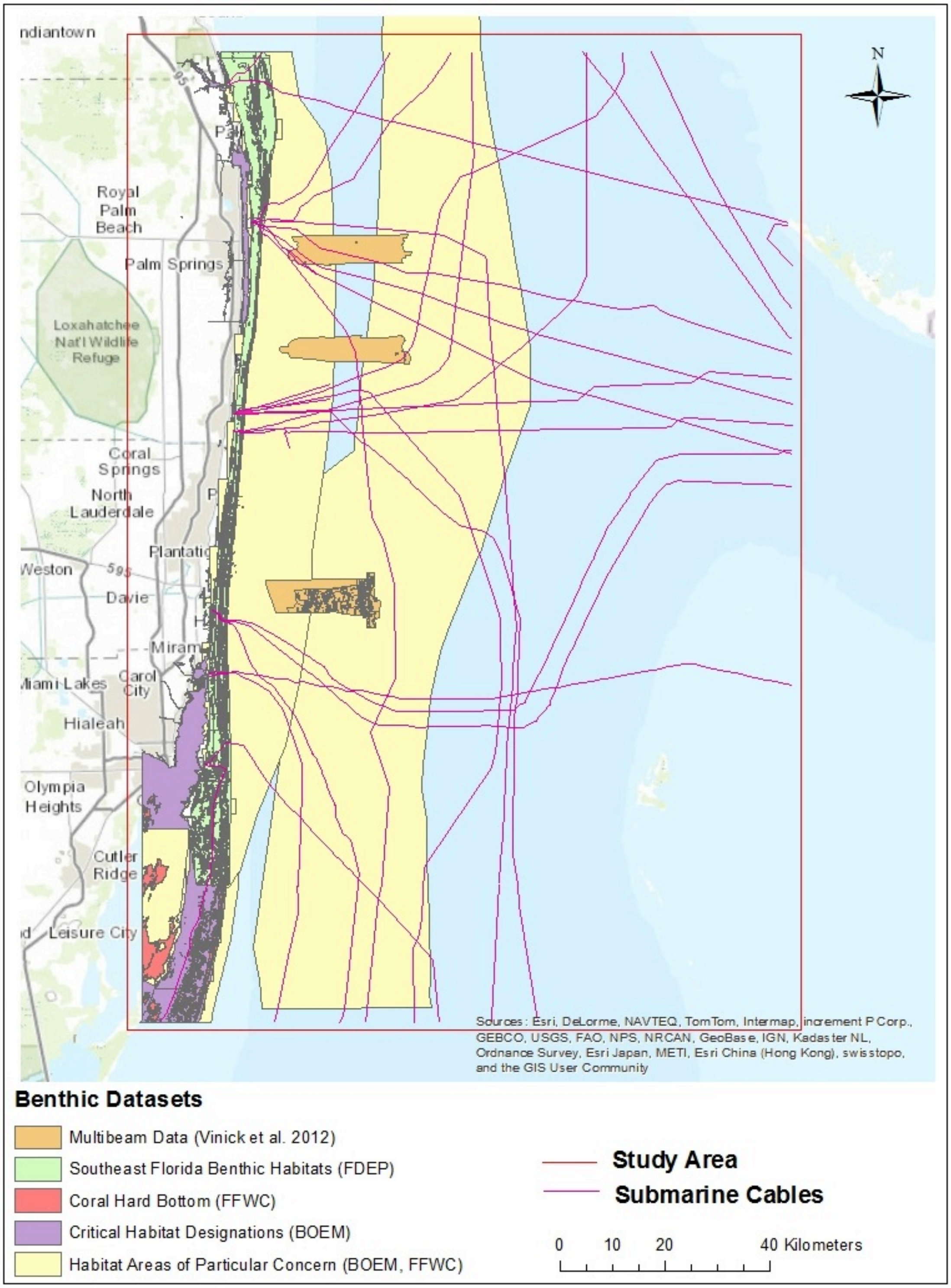
Figure 2. Study Area

4.2 Data

4.2a Multibeam data and submarine cable data

Multibeam data from Vinick et al. (2012) that was previously used in BOEM's EA (Section 3.6) will be expanded upon using additional seafloor geology and benthic habitat data to assess offshore southeastern Florida's suitability for sustaining OCE by isolating favorable deployment sites (aka. soft bottom) within the general proposed deployment area (Figure 3). The multibeam data measured distance as a map over the study area over which the vessel cruised and was collected using a Kongsberg EM 710 FM sweep multibeam backscatter and bathymetry system that operated in the 70 to 100 kHz range to collect the geophysical information (Vinick et al., 2012).

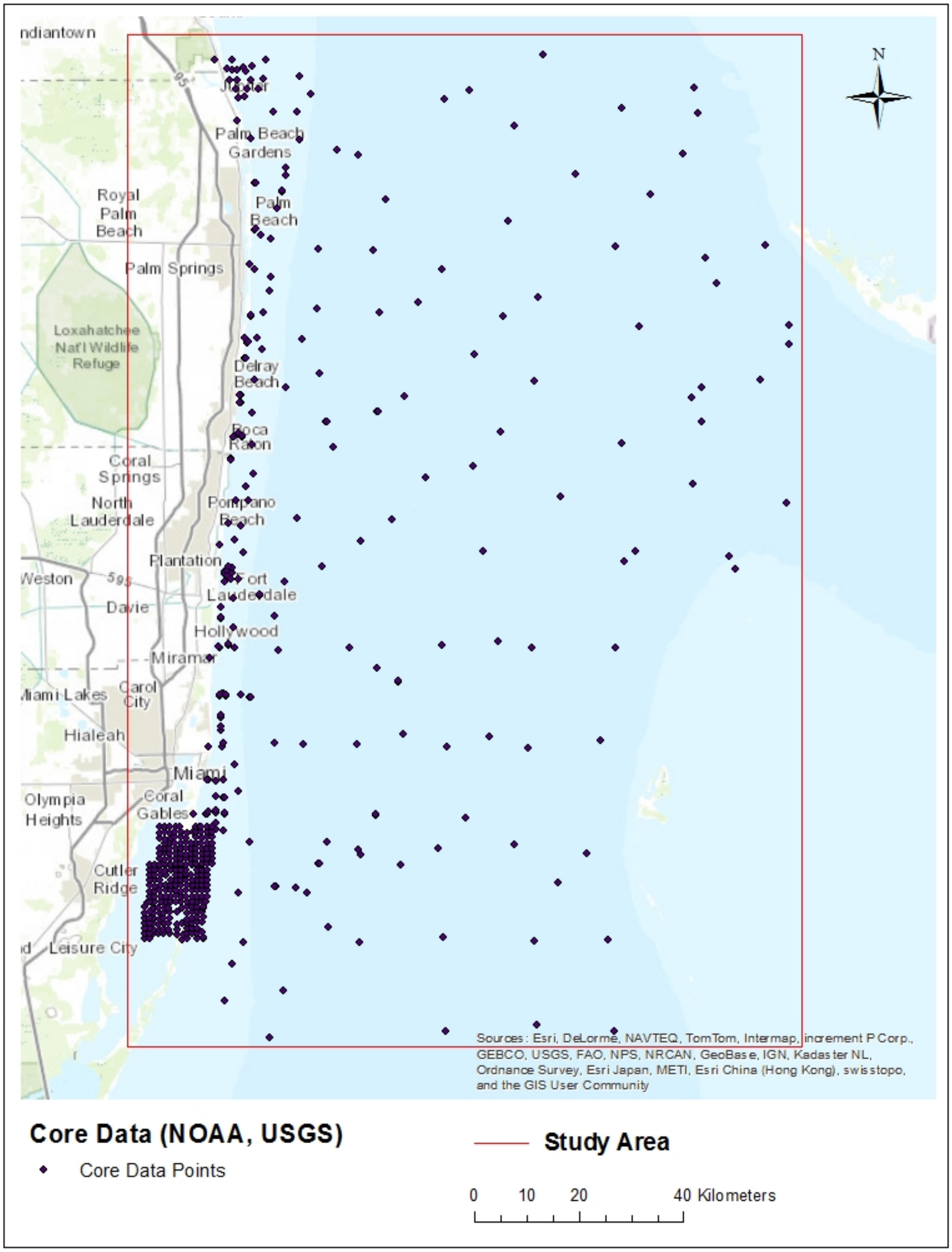
The submarine cable shapefile was acquired from BOEM's Marine Cadastre and shows the placement of existing submarine cables in U.S. navigable waters (Figure 3). The original source geometry and attribute information comes from NOAA's 2010 Electronic Navigational Charts (ENCs) and 2009 Raster Navigational Charts (RNCs). The data was updated in 2013 referencing the RNCs. Polyline features that were clearly defined as cables were assembled from the original sources, exclusive of features mentioned as 'cable areas'. Source material scaling was variable, and breaks between multiple sources were fixed using as few possible spatial adjustments (NOAA Coastal Services Center, 2011).



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

Figure 3. Study area (outlined in red) with all benthic datasets and existing submarine cable routes

4.2b Seafloor geology and bathymetry data



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

Figure 4. Study area (outlined in red) with all 646 core data points

With the exception the USGS Geologic LOng-Range Inclined Asdic (GLORIA), a side-scan sonar dataset, the remaining USGS Continental Margin Mapping Program (CONMAP), USGS usSEABED program, USGS East Coast Sediment Texture Database (ECSTD) and NOAA Index to Marine and Lacustrine Geological Samples (IMLGS) datasets consist of seafloor sediment core and grab samples (Figure 4). The sediment information from CONMAP is a collection of grain-size data originating from the sedimentation laboratory of the Woods Hole Science Center (WHSC) (USGS Coastal and Marine Geology Program), published studies, and unpublished studies. The Wentworth (1929) grain-size scale and the Shepard (1954) system of sediment classification were employed to catalogue sediment samples. The sediment designation for any given area is the principal surficial sediment type for that area, while secondary sediment types are not shown (other sediment types may or may not be present within the area) (Poppe et al., 2005a).

GLORIA gathered side-scan sonar data for the EEZ Atlantic continental margin seaward of the continental shelf from the Canadian border to the northern Blake Plateau offshore Florida during five cruises in 1987. This data was processed and digitally mosaicked creating continuous seafloor imagery. For the Atlantic margin, 23 digital mosaics with a 2 by 2 degree (or smaller) area and 50 meter pixel resolution were completed, 21 of these mosaics were integrated to generate an overview of the Atlantic continental margin ("U.S. Atlantic Continental Margin GLORIA Mapping Program," 2013). Although the GLORIA data is not directly used in this thesis, it constitutes portions of other seafloor geology datasets that are used (see below).

The usSEABED program essentially houses a single integrated seabed sample dataset made up of published and unpublished collected data from federal, state, local, and regional agencies, consortiums, and research institutions (educational reports, theses, etc.). Much of the Atlantic region data comes from the USGS (GLORIA and CONMAP). The Atlantic coast data may have duplicates because data from the sample location may have been published in more than one place (i.e. report or data compilation). The usSEABED program took effort to reduce data duplications when necessary, however data from varying sources for a single location was retained when significant additional information was gained (e.g. for a single site one source may contain grain size while another includes geophysical properties, in which case duplicate points were kept) (Reid et al., 2005).

The ECSTD includes sample location, description, and texture from multiple marine programs. Many of the samples originate from the USGS CONMAP and GLORIA projects. The database possesses data information for more than 26,000 samples from 1955 through January 2011 (Poppe et al., 2005b). NOAA's IMLGS has basic collection method, lithology, age, and texture information for seafloor samples recorded by about twenty oceanographic institutions and government agencies. Some samples also include primary and secondary lithology, rock type, texture, mineralogy, weathering, province, principal investigator, age, and other descriptive notes (Curators of Marine and Lacustrine Geological Samples Consortium, 2013). The Bathymetric Contours Southeast United States shapefile from NOAA's Coastal Services center represents vector coverage of bathymetry offshore North Carolina, South Carolina, and Florida. The bathymetry resolution increases nearer to coastal areas. The contours originate from a composite of multiple bathymetric datasets each of variable resolution and regional extent. Isobath intervals span from 2 meters (near shore coastal areas) up to 200 meters (deepwater offshore areas) (NOAA Coastal Services Center, 2000).

4.2c Biologic data

Offshore southeastern Florida Critical Habitat Designations and HAPC data was accessed from BOEM's Marine Cadastre service and FFWC while more detailed coral reef mapping information was obtained from the FFWC and FDEP (Figure 3). These additional offshore southeastern Florida benthic habitat resources will be taken into account with the previously outlined multibeam data as part of this thesis. There are two HAPC shapefiles, one containing shallow water (< 20km offshore) features from BOEM and one containing deepwater corals (>20km offshore) from FFWC. The HAPC shapefiles spatially represent areas where coral and hard bottom activity is considered high with respect to ecological function, probability of stressor introduction, sensitivity, and Essential Fish Habitat-Habitat Areas of Particular Concern (EFH-HAPC) criteria (FFWC & FWRI, 2005). Government and academic research studies mapping the locations of coral habitats offshore Florida constitute the basis of these HAPC files, which aim to protect what may be the greatest distribution of deepwater coral ecosystems globally (FFWC & FWRI, 2008). It is important to note that these shapefiles cloak large swaths of the study area rather than showing precise coral community locations, therefore it is likely that soft bottom (sand or sediment with no biologic presence) areas are present but masked out by the large areal coverage.

The Critical Habitat Designations shapefile shows "critical habitat" areas for species listed under the ESA offshore Florida. Critical habitat can be considered: 1)

Specific areas in which physical or biological features essential to conservation of the listed species reside (and those features may necessitate protection or special management) and 2) Certain areas outside the geographical extent inhabited by the listed species if the agency concludes the area itself is necessary for species conservation (NOAA Coastal Services Center, 2012). The FFWC coral hard bottom habitat GIS dataset is a collection of coral and hard bottom type data available to the Fish and Wildlife Research Institute (FWRI) as of 2013. The time frame, resolution, mapping methods, and physical extent vary by source dataset. Data gaps exist amid small, narrow polygons that represent differences in overlying study areas and actual small polygons from the original source data. The attribute table or metadata of this file should be consulted for more references to the source data (FFWC & FWRI, 2013).

Southeast Florida benthic habitats were mapped using the combined technique discussed in Walker et al. (2008). First, high-resolution (4 meter resolution) Light Detection and Ranging (LIDAR) bathymetric and aerial photography surveys were done to collect images of the seafloor as deep-water clarity issues prohibited underwater image-based analyses. Habitats delineated in these surveys were catalogued and described to produce habitat maps. The maps build upon data from various surveys including the FFWC Martin LIDAR bathymetry and aerial photography (2008 and 2009), FFWC Biscayne aerial photography (2005), USACE coastal LIDAR (2006), Broward LIDAR (2001), and Palm Beach and Miami-Dade LIDAR (2002). All habitats in this dataset were categorized in accordance with NOAA guidelines and the National Ocean Service Coral Mapping Program (Walker, 2013).

4.3 Data Analysis (Objective 1)

To fulfill objective 1 of this thesis the benthic and geologic datasets were assembled and analyzed for their pertinence in siting OCE offshore southeastern Florida. Shapefile core samples from the USGS and NOAA are categorical point data features that cover a sizeable portion of the study area (Figure 2) and whose corresponding descriptive text fields are feasible for use in modified spatial interpolation techniques aimed at estimating seafloor geology surfaces. Given that TPA assigns interpolated value based on the value found at the nearest sample location, this method will maintain the integrity of the initial discrete core data points without assuming any transition zones of substrate type from one point to another. The kriging (EBK) process possesses three parts: 1) a deterministic component 2) spatially correlated Bayesian random effects and 3) a random stochastic component ("How Kriging Works," 2011). Because it is a probabilistic method, some randomness should be expected in the seafloor substrate map produced by EBK. For this study: 1) the seafloor core data supplies the structure or deterministic component of the interpolation 2) the spatially correlated random effects will factor into seafloor substrate transition zones that go missed by the TPA (i.e. where gravelly sediment transitions into sand or sand transition into mud/ooze etc.) and 3) the overall distribution is evaluated and certain values are stochastically simulated based on a model fitted to an empirical semivariogram ("How Kriging Works," 2011; "Universal Kriging," n.d.).

The Critical Habitat Designation and HAPC benthic shapefiles possess coarse spatial resolution covering broad extents within the study area (Figure 3). Therefore, they help to identify generally important biologic areas but only vaguely indicate possible reef gaps for OCE cables among benthic communities. The Florida Benthic Habitat and Coral Hard Bottom Habitat shapefiles have a more refined spatial resolution showing somewhat detailed coral reef locations among the surrounding unconsolidated sediment. As such, these datasets are useful for determining sensitive biologic zones and determining potential OCE cable routes. The Vinick et al. (2012) multibeam data is a very high-resolution dataset that designates sediment and benthic community locations. Due to its high-resolution it can act as a verification data source for the accuracy of the seafloor core data analyses in this thesis. Lastly, the Submarine Cables shapefile indicates existing reef gaps already containing underwater cables. The routes in this dataset offer potential pathways for OCE cables when taken into consideration with the other benthic datasets.

4.4 Data Processing

4.4a Seafloor Geology Analysis (Objective 2)

The first step in determining suitable OCE siting areas is to characterize the study area substrate extent by interpolating the acquired seafloor data points to create a map of seafloor geology. To do this, the IMLGS (NOAA), ECSTD and usSEABED (USGS) shapefiles were spatially referenced to the Florida State Plane East projected coordinate system (NAD_1983_HARN_StatePlane_Florida_East_FIPS_0901 US Meters) and clipped to fit the study area shown in Figures 1 and 2. All datasets contained points with missing data entries, which were removed. Furthermore, there was overlap between data points from each dataset, for these points the individual descriptions were examined and the most detailed description was kept. This resulted in a seafloor geology shapefile containing a total of 646 core data points each with different descriptions. To rectify the discrepancy in description, the attribute table from each data source (after being corrected for missing data and overlapping points) was imported into Excel, and then one uniform attribute table for all datasets was created. To this consolidated attribute table a new field was added (no existing fields where changed) which contained a unified code system used to describe all data points. The ECSTD file was used to construct the codification scheme as it contained the most detailed descriptions out of all the datasets. Then, the file was geocoded by latitude/longitude and a new layer was generated in which all three datasets are merged and are classified by a unified description code consisting of five geology classes (ooze/mud/silt/clay/sand, sand/sediment, gravelly sediment, seagrass presence, and coral presence/hard bottom/miscellaneous biota/phosphorous nodules/phosphorous in sand). Typically, interpolation techniques utilize numerical data fields, rather than textual (categorical) data fields (Goff et al., 2008). The reason being is that locations between numbers can be estimated using decimal points (i.e. between data point 3 and data point 5 a value of 4 can be mathematically estimated), however there is no proxy by which to estimate between locations defined by text descriptions (i.e. the substrate between a sand data point and a coral data point could be any range of substrate types like mud, sand, coral, etc.). For this reason, a numerical attribute field ("Code_3") was created that directly corresponds to the unified descriptive text attribute field. In "Code_3", the textual unified description code was assigned numerical values ranging from 1 to 5 (1 – Ooze/Mud/Silt/Clay/Sand, 2 – Sand/Sediment, 3 – Gravelly Sediment, 4 – Seagrass Presence, and 5 – Coral/Hard Bottom/Miscellaneous Biota/Phosphorous Nodules), thus permitting the dataset to undergo spatial interpolation. This yielded the fullest extent of the available seafloor geology data.

The streamlined core data was then subjected to Thiessen Polygon Analysis (TPA – deterministic), an Inverse Distance Weighted (IDW – deterministic) interpolation, and an Empirical Bayesian Kriging (EBK – probabilistic) interpolation, and an IDW-EBK “hybrid” approach to create seafloor surface maps of the study area in ArcGIS. The IDW and EBK were run using the “Code_3” (numerical attribute table field containing the five seafloor geology classes under the unified description code) as the input z-field, a cell size of 30 meters, and the remaining parameters were left at their default setting. The "hybrid" facet of this analysis combines the strengths of the deterministic IDW and probabilistic EBK to address the difference between biologic and geologic data points in the interpolations. Biologic factors are largely deterministic. For example, a coral reef or seagrass patch is situated in a fixed location that does not suddenly change; therefore they are better represented by the IDW. Ocean floor sediments vary and are dynamic in response to physicals parameters such as ocean currents and bathymetry data (Ewing et al., 1973; Karl, 2006). The probabilistic EBK honors the known seafloor data points while predicting transition zones between different seafloor sediment types (sand, gravel, mud etc.) producing a more realistic depiction of the ocean floor surface.

To implement the hybrid method, all biologic data points were removed from the study area (251 from a dense cluster in the southwest corner of the study area and 55 from the remainder of the study area). Then the EBK was re-run using the same parameters as previously stated. Average Nearest Neighbor (ANN) analysis of the removed biologic revealed a mean expected distance of roughly 500 meters between shallow water (near shore < 25 meters) biologic points and about 2500 meters between deepwater biologic data points. Buffers were placed around the each of the removed biologic points in the IDW interpolation (500 meter buffers for shallow water features, 2000 meter buffers for deepwater features) based on these calculated distances. Then the buffered areas were clipped from the IDW and merged with the EBK surface to create the IDW-EBK. Thus, an adjusted or hybridized EBK surface was created using the IDW to account for stationary, determined biologic data points amidst dynamic seafloor sediment without distorting the interpolations.

Based on preliminary coral mapping studies in the study area (Reed et al. 2006; Reed et al., 2012; Walker et al., 2008; Walker et al., 2009; Walker, 2012), a second set of buffers were placed around the coral areas (red bull's-eye patterns) in the IDW, extracted from the IDW surface, and overlaid on the IDW-EBK. This was done to bolster the IDW-EBK by offering an expanded view of the potential spatial extent of coral features in the study area. The original IDW-EBK surface (500 meter buffers for shallow water features, 2000 meter buffers for deepwater features based on ANN analysis) will be used for this thesis's suitability analysis due to its statistically backed buffer designations, while the bolstered IDW-EBK solely serves to highlight potential the spatial variability of coral coverage in the study area.

Bathymetry

552 of the 646 streamlined core data points contained water depth (in meters) as an attribute field. The other 94 data points possessed missing or null values in this field. To fill in the missing water depth values bathymetry surface raster was generated by interpolating bathymetric contours from NOAA's Coastal Services Center. This

interpolated raster allows seafloor substrate composition reflected in the IDW-EBK hybrid interpolation to be supported by bathymetry throughout the study area. Furthermore, the bathymetric data is used to validate the occurrence of biologic data points within the interpolation. Biologic data points, specifically seagrass and coral/hard bottom/miscellaneous biota, within the seafloor geology core dataset were sparsely distributed in the study area. Seagrasses are typically found in warm, shallow coastal waters (Orth et al., 2006; Nelson, 2009). Offshore southeastern Florida coral habitats can be found ranging from shallow waters (<30m) to deep waters (>700m). (Reed et al., 2006; Reed et al., 2012; Walker et al., 2008; Walker et al., 2009; Vinick et al., 2012). The bathymetry data was considered to ensure that the extent of the seagrass data interpolation is constrained by shallow water areas in the study area (i.e., no seagrass data range in the interpolation is found offshore in deep waters) and approximate the spatial extent of known coral/hard bottom data points.

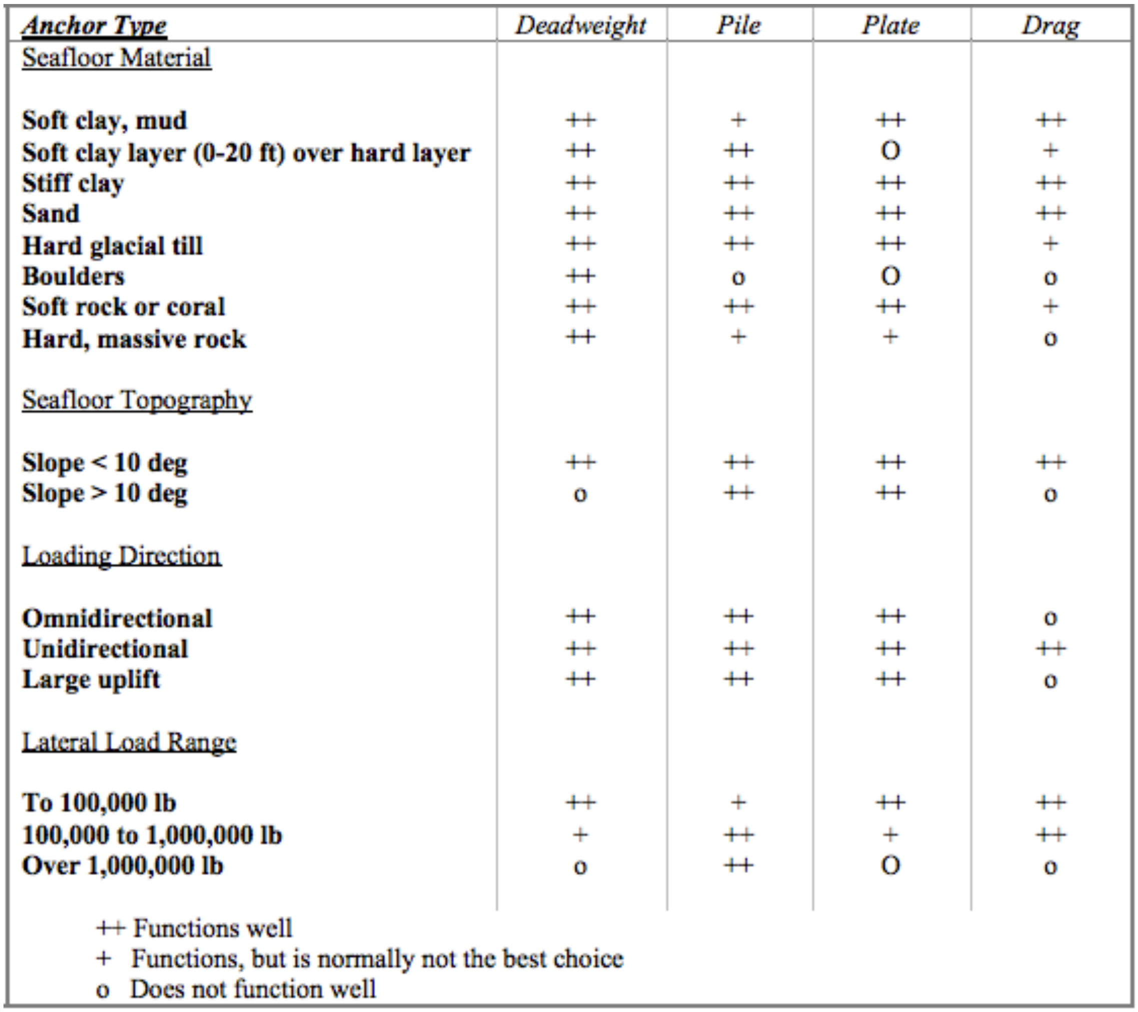
4.4b Benthic Data & Cable Data Analysis (Objectives 3-4)

The second step in determining OCE suitable areas is to locate biologic hotspots that should be avoided. This was done using the Coral Hard Bottom Habitat, Critical Habitat Designations, HAPC, Florida Benthic Habitats, and multibeam benthic datasets, which were converted from vector data (primarily polygon data) to raster data for use in ArcGIS suitability analyses. These five benthic datasets were reprojected to the State Plane Florida East projected coordinate system and clipped to fit the study area. The attributes of each benthic dataset (excluding the submarine cable shapefile) were reclassified to remove overlapping data fields. This resulted in a total of eight benthic data classes: coral/hard bottom/probable hard bottom, sinkhole/probable sinkhole, artificial Florida slope, unconsolidated sediment, seagrass, manatee habitat, crocodile habitat, and other. The eight benthic classes were each assigned a suitability value between 1 and 4 (see 4.4c below) which then allowed the benthic datasets to be reclassified again into two final classes (coral/hard bottom/biologic presence and sediment) with two suitability values. The third step towards illuminating OCE suitable areas is to isolate possible benthic community (reef) gaps through which OCE power transmission lines can be placed. To do this, the Submarine Cable shapefile, after being reprojected to the State Plane Florida East projected coordinate system and clipped, was overlaid atop the benthic datasets to view existing cable corridors within the study area that OCE cables can take advantage of.

4.4c Suitability Analysis (Objective 5)

To final step in assessing OCE suitable sites within the study area is to create a finalized spatial layer showing OCE suitable areas with respect to biologic and geologic parameters. Following the Van Cleve et al. (2013) framework, a uniform scale of OCE siting suitability was established by extracting OCE siting-pertinent information about the eight benthic classes and the eight seafloor geology classes from relevant literature sources. All biologic classes (coral, seagrass, manatee habitat, crocodile habitat and miscellaneous biota/sponge growth/tubes) were given a suitability of 1 (least suitable) in order to avoid harmful environmental impacts as a result of OCE siting (Dubbs et al., 2013; Orth et al., 2006; Vinick et al., 2012). The "Sinkhole" (geologically unstable), "Florida slope – artificial" (occupies minuscule portion of area, avoid geomorphologic complexity), "Phosphorous Nodules /Phosphorous in Sand" (rubble and/or rocky like bottom features created by the phosphorous presence) and "Other" (unknown or identified substrate type) substrate classes were also given a suitability of 1 due to their undesirable attributes. As aforementioned soft bottom refers to unconsolidated sediments or loose sand and it is the most suitable substrate for OCE anchors, cables, and moors (Valent et al., 1976; Taylor, 1982; Bennett & Glasser, 2009; Sound and Sea Technology, 2009; VanZwieten, et al., 2012; Vinick et al., 2012). Therefore, the “Sediment” and “Sand” classes were given a suitability of 4 meaning that they are potentially suitable for OCE structures. The Vinick et al. (2012) report notes that gravel occurs in tandem with hard bottom substrate as well as with sand/sediment substrate. This duplicity makes gravel somewhat less desirable than sand and is the reason that “Gravelly Sediment” class received a suitability of 3 (moderately suitable). The “Ooze/Sand/Mud/Silt/Clay” class received a suitability of 2 (less suitable) due to the potential presence of fine grained mud, ooze, silt and clay which may yield a more compact sand substrate (Foley, 2009; Kukal, 1971) disagreeable to OCE anchoring (Valent et al., 1976; Taylor, 1982; Sound and Sea Technology, 2009; VanZwieten, et al., 2012). Table 1 displays the most recent research on seafloor sediments in relation to MRE anchors. For this thesis gravel is equated with glacial seafloor material due their similarity in grain size (Bennett & Glasser, 2009). In Table 1 gravel is troublesome for one anchor type (drag), whereas clay/mud is challenging for two anchor types (pile and plate) and it is known to occur overlaying problematic hard layers (Sound and Sea Technology, 2009). Thus, because gravel is better suited to different anchor types (Table 1) it is given a higher suitability value (moderately suitable 3) than finer grained clay/mud sediments (less suitable 2). Using the assigned suitability values, the reclassified benthic datasets and submarine cable dataset were overlaid atop the IDW-EBK surface to expose areas most suitable for OCE in the study area.

Table 1. Behavior criteria for anchors (Sound and Sea Technology, 2009)



Anchor Type	*Deadweight*	*Pile*	*Plate*	*Drag*
Seafloor Material				
Soft clay, mud	++	+	++	++
Soft clay layer (0-20 ft) over hard layer	++	++	O	+
Stiff clay	++	++	++	++
Sand	++	++	++	++
Hard glacial till	++	++	++	+
Boulders	++	o	O	o
Soft rock or coral	++	++	++	+
Hard, massive rock	++	+	+	o
Seafloor Topography				
Slope < 10 deg	++	++	++	++
Slope > 10 deg	o	++	++	o
Loading Direction				
Omnidirectional	++	++	++	o
Unidirectional	++	++	++	++
Large uplift	++	++	++	o
Lateral Load Range				
To 100,000 lb	++	+	++	++
100,000 to 1,000,000 lb	+	++	+	++
Over 1,000,000 lb	o	++	O	o

++ Functions well
\+ Functions, but is normally not the best choice
o Does not function well

For the purposes of this study only, the OCE substrate suitability scale is defined in Tables 2-4 for the seafloor geology and benthic habitat data:

Table 2. Suitability Scale

Suitability Scale
1 - least suitable
2 - less suitable
3 - moderately suitable
4 - potentially suitable

Table 3. Benthic data classes with suitability

Class	Species/Habitat	Suitability
1	Coral/Hard bottom/Probable Hard Bottom	1
2	Sinkhole/Probable sinkhole	1
3	FL slope - artificial	1
4	Sediment	4
5	Seagrass	1
6	Manatee Habitat	1
7	Crocodile Habitat	1
8	Other	1

Table 4. Seafloor geology classes with suitability

Class	Seafloor Geology Type	Suitability
1	Ooze/Sand/Mud/Silt/Clay	2
2	Sand/Sediment	4
3	Gravelly Sediment	3
4	Seagrass Presence	1
5	Coral Presence/Hard Bottom/Rock Fragments/Limestone/Miscellaneous Biota/ Phosphorous Nodules in Sand	1

4.4d Error Analysis (Objective 6)

Sensitivity Analysis

A sensitivity analysis was conducted on the probabilistic EBK surface to address the Modifiable Areal Unit Problem (MAUP) in which the same data produces differing results when aggregated in different ways (Flowerdew, 2009). The MAUP has two components: a scale/aggregation portion and a group/zone portion. The scale effect concerns different statistical inferences and valuations made by the same data that is aggregated into different spatial resolutions (Ervin, 2014). The zone effect refers to when the analysis scale remains constant, however the shapes of the aggregation units change (Ervin, 2014). For this sensitivity analysis, the EBK interpolation was executed three times, using a 30-meter, 200-meter, and 500-meter input cell size parameter. EBK pixel values were recorded from each discrete core point location as well as from locations directly to the north, south, east and west of the individual core point. These values were used to create tables quantifying the correspondence between every discrete core data point and its place on the EBK interpolation surface for each of the three (30-meter, 200-meter, and 500-meter) EBK surfaces and revealed the influence of cell size variation on the EBK results.

Error Statistics

The Root Mean Square Error (RMSE), Coefficient of Relative Variation (CRV), and Mean Absolute Percentage Error (MAPE) were calculated for the IDW-EBK surface to assess interpolation accuracy. RMSE measures the difference between known locations and interpolated locations and indicates how closely the interpolation predicts the measured values (“Cross Validation (Geostatistical Analyst),” 2013). It is derived by squaring the differences between known (observed) and unknown (interpolated) data points, adding the differences together, dividing that by the number of total number of data points, and finally taking the square root of that result (Dettlaff, 2009).

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(\mathrm{i}_k - \mathrm{o}_k)^2}$$

RMSE values for the IDW-EBK hybrid interpolation were acquired from the Geostatistcal Wizard feature in ArcGIS 10.1. The CRV is defined as a ratio of the standard deviation to the mean and is commonly used as a measure of dispersion. It measures how dispersed the interpolated data is around a central tendency (i.e. the mean) (Wang & Vom Hofe, 2007).

$$\text{CRV} = \frac{\text{standard deviation}}{\text{mean}} = \frac{s}{\overline{x}}$$

The ArcGIS 10.1 Summary Statistics tool was used to calculate the standard deviation and mean values for the observed (original attribute field "CODE_3" identifying core data point values) and interpolated (manually recorded attribute field "CODE_int" cataloguing interpolated core data point values) core point values for both the IDW and EBK surfaces. Then the mean values were divided by the standard deviation values to derive finalized CRV scores. Lastly, the MAPE records the absolute value of deviation between interpolated data points and observed data points (Wang & Vom Hofe, 2007).

$$\text{MAPE} = \frac{1}{N}\sum_{k=1}^{N}\frac{|I_k - O_k|}{O_k}$$

A table of stretched pixel values (points were the EBK interpolation surface pixel does not correspond to the known core data point) for the IDW-EBK hybrid was constructed. These interpolated and observed values were inserted into the above equation and used to calculate the MAPE. Collectively, these statistics provide accuracy measures for the IDW-EBK spatial interpolation by which to assess the need for additional datasets (and what type they should be) to supplement this thesis.

Bathymetry Statistics

The Spearman rank coefficient and Kendall Tau rank correlation coefficient statistical tests were done to assess the correlation of water depth and sediment categories in the IDW-EBK interpolation. Both tests are non-parametric, meaning that they do not depend on data adhering to any particular distribution (Chok, 2010). Such non-parametric tests are suitable for the seafloor core sediment categories because the data is categorical and not normally distributed. For both tests the values range from -1 to 1, where -1 denotes strong negative correlation and 1 signifies strong positive correlation (Chok, 2010). The Kendall Tau rank correlation coefficient explores the null hypothesis that two variables are independent (Chok, 2010). If the value of the test is close to zero, then the variables are not thought to be statistically dependent (Chok, 2010).

5. RESULTS AND DISCUSSION

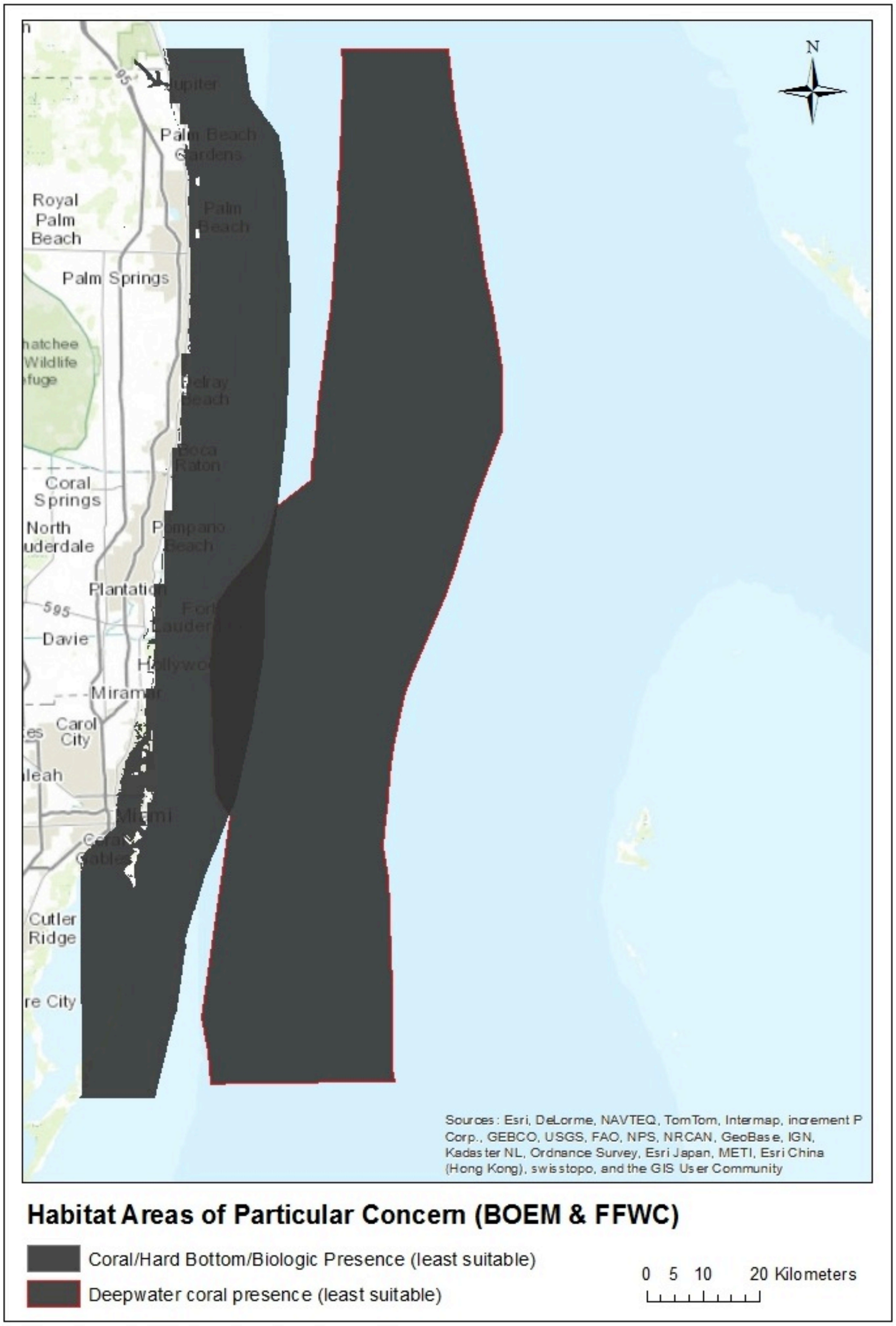
5.1 Benthic Analysis

Figures 5-9 display the re-classified benthic datasets with their respective suitability labels. The coarser resolution Critical Habitat Designations and HAPC cover large area swaths thus masking out any potentially useable substrate subsets contained within these locations (Figures 5-6). There are two main breaks that are helpful for identifying OCE cable paths in the Critical Habitat Designations file, one north of Delray Beach and the other near Fort Lauderdale. The Coral/Hard Bottom and Florida Benthic Habitats datasets (Figures 7-8) are higher resolution than the Critical Habitat Designation and HAPC, which allows for more detailed recommendations for OCE cable placement. Figures 7-8 depict a mix of coral and sediment pattern running along Florida's coast signifying that there are a variety of existing OCE cabling possibilities. The multibeam dataset from Vinick et al. (2012) possesses the highest resolution of all the benthic datasets and displays the eastern most benthic data as a series of three rectangular blocks (Figure 9). The bottom rectangle is primarily biologic in nature with small patches of sediment on its eastern most fringe, while the top and middle blocks are largely comprised of sediment (with the exception of the lower left section of the middle rectangle that is coral/hard bottom).

Critical Habitat Designations (BOEM)

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

Figure 5. Critical Habitat Designations (BOEM)



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

Figure 6. Habitat Areas of Particular Concern (BOEM)

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

Figure 7. Coral Hard Bottom (FFWC)

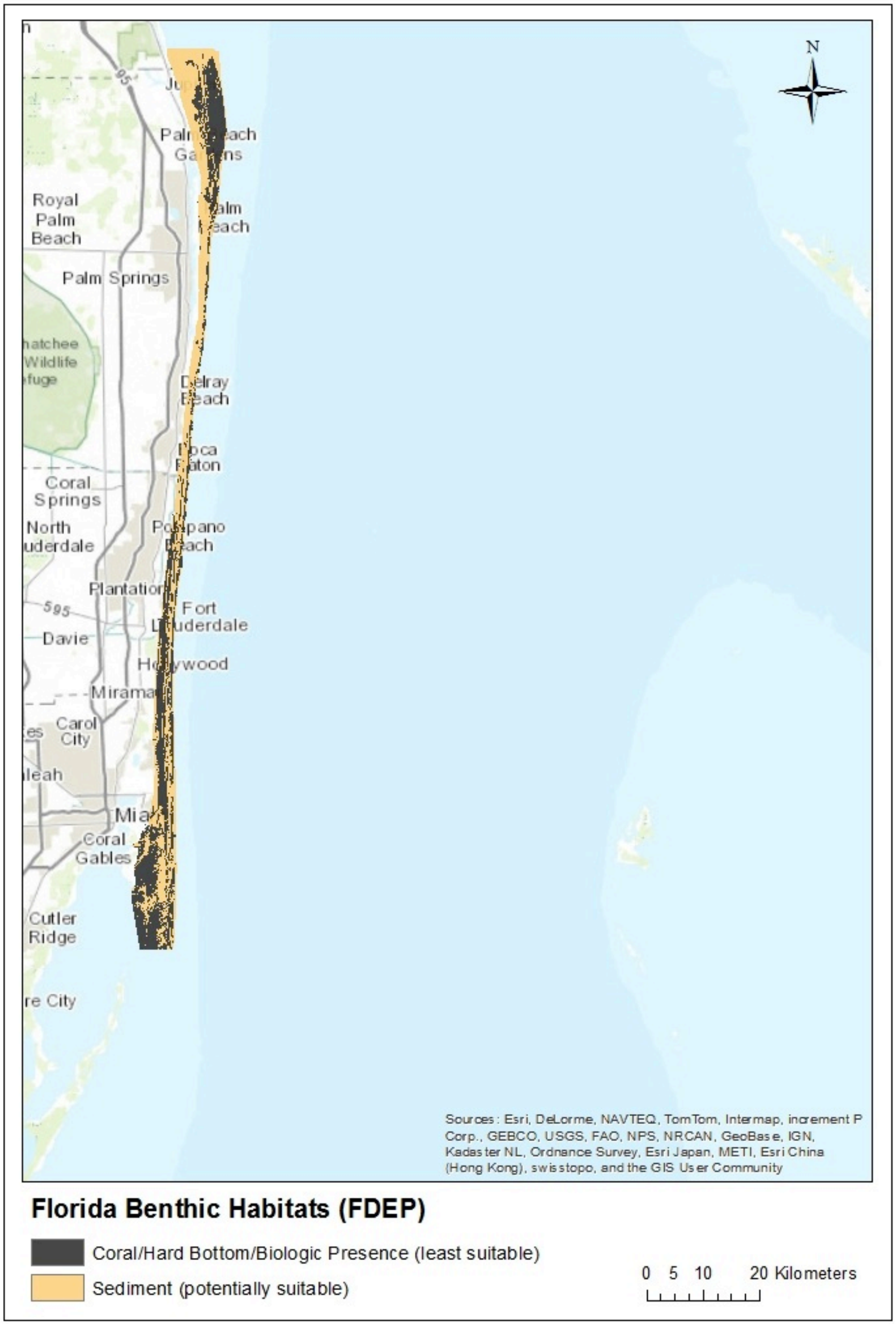
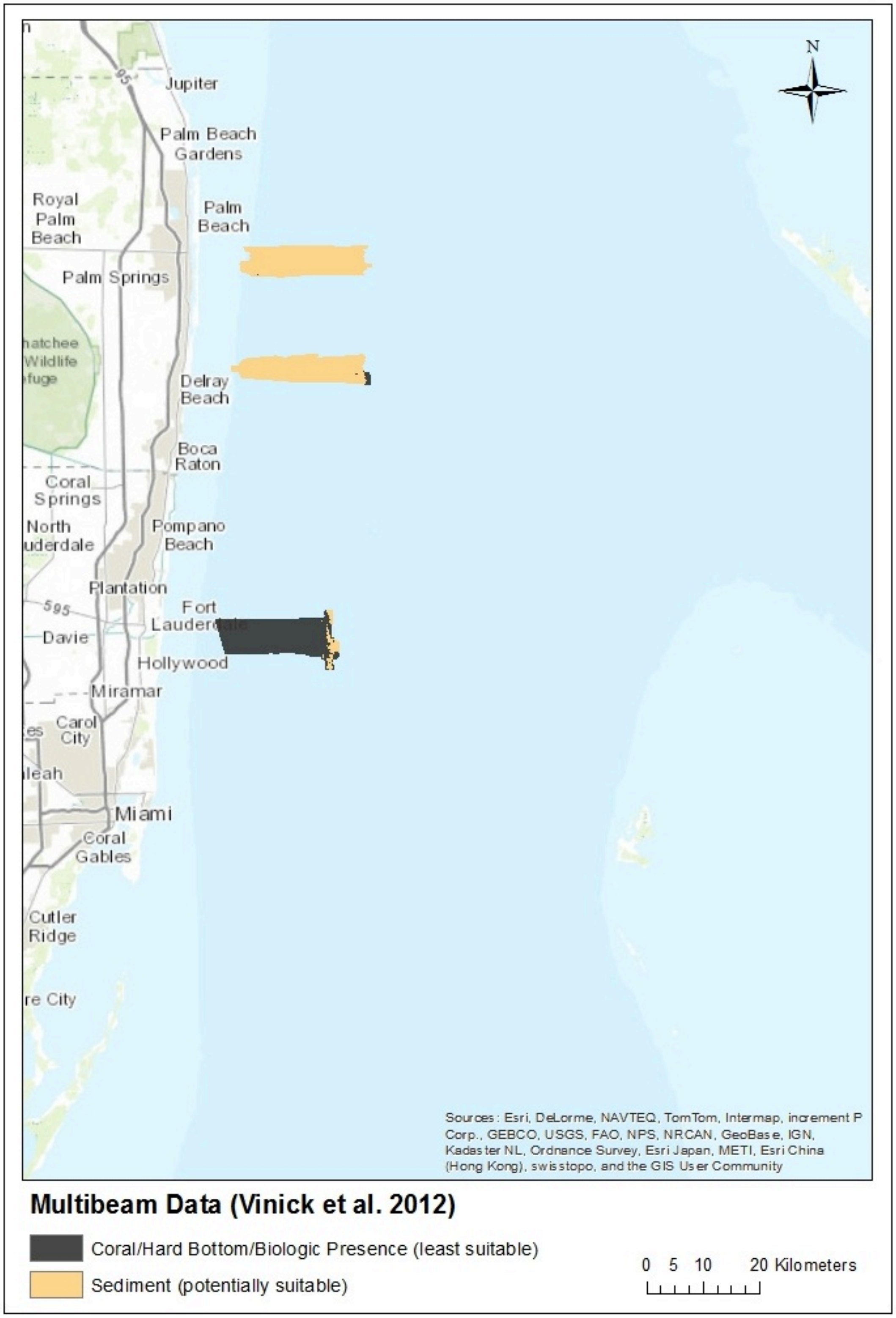


Figure 8. Southeast Florida Benthic Habitats (FDEP)



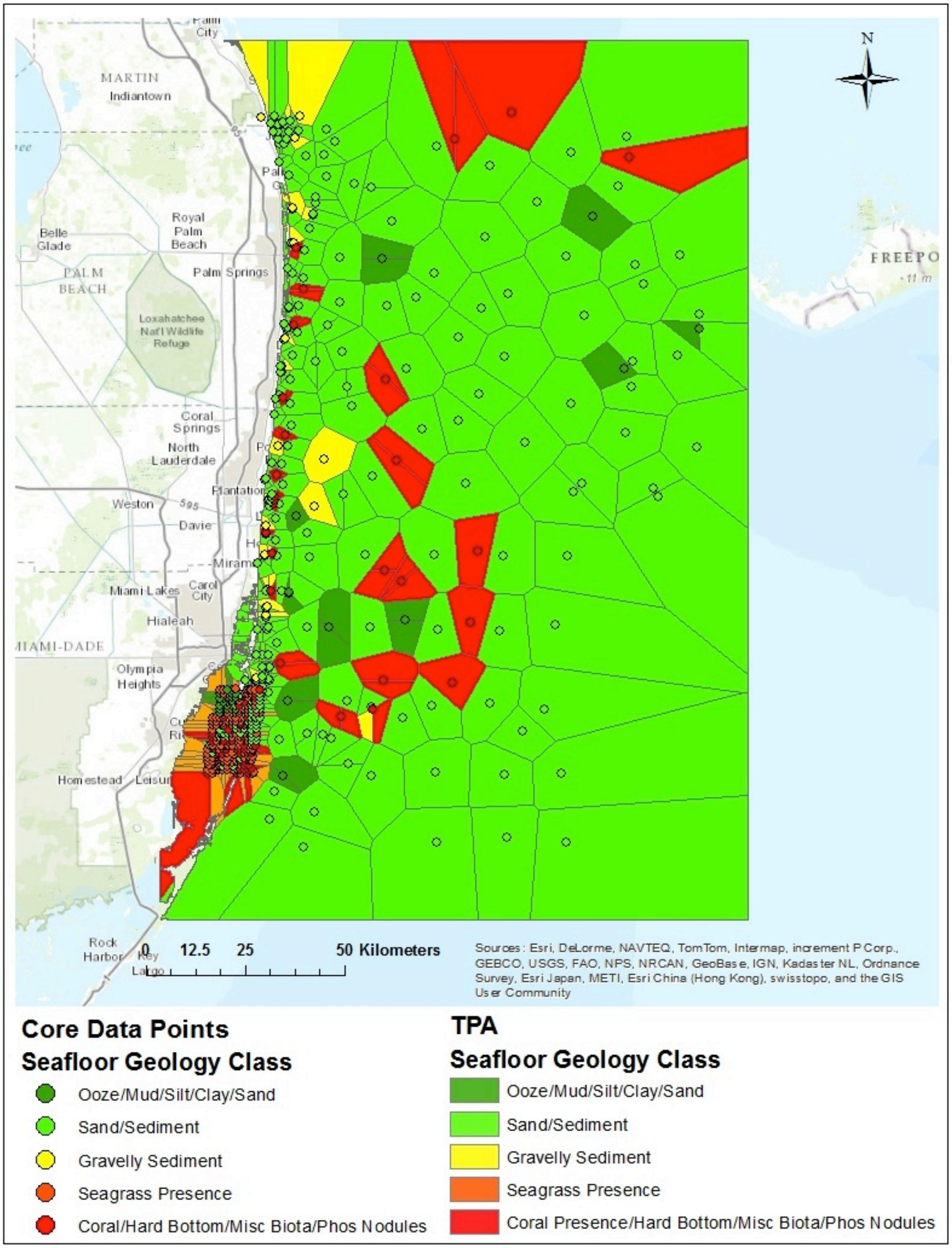
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Multibeam Data (Vinick et al. 2012)

Figure 9. Multibeam Data (Vinick et al., 2012 – DOE)

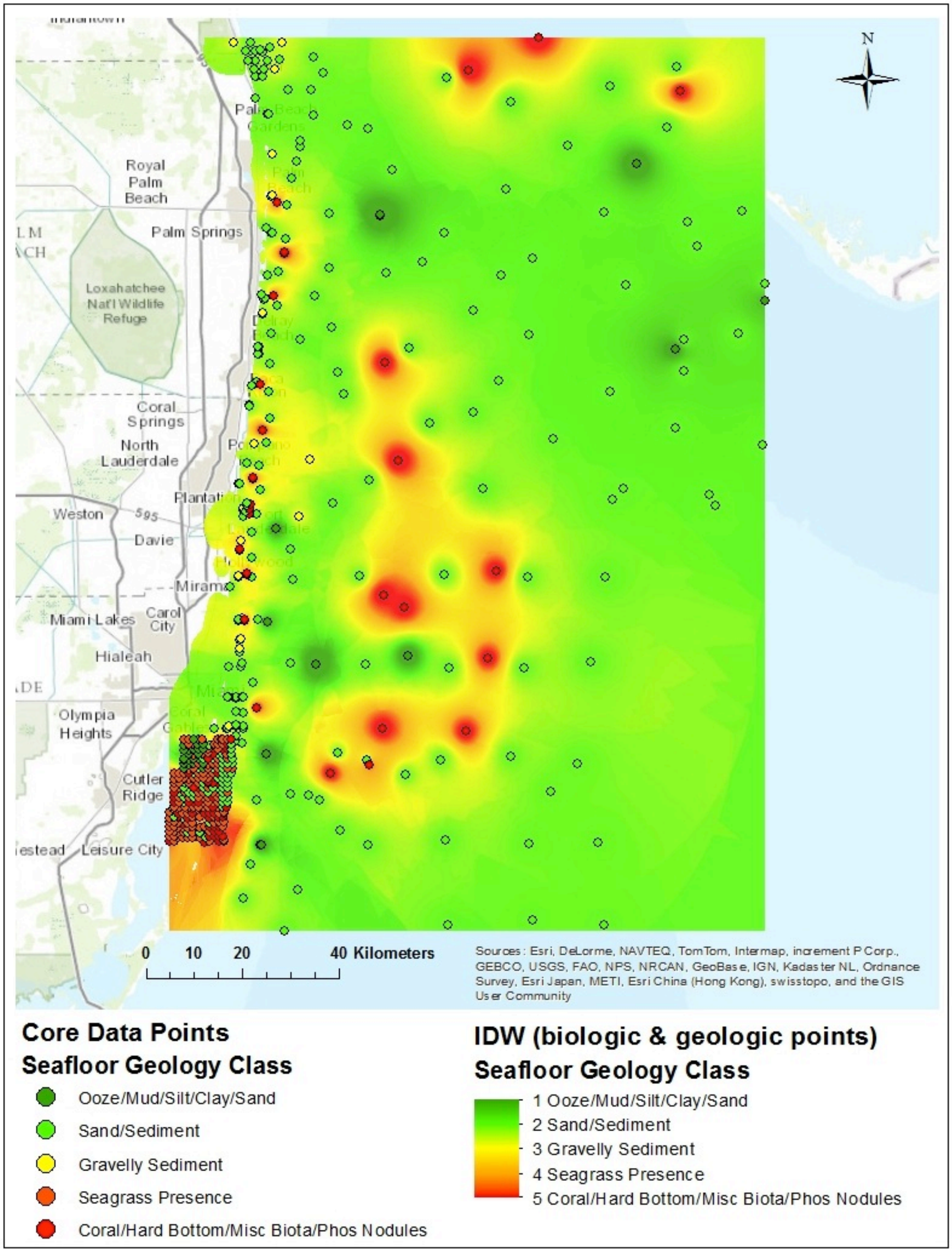
5.2 Seafloor Geology Analysis

Figures 10-14 illustrate the TPA, IDW and EBK interpolation results. In the color scheme used for Figures 10-14 green expresses “Sand/Sediment”, the most favorable OCE substrate type, while red and orange represent unfavorable OCE substrate types (“Coral/Hard Bottom/Miscellaneous Biota/Phosphorous Nodules” and “Seagrass Presence”). As the color scale transitions away from green (green-yellow-orange-red) the substrate becomes less desirable. The TPA surface (Figure 10) honors the known (original) core data points and yields a checkerboard pattern of seafloor substrate distribution. In reality transitions between substrate types are not as rigidly defined, meaning that the TPA is missing intermediary substrate types between the discrete core data points. The IDW seafloor substrate surface (Figure 11) is also deterministic and matches the known data points like the TPA, however it produces larger spherical boundaries between substrate types rather than sharp polygons. The IDW includes a moderate amount of smoothing between substrate types (circular, bull’s-eye color patterns) denoting substrate transitions. The IDW represents a step between the TPA and EBK analyses, and offers another visualization of the processed seafloor data. The seafloor substrate surface created by the EBK (Figure 12) is probabilistic (creating a probability surface of the interpolated features from the known data points) and only accounts for the known geologic data points in the core dataset. It generally maintains the integrity of the original data points and illustrates predicted substrate transition regions between discrete data. The EBK mirrors the pattern seen in the TPA and IDW, however it blends the areas between red and yellow (going from red to orange to mustard yellow to bright yellow) more robustly than the TPA or IDW indicating a gradual change in geologic bottom type. Figure 13 displays the IDW-EBK hybrid interpolation. Removing the biologic points from the EBK prevented the interpolation from being skewed by biologic data points adjacent to geologic data points and by the southwest cluster of biologic data points. The IDW buffers honor the original biologic data points and represent their mean expected extent, while the EBK honors the known geologic points and predicts transitions between them. This approach resulted in few instances where the core data point disagrees with the IDW-EBK surface pixel value ("stretched" points). While both the TPA and EBK results stay true to the original core data, the gradient between substrate types (unsampled areas) differ due to the difference in deterministic and probabilistic methods. Figure 14 contains the same information as Figure 13, and includes the coral patches (red bull's-eye areas) predicted in the IDW. Based on previous coral mapping studies in the study area and the benthic data set coverage, it is likely that Figure 14 is a more accurate reflection of coral reef expanse in the study area. However, with no concrete coral reef delineations documented it is difficult to form a solid conclusion regarding this. Altogether, the TPA, IDW, EBK and IDW-EBK results contribute to a more diversified and comprehensive understanding of seafloor substrate in the study area.



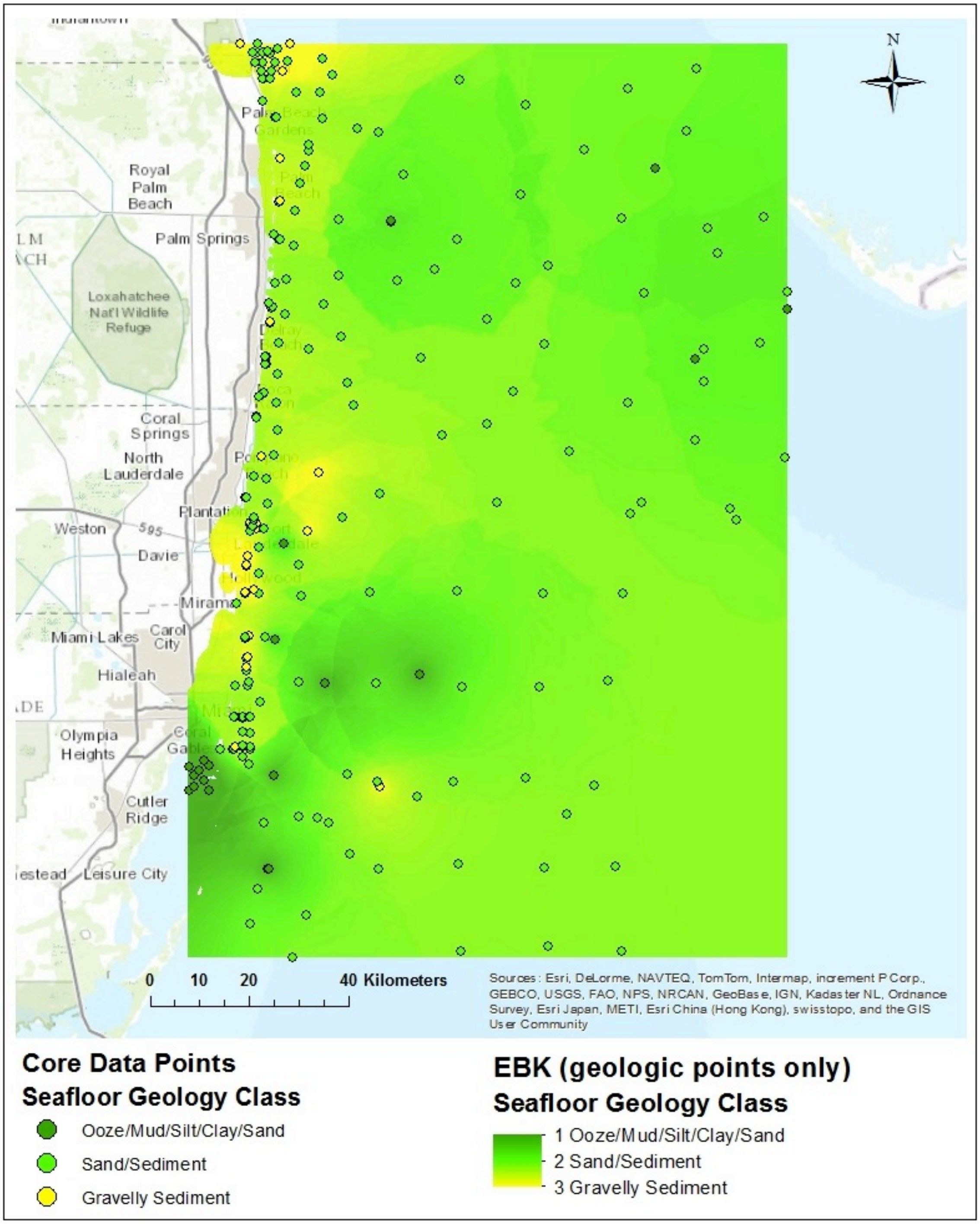
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure 10. Thiessen polygon analysis results



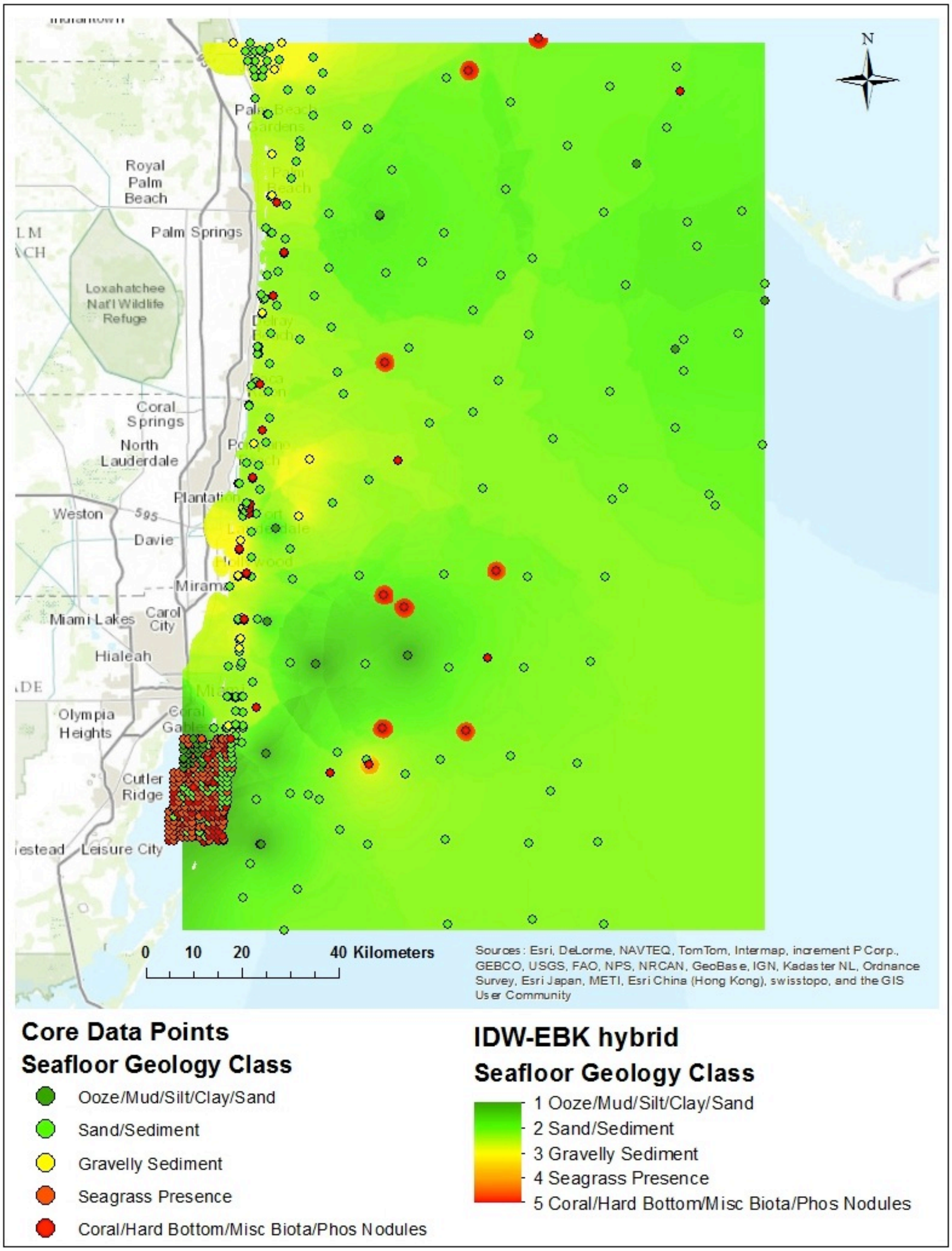
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure 11. IDW interpolation (all geologic and biologic data points) results



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

Figure 12. EBK interpolation (geologic data points only) results



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

Figure 13. IDW-EBK hybrid interpolation results

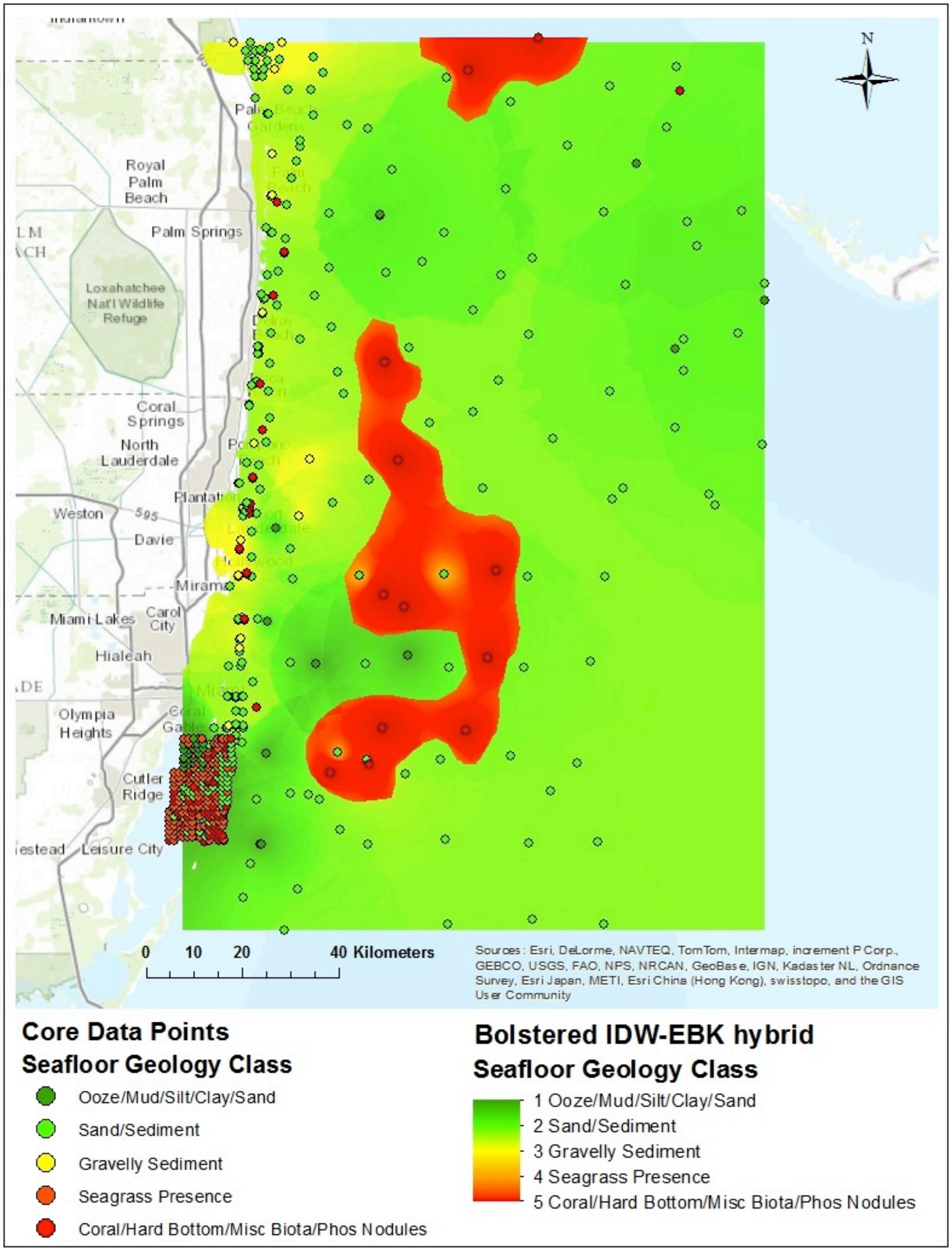
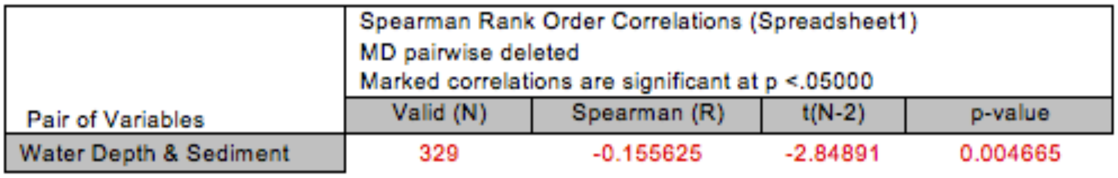


Figure 14. Bolstered IDW-EBK hybrid interpolation using IDW red bull's-eye buffers

5.2a Bathymetry

The Spearman rank coefficient test results imply that the direction of association between sediment categories (generally defined by grain size) and water depth is negative. According to Table 5 the null hypothesis cannot be rejected at the 0.001, and the p-value of 0.004665 provides evidence that a statistical association between water depth and sediment categories do exist. The Kendall tau test returned a test statistic of -3.24 with a p-value of 0.001196 (Table 6) which indicates that the null hypothesis cannot be rejected at the $\alpha = 0.001$ significance level. This means that at the current level a statistically significant correlation between sediment categories (and/or grain size) and water depth is present, albeit weak. Because the test statistic is negative, it can be inferred that there is evidence of a relationship between water depth and grain size in which grain size decreases as water depth increases. This finding is consistent with the literature on sediment distribution patterns in the ocean (Karl, 2006; "Oceanography: 7 The type of sediment on the ocean floor varies," 2008). The Kendall Tau test is not statistically significant at the 0.05 and 0.01 significance levels.

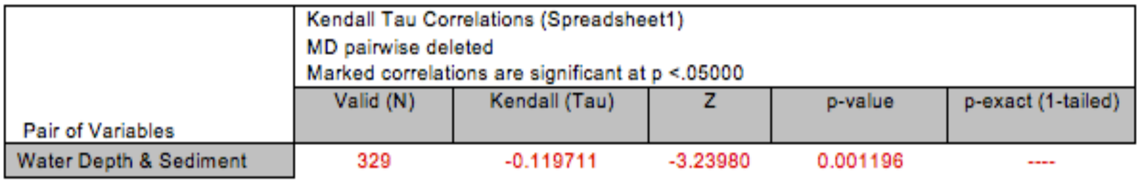
Table 5. Spearman rank coefficient results



Spearman Rank Order Correlations (Spreadsheet1)
MD pairwise deleted
Marked correlations are significant at p <.05000

Pair of Variables	Valid (N)	Spearman (R)	t(N-2)	p-value
Water Depth & Sediment	329	-0.155625	-2.84891	0.004665

Table 6. Kendall Tau rank correlation coefficient results



Kendall Tau Correlations (Spreadsheet1)
MD pairwise deleted
Marked correlations are significant at p <.05000

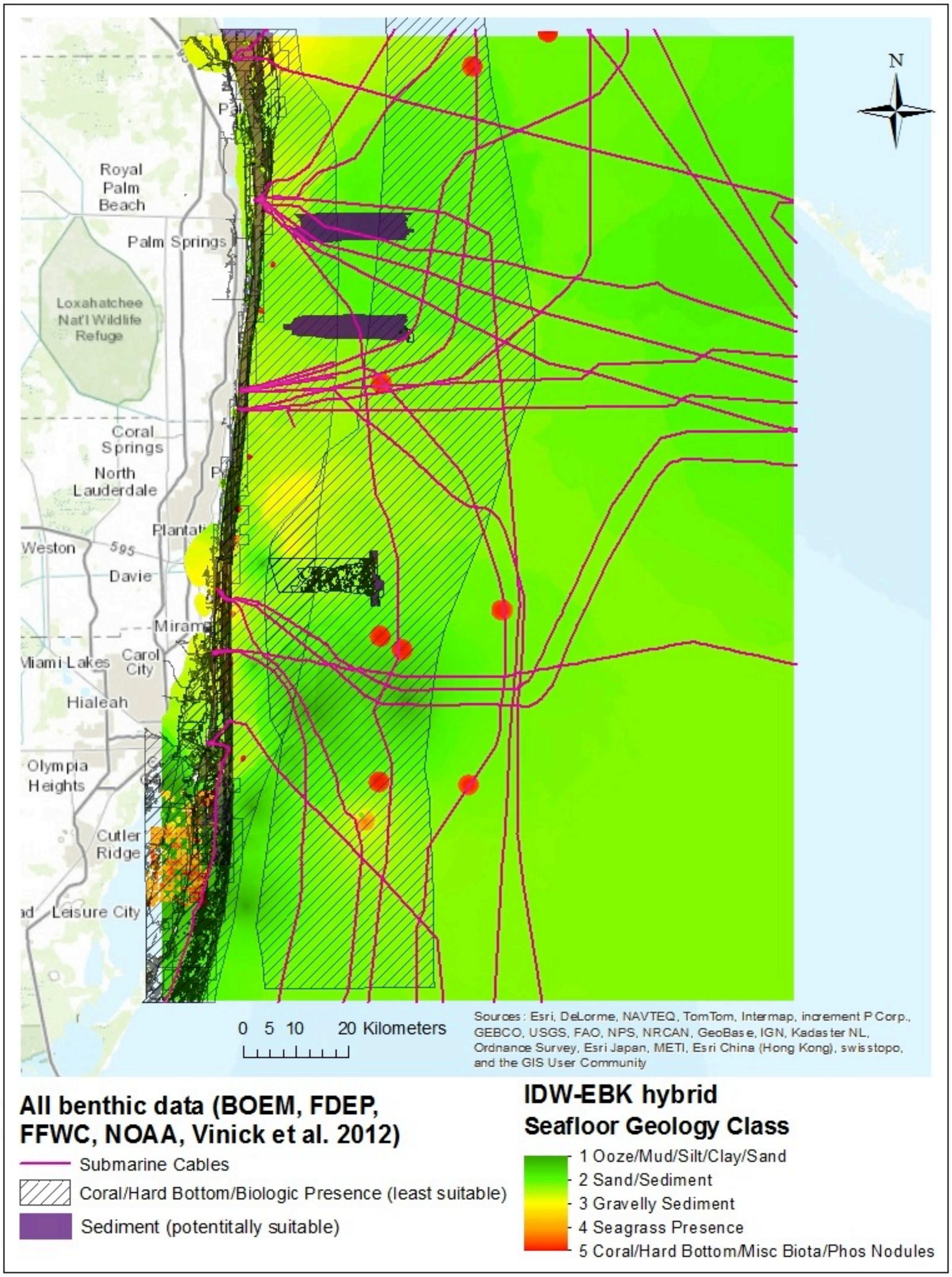
Pair of Variables	Valid (N)	Kendall (Tau)	Z	p-value	p-exact (1-tailed)
Water Depth & Sediment	329	-0.119711	-3.23980	0.001196	----

5.3 Suitability Analysis

Figure 15 displays all the processed benthic datasets and existing submarine cables overlaid atop the IDW-EBK hybrid seafloor substrate surface. The IDW-EBK indicates that the eastern half of the study area potentially contains the highest abundance of sand or sediment favorable to OCE anchoring. Conversely, the IDW-EBK demonstrates that the near shore, especially lower left (southwest) corner, portions of the study area holds numerous biologic data points rendering these locations undesirable for OCE development. The benthic datasets do not perfectly match the underlying seafloor geology substrate predicted by IDW-EBK, however there is a relatively decent correlation between the interpolations and the benthic overlays. For instance, where the multibeam data (Figure 9 and three rectangular areas further offshore in Figure 15) shows sediment, the IDW-EBK is sand/sediment/mud etc. and where the multibeam data portrays coral/hard bottom the IDW-EBK is miscellaneous biota/coral/hard bottom etc. The minor discrepancies between the EBK surfaces and the benthic datasets are likely due to the probabilistic nature of the EBK tool. On a whole, these benthic results complement the findings in the Vinick et al. (2012).

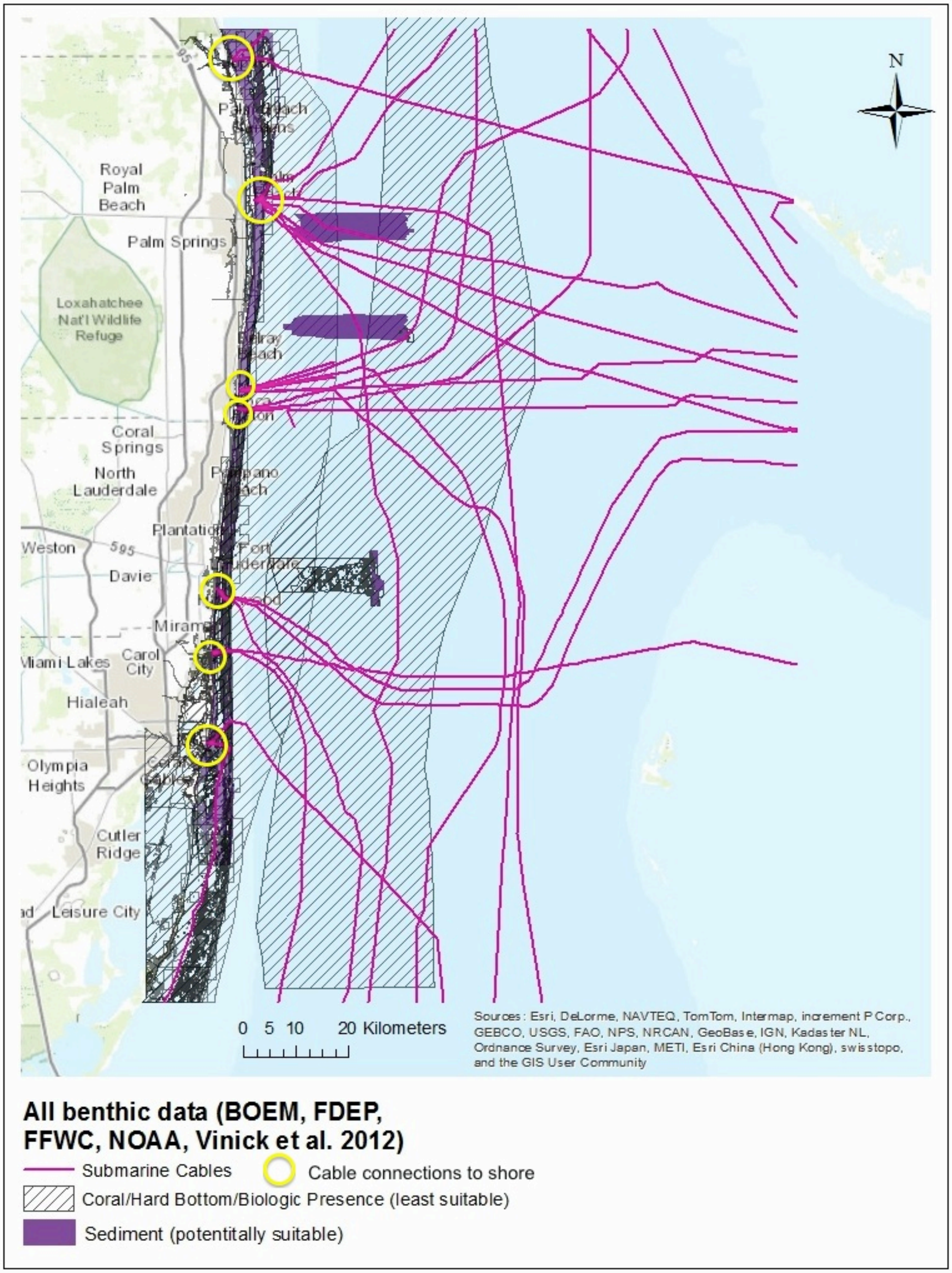
Figures 15-16 illuminate existing submarine cable locations with respect to the processed benthic and seafloor geology data. There are roughly seven main existing cable connections to Florida’s coast (Figure 16). In Figure 16 the following cable connections to shore are shown: one north of Palm Beach Gardens, one in Palm Beach (many submarine cables appear to funnel through one existing path), two near Boca Raton (also areas where multiple cables intersect to fit through singular path), one north of Hollywood Beach (coincides with the Hollywood-Fort Lauderdale data gap in the

Critical Habitat Designations dataset - Figure 5), one around North Miami, and one in Miami. This signifies that there currently are reef gaps available for OCE cabling, that have gone undetected by the benthic data analysis in this thesis due to low spatial resolution of the benthic data. Collectively, the benthic data and seafloor substrate surfaces (TPA, IDW, EBK, and IDW-EBK) highlight the eastern half of the study area as containing the largest abundance of potentially suitable sand and sediment substrates for siting OCE while the submarine cable dataset illuminates eight existing potential OCE cable corridors located within the vicinity of these potentially suitable areas.



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

Figure 15. All processed benthic datasets and existing submarine cables routes overlaid atop IDW-EBK surface



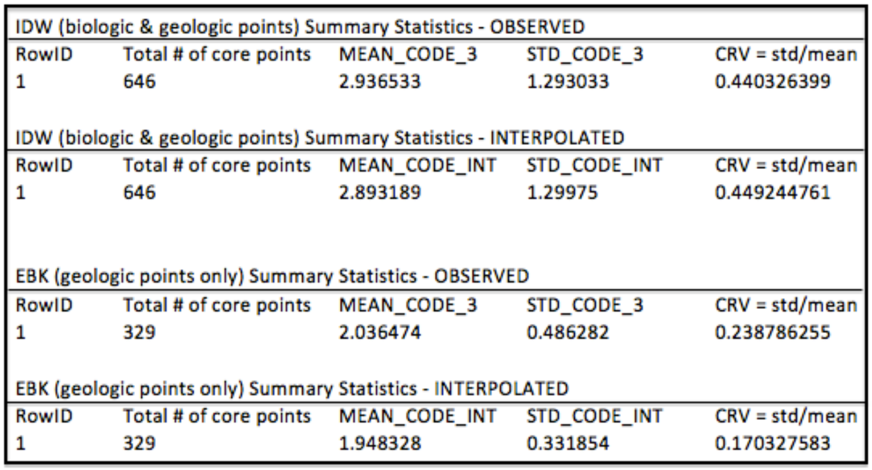
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure 16. Submarine cable routes with respect to benthic data only

5.3a Error Analysis

The tables containing EBK pixel values versus discrete core data point values show minimal variation between the 30 meter, 200 meter, and 500 meter EBK interpolations which suggests that cell size does not affect the EBK interpolation accuracy. Overall, it appears that the EBK interpolations are not sensitive to changes in raster cell size. Therefore, we can conclude that scale effect component of MAUP does not influence the results of the interpolation. The RMSE value calculated by the Geostatistical Wizard feature in ArcGIS was 0.339907. Tables 5 shows CRV values of approximately 0.44 for the IDW component, and values of roughly 0.24 and 0.17 for the EBK component of the hybrid surface. Finally, the MAPE calculation (Table 6) revealed a mean average percentage error of roughly 4% for the IDW-EBK hybrid surface.

Table 7. CRV calculations for IDW and EBK components of IDW-EBK hybrid



IDW (biologic & geologic points) Summary Statistics - OBSERVED

RowID	Total # of core points	MEAN_CODE_3	STD_CODE_3	CRV = std/mean
1	646	2.936533	1.293033	0.440326399

IDW (biologic & geologic points) Summary Statistics - INTERPOLATED

RowID	Total # of core points	MEAN_CODE_INT	STD_CODE_INT	CRV = std/mean
1	646	2.893189	1.29975	0.449244761

EBK (geologic points only) Summary Statistics - OBSERVED

RowID	Total # of core points	MEAN_CODE_3	STD_CODE_3	CRV = std/mean
1	329	2.036474	0.486282	0.238786255

EBK (geologic points only) Summary Statistics - INTERPOLATED

RowID	Total # of core points	MEAN_CODE_INT	STD_CODE_INT	CRV = std/mean
1	329	1.948328	0.331854	0.170327583

Table 8. MAPE calculation for IDW-EBK hybrid surface

OBJECTID_1	Water depth (m)	Interpolated (stretched) pixel value	Observed value	Interpolated description	Observed description	MAPE Calculation
233	2	2.36	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.213333333
232	68	2.46	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.18
227	0	2.36	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.213333333
231	61	2.34	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.22
229	64	2.29	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.236666667
224	65	2.47	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.176666667
223	0	2.24	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.253333333
220	128	2.4	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.2
221	22	2.4	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.2
215	128	2.32	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.226666667
192	41	2.2	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.266666667
193	41	2.2	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.266666667
194	41	2.2	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.266666667
160	28	2.13	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.29
150	34	2.16	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.28
151	34	2.16	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.28
146	8	2.15	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.283333333
140	36	2.14	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.286666667
141	36	2.14	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.286666667
99	230	2.41	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.196666667
18	683	2.19	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.27
127	92	2.2	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.266666667
111	52	2.16	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.28
87	29	2.4	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.2
88	29	2.4	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.2
74	72	2.44	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.186666667
77	72	2.44	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.186666667
78	72	2.44	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.186666667
69	46	2.45	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.183333333
66	34	2.38	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.206666667
46	41	2.13	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.29
36	58	2.18	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.273333333
37	58	2.18	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.273333333
33	18	2.22	3	Sand/Sediment - 2	Gravelly Sediment - 3	0.26
283	673	1.89	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.89
281	382	1.73	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.73
631	382	1.73	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.73
632	382	1.73	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.73
274	697	1.84	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.84
272	526	1.84	1	Sand/Sediment - 2	Ooze/Mud/Silt/Clay/Sand - 1	0.84
					Sum of errors	12.84666667
					MAPE	0.039047619

6. CONCLUSIONS

6.1 Seafloor geology data - core interpolations and need for additional datasets

The majority of the 646 core data points analyzed in the TPA and EBK interpolations are located near shore and become sparse further away from Florida's coast. In this analysis, the seafloor core data points were categorical (i.e. the text field describing varying seafloor bottom types for each of the 646 data points was coded to into a numerical scheme used for interpolation), rather than numerical. Categorical data is not continuous data like elevation, temperature, etc., therefore arranging the coded category order for interpolation had to be carefully done using logical and literature backed principles. In this case, Karl (2006), Verfaillie et al. (2006) and Goff et al. (2008) were used to determine geologic category placement prior to interpolation based on their research involving sediment grain size transitions and overall sediment distribution on the seafloor. The codification of strictly geologic categorical data points resulted in fairly accurate (see Section 6.1c below) IDW and EBK interpolations (Figures 11-12), however the biologic data classes (seagrass presence and coral/hard bottom/miscellaneous biota/phosphorous nodules) proved problematic. Because there is no solid literature to support a generic transition relationship between biologic and geologic categories, it is unlikely that a logical transition exists. This lack of a clear connection between geologic and biologic data points compromised the accuracy of the

EBK interpolation. For example, the EBK would predict a pixel value of 4 (seagrass presence) for areas in between a coral data point (category 5) and a sand data point (category 3), even though there is no scientific basis or known data points to support a predicted pixel value of 4. In this way, the EBK had a tendency to generate “stretched” or “false” substrate categories in places where geologic and biologic points exist close to one another. Ultimately, this led to the necessary removal of biologic data points from the EBK interpolation and development of the IDW-EBK hybrid approach that is able to identify trends in the study area and highlight sites of potential investigation for more detailed surveying.

Generally, more seabed core sample points (both geologic and biologic in nature) throughout the study area (especially in deeper water areas where the Florida Current passes) will refine the detail and improve the accuracy of the TPA, IDW and EBK seafloor geology surfaces by providing additional concrete data points to ground the interpolations. A more sophisticated method of translating categorical data into numerical data for interpolation would helpful in capturing the wealth of categorical information contained in core data points. Categorical data interpolation approaches (both deterministic and probabilistic) must be further developed in order to reduce the “stretched” substrate errors. This may entail further hybridization between deterministic and probabilistic components like the IDW-EBK method used here.

If mean grain size information could be acquired for each of the geologic core data points, they could be interpolated using this attribute field via more established numerical interpolation techniques (co-kriging, kriging with an external drift, etc.). This tactic would use the correlation between grain size and substrate type (i.e. large grain size correlates to gravel, fine grain size reflects silts, clays) to determine seafloor sediment configuration. In this scenario, the biologic data would have be analyzed (using deterministic method like TPA or IDW) separately from geologic data and then later combined (by either overlay or mosaic) to view overall benthic conditions in the study area. Lastly, higher resolution geophysical surveys (Section 3.6) as well as ground truthing are key to better understand seafloor properties (morphology, sub-surface, etc.) as they pertain to OCE and would bolster the accuracy and usefulness of this thesis.

6.2 Benthic data and need for additional datasets

While the benthic data spatial coverage is less than the geologic data extent captured in the core data interpolation, the benthic data generally agrees with the seafloor geology surface, especially in the near shore areas where water depth is <200 meters (Figures 13 core data points versus Figure 15 BOEM, FDEP and FFWC datasets). Vinick et al. (2012) is the only known source to have produced high-resolution benthic datasets intended for OCE in this study area. More high-resolution data collection (i.e. side-scan sonar, LIDAR), especially in the “potentially suitable” areas, are required to increase the precision of locating sensitive biologic hotspots that should be avoided when siting OCE in the study area. At present, patches of hard bottom, coral, etc. may exist within the study area and go undetected due to insufficient sampling density within the spatial extent. As noted above, the differences between the multibeam data and the IDW-EBK surface may be an example of this.

This thesis is able to discuss the proximity of existing submarine cable lines to favorable OCE deployment areas, however it is unable to discern specific OCE cable routes (Figures 15-16). This is due to the fact that the acquired benthic datasets contain polygon features that do not display specific data point locations, rather they cover areas of varying sizes which prohibits the visualization of any soft bottom pathways in between reef system or hard bottom areas. In the context of this thesis, more point feature benthic datasets (ex. core data points with biologic descriptions) and near shore high-resolution benthic datasets (i.e. designated reef gaps cited in Vinick et al. (2012)) are necessary in order to isolate possible near shore OCE cables routes and the proximity of suitable OCE development areas to said cables routes. And finally, ground truthing prior to any OCE cabling would be essential for ensuring no benthic habitats are disturbed in the OCE process.

6.3 Error Analysis

The low RMSE score (approx. 0.34) suggests that the IDW-EBK surface is quite accurate (accuracy increases as RMSE decreases). The CRV values of 0.44, 0.23 and 0.17 indicate that the interpolated data is a good fit to the observed data (the lower the CRV value, the better fit of predicted data to observed data). The MAPE of 4% suggests that the IDW-EBK hybrid approach is 96% accurate at capturing the known core data points and interpolating their predicted locations throughout the study area.

6.4 Final Conclusions

The suitability analysis executed here pulls from a comprehensive database of all presently available biologic and geologic datasets from BOEM, FDEP, FFWC, NOAA, USGS and Vinick et al. (2012), and considers this data within the legal framework of OCE laws, policy and regulations (Section 2.4). OCE related literature sources were employed to assess levels of suitability for the legally constrained biologic and geologic datasets. Geostatistical techniques (i.e. interpolations) via ArcGIS then facilitated the visualization and interpretation of study area datasets allowing them to be analyzed spatially as well as in terms of suitability. The interpolated seafloor substrate maps (based on the seafloor geology core data) generally revealed biologic substrate types closer to shore (<200 meters water depth) and sand/sediment substrates further offshore (>200 meters water depth), particularly throughout the eastern half portion of the study area. Analysis of the benthic data highlighted biologic hotspots (red circular areas in Figure 13) that must be avoided when siting OCE so as to minimize potential negative environmental impacts. Existing submarine cable routes identified multiple cable pathways already being used in Palm Beach, Broward, and Miami-Dade counties, which offer potential corridors for OCE power transmission cables to connect to land-based power grids. The finalized suitability map containing all datasets suggests the eastern study area as most suitable for OCE siting due to its abundance of potentially suitable sand and sediment substrates, access to existing underwater cable routes, and minimal biologic presence. While this suitability analysis is able to offer potential areas for OCE siting on a larger scale, higher resolution biologic and geologic datasets (i.e. side-scan sonar) are necessary to pinpoint specific OCE siting locales and comprehensively understand benthic conditions therein to reduce the likelihood of negative environmental impacts.

REFERENCES

(1998). *Esri shapefile technical description.* Retrieved from http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf

(2007). *How Inverse Distance Weighted (IDW) interpolation works.* Retrieved from http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How_Inverse_Distance_Weighted_(IDW)_interpolation_works

(2008). *Oceanography: 7 The type of sediment on the ocean floor varies.* Retrieved from http://www.hsc.csu.edu.au/earth_environmental/options/oceanography/3208/ocean_7htm

(2011). *How kriging works*. Retrieved from http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z00000076000000.htm

(2013). *Cross validation (Geostatistical Analyst).* Retrieved fromhttp://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00300000000z000000.

(2013). *Multibeam echosounders*. Retrieved from http://www.km.kongsberg.com/KS/WEB/NOKBG0240.nsf/AllWeb/620F423FA7B503A7C1256BCD0023C0E5?OpenDocument

(2013). *U.S. Atlantic continental margin GLORIA mapping program*. Retrieved from http://coastalmap.marine.usgs.gov/gloria/eastcst/index.html (n.d.) *Universal kriging.* Retrieved from http://spatialanalyst.net/ILWIS/htm/ilwisapp/universal_kriging_algorithm.htm

Bennett, M.M. & Glasser, N.F. (2009). *Glacial geology: Ice sheets and landforms*. Wiley.

Cato, I. & Kjellin, B. (2008). Maringeologiska underso˙kningar vidvågkraftsanla¨ggningutanfo¨r Islandsberg, Bohusla¨n. (Marine geological research of wave power facility outside of Islandsberg, Bohuslan). Sveriges geologiska underso¨kning, Uppsala. SGU-rapport 10.

Chok, N.S. (2010). *Pearson's versus Spearman's and Kendall's correlation coefficients for continuous data* (unpublished Master of Science thesis). University of Pittsburgh: Pittsburgh, Pennsylvania.

Cole, J. (2007). *Introduction to Marine Ecology* [PowerPoint Slides]. Retrieved from http://www.geo.arizona.edu/geo4xx/geos412/OcSci07.EcolIntro.pdf

Croom, M. M. (2011, June 23). Comment letter from NOAA NMFS southeast regional office [http://www.regulations.gov/#!docketBrowser;rpp=25;po=0;dct=PS;D=BOEM-2011-0012].

Curators of Marine and Lacustrine Geological Samples Consortium. (2013). *The Index to Marine and Lacustrine Geological Samples (IMLGS)*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. doi:10.7289/V5H41PB8

Dettlaff, C. (2009). *Root mean square error* [PowerPoint Slides]. Retrieved from http://web.pdx.edu/~jduh/courses/geog475f09/Students/W7_RMSE.pdf

DiGiovanni, F. C. (2011, June 23). Department of defense comments BOEM 2011 [http://www.regulations.gov/#!docketBrowser;rpp=25;po=0;dct=PS;D=BOEM-2011-0012].

Dubbs, L., Keeler, A., & O'Meara, T. (2013). Permitting, risk and marine hydro-kinetic energy development. *The ELectricity Journal, 26*(10), 64-74.

Ervin, D. (2014). *MAUP An Introduction to the Modifiable Areal Unit Problem*. Retrieved from http://gispopsci.org/maup/

Ewing, M., Carpenter, G., Windisch, C., & Ewing, J. (1973). Sediment distribution in the oceans: The Atlantic. *Geological Society of American Bulletin 84*(1), 71-88.

Fader, G. (2009). *Geology, bathymetry, ice and seismic conditions in environmental assessment of the Bay of Fundy tidal power project, ed. AECOM, 76*. Halifax, Nova Scotia: Minas Basin Pulp and Power Ltd.

Fader, G. (2011). *Environmental monitoring of seabed sediment stability, transport and benthic habitat at the reference site and the vicinity of the NSPI TISEC location in the Minas Passage ed. AECOM, 76*. Halifax, Nova Scotia: Minas Basin Pulp and Power Ltd. and Seaforth Geosurveys Inc.

FAMU and FAU Reports. (2012). *FESC research, education and outreach project progress reports (attachment to main report)*. Orlando, FL. Retrieved from: http://www.floridaenergy.ufl.edu/wp-content/uploads/FAMU-and-FAU-Project-Reports_Nov-2012.pdf

Florida Fish and Wildlife Commission & Florida Wildlife Research Institute. (2005). *Coral, Coral Reef and Live Hard Bottom EFH HAPCs*. Florida Fish and Wildlife Commission. Retrieved from http://ocean.floridamarine.org/efh_coral/metadata/Coral,%20Coral%20Reef%20and%20Live_Hard%20Bottom%20EFH-HAPC.htm

Florida Fish and Wildlife Commission & Florida Wildlife Research Institute. (2008). *Deepwater Coral HAPCs*. Florida Fish and Wildlife Commission. Retrieved from http://ocean.floridamarine.org/efh_coral/zip/Final_DC_HAPC.shp.xml

Florida Fish and Wildlife Commission & Florida Wildlife Research Institute. (2013). *Coral and Hard Bottom Habitats Florida*. Florida Fish and Wildlife Commission. Retrieved from http://atoll.floridamarine.org/Data/Metadata/SDE_Current/coral_hardbottom_poly.htm

Flowerdew, R. (2009). *Understanding the modifiable areal unit problem* [PowerPoint Slides]. Retrieved from http://www.geos.ed.ac.uk/research/eeo/seminars/RFlowerdew_Slides.pdf

Foley, N. K. (2009). *Environmental characteristics of clays and clay mineral deposits*. Retrieved from http://pubs.usgs.gov/info/clays/

Goff, J. A., Jenkins, C.J., Williams, S.J. (2008). Seabed mapping and characterization of sediment variability using the usSEABED data base. *Continental Shelf Research 28*, 614–633.

Hagemann, J. (1958). U.S. Patent No. 4197591 A *Facsimile recording of sonic values of the ocean bottom*. U.S. Patent and Trademark Office.

Hanson, H.P., Skemp S. H., Alsenas G.M., & Coley C.E. (2010). Power from the Florida Current: A new perspective on an old vision. *Bulletin of the American Meteorological Society, 91*, 861-867.

Hanson, H. P., Bozek, A., & Duerr, A. E. (2011). The Florida current: A clean but challenging energy resource. *EOS, Transactions, American Geophysical Union, 92*(4), 29-36. Retrieved from http://iiiprxy.library.miami.edu:9033/store/10.1029/2011EO040001/asset/eost17611.pdf?v=1&t=hjzzt4ja&s=4b8ef112c1481083a6ced09da8c2a201fcee5c41

Harrison, J. T. (2009). *The 40 MWe OTEC plant at Kahe Point, Oahu, Hawaii: A Case study of potential biological impacts*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Center. Retrieved fromhttp://www.pifsc.noaa.gov/tech/NOAA_Tech_Memo_068.pdf

Hengl, T. (2007). *A practical guide to geostatistical mapping of environmental variables*. European Commission. Joint Research Centre. Institute for Environment and Sustainability. Scientific and Technical Research Reports. Retrieved from http://publications.jrc.ec.europa.eu/repository/handle/111111111/8118

Henkel, S.K. (2011). *Baseline characterization and monitoring of the OSU mobile ocean test berth site.* Oregon Wave Energy Trust. Oregon State University. Hatfield Marine Science Center. Northwest National Marine Renewable Energy Center. Retrieved from http://ir.library.oregonstate.edu/xmlui/bitstream/handle1957/29314/OSU_MOTB-Benthic-Characterization Final-Report.pdf?sequence=1

ICF International. (2012). *Biological Assessment.* Portland, OR: Oregon State University. Northwest National Marine Renewable Energy Center.

Karl, H.A. (2006). *Sediment of the Sea Floor.* United States Geological Survey. Retrieved from http://pubs.usgs.gov/circ/c1198/chapters/090-100_ Sediment.pdf

Keenan, G., Sparling, C., Williams, H., & Fortune, F. (2011). *SeaGen environmental monitoring programme final report.* Edinburgh, United Kingdom: Royal Haskoning Enhancing Society. Retrieved from http://www.marine turbines.com/sites/default/files/SeaGen-Environmental-Monitoring-Programme-Final-Report.pdf

Knotters, M., Heuvelink, G.B.M.,Hoogland, T., & Walvoort, D.J.J. (2010). *A disposition of interpolation techniques*. Wageningen, Statutory Research Tasks Unit for Nature and the Environment, WOt-werkdocument 190. Retrieved from http://www.wageningenur.nl/upload_mm/e/c/f/43715ea1-e62a-441e-a7a1-df4e0443c05a_WOtwerkdocument%20190%20webversie.pdf

Krivoruchko, K. (2012). *Empirical bayesian kriging*. Retrieved from http://www.esri.com/news/arcuser/1012/empirical-byesian-kriging.html

Krivoruchko, K. & Butler, K. (2013). *Unequal probability-based spatial mapping*. Retrieved from http://www.esri.com/esri-news/arcuser/spring2013/~/media/ Files/Pdfs/news/arcuser/0313/unequal.pdf

Kukal, Z. (1971). *Geology of Recent Sediments*. London: Academic Press Inc.

Langhamer, O. (2010). Effects of wave energy converters on the surrounding soft bottom macrofauna (west coast of Sweden). *Marine Environmental Research, 69*(5), 374–381.

Langhamer, O., Wilhelmsson , D., & Engstrom, J. (2009). Artificial reef effect and fouling impacts on offshore wave power foundations and buoys – a pilot study. *Estuarine, Coastal and Shelf Science, 82*(3), 426-432.

Law, M. & Collins, A. (2013). *Getting to know ArcGIS for desktop*. Esri Press.

Leijon, M., Boström, C., Danielsson, O., Gustafsson, S., Haikonen, K., Langhamer, O., Strömstedt, E., Stålberg, M., Sundberg, J., Svensson, O., Tyrberg, S., & Waters, R. (2008). Wave Energy from the North Sea: Experiences from the Lysekil Research Site. *Surveys in Geophysics, 29*, 221-240.

Li, J. & Heap, A.D. (2008). *A review of spatial interpolation methods for environmental scientists.* Geoscience Australia, Record 2008/23. Retrieved from http://www.ga.gov.au/image_cache/GA12526.pdf

Li, J. (2013). *Predicting the spatial distribution of seabed gravel content using random forest, spatial interpolation methods and their hybrid methods*. Paper presented at 20th International Congress on Modelling and Simulation, Adelaide, Australia.

Muench, L. M. (2011, June 23). Comments on FL turbine to docket [http://www.regulations.gov/#!docketBrowser;rpp=25;po=0;dct=PS;D=BOEM-2011-0012].

Nelson, W.G. (2009). *Seagrasses and protective criteria: A review and assessment of research status.* U.S. Environmental Protection Agency, National Health and Environmental Effects Laboratory, Office of Research and Development. Retrieved from http://www.epa.gov/wed/pages/publications/authored/Seagrasses%20and%20Protective%20Criteria%20EPA600R-09050.pdf

NOAA Coastal Services Center. (2000). *Bathymetry Contours Southeast United States*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Coastal Services Center: Charleston, SC. Retrieved from http://atoll.floridamarine.org/Data/Metadata/SDE_Current/bathy_southeast_us_arc.htm

NOAA Coastal Services Center. (2011). *Submarine Cables*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Coastal Services Center: Charleston, SC. Retrieved from http://www.northeastoceandata.org/files/metadata/OceanUses/SubmarineCables.htm

NOAA Coastal Services Center. (2012). *Critical Habitat Designations for the coastal US and US waters as of October 2012*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Coastal Services Center: Charleston, SC. Retrieved from ftp://ftp.csc.noaa.gov/pub/metadata/anne/MayUpdate_save/Physical/CriticalHabitatDesignations.xml

Normark, W. R., Chase, T. E., Wilde, P., Hampton, M. A., Gutmacher, C. E., Seekins, B.A., & Johnson, K. H. (1982). *U.S. Geological Survey geologic report for the OTEC site off Kahe Point, Oahu, Hawaii*. U.S. Department of the Interior. U.S. Geological Survey. Retrieved from http://pubs.usgs.gov/of/1982/0468a/report.pdf

Nybakken, J. W. (2001). *Marine biology: An ecological approach*. San Francisco, CA: Benjamin Cummings

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourquerean, J.W., Heck, K.L., Hughes, R.A., Kendrick, G.A., Kenworthy, J.W., Olyarnik, S., Short, F.T., Waycott, M., & Williams, S.L. (2006). A global crisis for seagrass ecosystems. *BioScience, 56*(12), 987-996.

Peterson, C. H. et al. (2000). Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat. *Bulletin of Marine Science 66*(3):759-774.

Poppe, L. J., Williams, S.J., & Paskevich, V.F. (2005a). *CONMAPSG: Continental Margin Mapping (CONMAP) sediments grainsize distribution for the United States East Coast Continental Margin*. U.S. Geological Survey, Coastal and Marine Geology Program, Woods Hole Science Center, Woods Hole, MA.

Poppe, L. J., Williams, S.J., & Paskevich, V.F. (2005b). *USGS East-Coast Sediment Analysis: Procedures, Database, and GIS Data*. (Open-File Report 2005-1001) U.S. Geological Survey, Coastal and Marine Geology Program, Woods Hole Science Center, Woods Hole, MA.

Portman, M. E. (2010). Marine renewable energy policy some U.S. and international perspectives compared. *Oceanography, 23*(2), 98-105. Retrieved from http://www.tos.org/oceanography/archive/23-2_portman.pdf

Reed, J.K., Weaver, D., Pomponi S.A. (2006). Habitat and fauna of deep-water Lophelia pertusa coral reefs off the southeastern USA: Blake Plateau, straits of Florida, and gulf of Mexico. *Bulletin of Marine Science 78*(2): 343-375.

Reed, J.K., Messing, C.,Walker, B. K., Brooke, S., Correa, T., Brouwer, M., & Udouj, T. (2012). Habitat characterization, distribution, and areal extent of deep-sea coral ecosystem habitat off Florida, southeastern United States. *Journal of Caribbean Science.*

Reid, J.M., Reid, J.A., Jenkins, C.J., Hastings, M.E., Williams, S.J., and Poppe, L.J, (2005). *usSEABED: Atlantic coast offshore surficial sediment data release.* (Data Series 118, version 1.0) U.S. Geological Survey, Woods Hole Science Center, Woods Hole, MA. Retrieved from http://pubs.usgs.gov/ds/2005/118/

Salcido, R. (2011). Siting offshore hydrokinetic energy projects: A comparative look at wave energy regulation in the Pacific Northwest. *Golden Gate University Environmental Law Journal, 5*(1), 109-158. Retrieved from http://digitalcommons.law.ggu.edu/cgi/viewcontent.cgi?article=1071&context=gguelj

Skemp S.H. (2012). Florida Atlantic University Southeast National Marine Renewable Energy Center Lecture Series: Marine Renewable Energy. Florida Atlantic University (Davie, FL; Boca Raton, FL; Jupiter, FL; and Ft. Pierce, FL)

SNMREC. (2012). *Project application to the U.S. Department of Interior Bureau of Ocean Energy Management, Regulation and Enforcement for an Outer Continental Shelf renewable energy program Interim Policy Lease*. Retrieved from http://snmrec.fau.edu/sites/default/files/BOEMREintegratedApp_Feb_2012.pdf

Sound and Sea Technology. (2009). *Advanced anchoring and mooring study*. Oregon Wave Energy Trust. Oregon State University. Hatfield Marine Science Center. Northwest National Marine Renewable Energy Center. Retrieved from http://oregonwave.org/oceanic/wp-content/uploads/2013/09/Advanced-Anchoring-and-Mooring-Study-November-2009.pdf

Stewart, P. L. (2010). *Suspended Sediment Monitoring. In Environmental Assessment of the Bay of Fundy Tidal Power Project, ed. AECOM, 76*. Halifax, Nova Scotia: Envirosphere Consultants Limited Windsor.

Street, M.W., A.S. Deaton, W.S. Chappell, & P.D. Mooreside. (2005). *North Carolina Coastal Habitat Protection Plan*. North Carolina Department of Environment and Natural Resources. Division of Marine Fisheries.

Sumner-Fromeyer, J. (1999). *Corals and Coral Reefs*. Retrieved from http://www.msstarship.com/sciencenew/corals.htm

Taylor, R.J. (1982). *Interaction of anchors with soil and anchor design.* U.S. Department of Defense. Department of the Navy. Naval Facilities Engineering Command. Naval Civil Engineering Laboratory. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a116597.pdf

Tchoukanski, I. (2013). Build Thiessen Polygons. *ET Spatial Techniques*. Retrieved from http://www.ian-ko.com/ET_GeoWizards/UserGuide/thiessenPolygons.htm

Tucker, D. L. (2011, June 17). Florida comments NOI EA 6-17-11 [http://www.regulations.gov/#!docketBrowser;rpp=25;po=0;dct=PS;D=BOEM-2011-0012].

U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Weather Service, National Buoy Data Center. (2012). *Moored Buoy Program*. Retrieved from http://www.ndbc.noaa.gov/mooredbuoy.shtml.

U.S. Department of Energy. (2012). *Oregon State University and Northwest National Marine Renewable Energy Center Wave Energy Test Project Final Environmental Assessment* DOE/EA-1917.

U.S. Department of the Interior. Bureau of Ocean Energy Management. Office of Renewable Energy Programs. (2013a). *Guidelines for providing benthic habitat survey information for renewable energy development on the Atlantic outer continental shelf pursuant to 30 CFR part 585*. Retrieved from http://www.boem.gov/uploadedFiles/BOEM/Renewable_Energy_Program/Regulatory_Information/Habitat Guidelines.pdf

U.S. Department of the Interior. Bureau of Ocean Energy Management. Office of Renewable Energy Programs. (2013b). *Lease issuance for marine hydrokinetic technology testing on the outer continental shelf offshore Florida revised environmental assessment.* Retrieved from http://www.boem.gov/Florida-Revised-EA-FONSI-August2013/

U.S. Department of the Interior. Bureau of Ocean Energy Management. (2012). *Notice of the availability of an environmental assessment outer continental shelf (OCS) renewable energy program leasing for marine hydrokinetic technology testing offshore Florida* (BOEM-2012-0011). Retrieved from http://www.gpo.gov/fdsys/pkg/FR-2012-04-25/pdf/2012-9983.pdf#page=1

U.S. Department of the Interior. Bureau of Ocean Energy Management (2011). *Notice of intent to prepare an environmental assessment for outer continental shelf (OCS) renewable energy program interim policy leasing for marine hydrokinetic technology testing offshore Florida* (BOEM-2011-0012). Retrieved from http://www.regulations.gov/

U.S. Department of the Interior. Minerals Management Service. (2009). *Final environmental impact statement for the proposed cape wind energy project, Nantucket Sound, Massachusetts* (adopted), DOE/EIS-0470. OCS Publication No.: 2008-040. 801 pp. Retrieved from http://www.boem.gov/Renewable-Energy-Program/Studies/Cape-Wind.aspx

Valent, P.J., Taylor, J.M., Beard, R.M. (1976). *OTEC single anchor holding capacities in typical deep sea sediments.* U.S. Energy Research and Development Administration. Division of Solar Energy. Retrieved from https://archive.org/stream/otecsingleanchor00vale#page/n0/mode/2up

Van Cleve, F.B., Judd, C., Radil, A., Ahmann, J., Geerlofs, S.H. (2013). *Geospatial Analysis of Technical and Economic Suitability for Renewable Ocean Energy Development on Washington's Outer Coast.* U.S. Department of Energy. Retrieved from http://www.msp.wa.gov/wp-content/uploads/2013/07/PNNL_EnergySuitability_Final-Report.pdf

VanZwieten, J.H., Seibert, M.G., & Von Ellenreider, K. (2012). *Anchor selection study for ocean current turbines.* Florida Atlantic University Southeast National Marine Renewable Energy Center. Retrieved from http://snmrec.fau.edu/sites/default/files/research/reports/TR-12-003.pdf

Verfaille, E., Van Lancker, V., Van Meirvenne, M. (2006). Multivariate geostatistics for the predictive modelling of the surficial sand distribution in shelf seas. *Continental Shelf Research 26*, 2454–2468.

Vinick, C., Riccobono, A., Messing, C.G., Walker, B.K., Reed, J.K., & Rogers, S. (2012). Siting study for a Hydrokinetic Energy Project Located Offshore Southeastern Florida: Protocols for Survey Methodology for Offshore Marine Hydrokinetic Energy Projects. Final Report Submitted to United States Department of Energy, Golden Field Office, [DOE Grant Award Number: DEEE0002655] By Dehlsen Associates, LLC in Cooperation with Ecology & Environment, In., Nova Southeastern University Oceanographic Center, and Florida Atlantic University (Southeast National Marine Renewable Energy Center/Harbor Branch Oceanographic Institute).

Walker B.K., Riegl B.M., & Dodge, R.E. (2008). Mapping Coral Reef Habitats in Southeast Florida Using a Combined Technique Approach. *Journal of Coastal Research 24*(5), 1138-1150.

Walker B.K., Jordan L.K.B., and Spieler R.S. (2009). Relationship of fish assemblages and topographic complexity on southeastern Florida coral reef habitats. *Journal of Coastal Research SI* (53), 39-48.

Walker, B.K. (2013). *SE FL Benthic Habitats*. Florida Department of Environmental Protection, Southeast Florida Coral Reef Initiative.

Wang, X. & Vom Hofe, R. (2007). *Research Methods in Urban and Regional Planning*. Beijing: Tsinghua University Press.

Westbury, A. (2012, January 23). A great idea; proving it seems to take forever [http://www.regulations.gov/#!docketBrowser;rpp=25;po=0;dct=PS;D=BOEM-2012-0011].