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BENTHIC HABITAT MAPPING AND ITS APPLICATIONS TO COASTAL RESOURCE MANAGEMENT

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BY

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ABSTRACT

This dissertation is comprised of three chapters focused on benthic habitat mapping of coastal waters within northeast region of the United States to support science-based regulatory and management strategies. The first chapter is entitled: Shallow water benthic habitat mapping utilizing the Coastal and Marine Ecological Classification Standard (CMECS) to establish baseline conditions post-Hurricane Sandy at Fire Island National Seashore, New York. In response to Hurricane Sandy, a benthic habitat mapping study was conducted at Fire Island National Seashore (FIIS), New York, representing one of the first comprehensive mapping efforts undertaken by the National Park Service. FIIS was of particular interest because of the tidal inlet formed by Sandy, leading to an influx of ocean water into and consequently altering Great South Bay. Data acquired include sidescan, bathymetry, sediment profile imagery, and sediment and macrofauna samples. The Coastal and Marine Ecological Classification Standard (CMECS) played a key role in developing map units, interpreting habitats (biotopes), and examining statistically significant relationships between macrofaunal communities and their environment.

The resulting biotopes are primarily defined by sand waves, dunes, flats, and basins and dominated by polychaete worms, small bivalves, and amphipods. The data also reveal the variable distribution of seagrass. While this study's findings cannot be directly compared to pre-Sandy conditions, evidence suggests the influence of the new inlet is positive. For example, seagrass has increased in close proximity to the inlet, while it has declined further away. Additionally, dense concentrations of blue mussels were recovered near the inlet, although they were largely absent elsewhere.

This study demonstrates the value of benthic habitat mapping and CMECS in providing ecologically meaningful information applicable to scientists and agencies, and argues the need for the establishment of a monitoring program. A multidisciplinary understanding of an ecosystem's resources, structure, function and temporal variability will guide science-based management strategies that maintain a balance between the protection and use of submerged lands.

The second chapter is entitled: Benthic monitoring to assess near-field changes at the Block Island offshore wind farm. The Block Island Wind Farm, located in the northeast Atlantic Ocean, is the first offshore facility in the United States. The primary objectives for this two-year study were to investigate near-field alterations in benthic macrofaunal communities, sediment composition, and organic enrichment among turbine and control areas, as a function of distance from the turbine foundations. At three turbines, grab sample and imagery data were collected within the footprint of the jacket foundations and 30m – 90m from the center point under the foundations. No appreciable differences were detected in either abiotic or biotic variables, with the exception of substantial changes exhibited within the footprint of one turbine. The variable spatial and temporal pattern over which changes are occurring poses challenges for predicting future conditions and highlights the complexity of attempting to do so. Monitoring efforts should continue to be focused on documenting alterations from offshore development and understanding the complex abiotic-biotic interactions that cause such alterations.

The third chapter is entitled: Conclusions: Benthic habitat mapping and its application to coastal resource management. This chapter provides an overview of the two manuscripts and discusses how benthic habitat mapping and associated techniques are broadly applicable and can be used to accomplish various study objectives. As examples, the value of using multivariate statistics and the Coastal and Marine Ecological Classification Standard (CMECS) is examined. Additionally, the relevance of these studies from a management and regulatory perspective is provided.

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absolute best dog anyone could dream of…he makes everything in life so much better! Let me end here with a quote by JFK – while it may not be exactly factual, it perfectly captures the enduring passion and admiration I have for the ocean, which has driven me to pursue a career in oceanography. “And it is an interesting biological fact that all of us have, in our veins the exact same percentage of salt in our blood that exists in the ocean, and therefore, we have salt in our blood, in our sweat, in our tears. We are tied to the Ocean” - JKF

PREFACE

Two of the three chapters within this dissertation are presented in Manuscript Format. Chapter 1, entitled, *Shallow water benthic habitat mapping utilizing the Coastal and Marine Ecological Classification Standard (CMECS) to establish baseline conditions post-Hurricane Sandy at Fire Island National Seashore, New York, USA,* is in preparation for the journal *Estuaries and Coasts*. Chapter 2, entitled: *Benthic monitoring to assess near-field changes at the Block Island offshore wind farm, USA,* is in preparation for the journal *Marine Environmental Research*. The formatting for both of these chapters follow those required by each journal. Chapter 3, entitled: *Conclusions: Benthic habitat mapping and its application to coastal resource management*, is not intended for publication. Rather, this Chapter provides an overview of the two manuscripts and discusses how benthic habitat mapping and associated techniques are broadly applicable and can be used to accomplish various study objectives.

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MANUSCRIPT 1: Shallow water benthic habitat mapping utilizing the Coastal and Marine Ecological Classification Standard (CMECS) to establish baseline conditions post-Hurricane Sandy at Fire Island National Seashore, New York

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Abstract

In response to Hurricane Sandy, a benthic habitat mapping study was conducted at Fire Island National Seashore (FIIS), New York, representing one of the first comprehensive mapping efforts undertaken by the National Park Service. FIIS was of particular interest because of the tidal inlet formed by Sandy, leading to an influx of ocean water into and consequently altering Great South Bay. Data acquired include sidescan, bathymetry, sediment profile imagery, and sediment and macrofauna samples. The Coastal and Marine Ecological Classification Standard (CMECS) played a key role in developing map units, interpreting habitats (biotopes), and examining statistically significant relationships between macrofaunal communities and their environment.

The resulting biotopes are primarily defined by sand waves, dunes, flats, and basins and dominated by polychaete worms, small bivalves, and amphipods. The data also reveal the variable distribution of seagrass. While this study's findings cannot be directly compared to pre-Sandy conditions, evidence suggests the influence of the new inlet is positive. For example, seagrass has increased in close proximity to the inlet, while it has declined further away. Additionally, dense concentrations of blue mussels were recovered near the inlet, although they were largely absent elsewhere.

This study demonstrates the value of benthic habitat mapping and CMECS in providing ecologically meaningful information applicable to scientists and agencies, and argues the need for the establishment of a monitoring program. A multidisciplinary understanding of an ecosystem's resources, structure, function and temporal variability will guide science-based management strategies that maintain a balance between the protection and use of submerged lands.

1.1. Introduction

Benthic habitat maps aim to describe and understand the relationships biological assemblages occupying the seafloor have with their associated environment, such as geological conditions (e.g. sediment type, geomorphology) and physical conditions (e.g. water depth, temperature, salinity, nutrient levels). The field of benthic habitat mapping is well-recognized and extensive overviews of various approaches, methodologies, and technologies can be found in Brown et al., 2011; Brown et al., 2009; Anderson et al., 2008; Diaz et al., 2004; Solan et al., 2003; and Kenney et al., 2003. The ecological objectives of habitat mapping are wide ranging and include establishing environmental baselines (Smith et al., 2015; Oakley et al., 2012; Hewitt et al., 2004), investigating the relationship between biological and environmental parameters across various spatial scales (Lecours et al., 2015; De Leo et al., 2014; LaFrance et al., 2014; McArthur et al., 2010; Ierodiaconou et al., 2007; Zajac et al., 2000), and creating species or habitat prediction and modeling tools (Porskamp et al., 2018; Ierodiaconou et al., 2018; Lecours et al., 2017; Mitchell et al., 2017; Young et al., 2015; Ierodiaconou et al., 2011; Valesini et al., 2010, Degraer et al., 2008). In addition to studying an area of interest, mapping efforts can focus on a specific habitat type, such as fish habitat (Malcolm et al., 2016; Kendall et al., 2011; Rooper and Zimmermann, 2007; Friedlander et al., 2006; Greene et al., 1999) or habitats that exhibit unique acoustic signatures and, therefore, can be readily identified in sidescan sonar imagery, including submerged aquatic vegetation (e.g. Greene et al., 2018; Sánchez-Carnero et al., 2012; Lefebvre et al., 2009; Jones et al., 2007; Sabol et al., 2002), shellfish beds (e.g. Isachenko et al. 2014; Raineault et al., 2012; van Overmeeren et al., 2009; Kostylev et al., 2003), coral reefs (e.g. El-Gharabawy et al., 2017; Collier and Humber, 2007; Kendall et al., 2005; Roberts et al., 2005; Mumby et al., 2004), and artificial reefs (e.g. Dong et al., 2017; Raineault et al., 2013). These maps can be particularly informative tools for developing management strategies based on best available science, including regulating resources and human uses, guiding marine spatial planning initiatives, addressing and anticipating global climate change issues, and assessing past and future natural and human-induced impacts (Malcolm et al., 2016; LaFrance et al., 2014; van Rein et al., 2011; Last et al., 2010; McArthur, 2010; Auster et al., 2009; Ierodiaconou et al., 2007; Valentine et al., 2005; Diaz et al., 2004; Kostylev et al., 2001; Greene et al., 1999; Zajac, 1999).

The type and resolution of benthic mapping data collected and the methodologies applied for data analysis are important considerations for any study, as these decisions will determine the scale at which maps can be produced and biotic-abiotic relationships can be identified and interpreted (Porskamp et al., 2018; Lecours et al., 2015; De Leo et al., 2014; FGDC, 2012; Van Lancker and Foster-Smith, 2007). These variations also pose challenges for directly comparing results across studies. Compounding these issues are inconsistencies in language used to describe mapping data and associated outputs. The implementation of a common data classification system can serve to reduce discrepancies across studies by offering a language that is consistent and well-defined. With this recognition, the Coastal and Marine Ecological Classification Standard (CMECS) was adopted as the US national standard by the Federal Geographic Data Committee (FGDC) in 2012 (FGDC, 2012). The framework provides a common language for organizing and describing scientific information about ecological features in marine and lacustrine environments and is able to accommodate any dataset, irrelevant of variables such as acquisition or processing methods, spatial or temporal scales, and resolution (FDGC, 2012). As such, CMECS can serve to enhance ecological understanding and support management needs.

The National Park Service (NPS) is responsible for the protection and management of 88 ocean, coastal, and Great Lakes parks across the United States (Curdts and Cross, 2013). These parks encompass 17,700 km (11,000 mi) of shoreline and 2.5 million acres of marine and estuarine areas (Curdts and Cross, 2013). Despite their extensive submerged holdings, no well-defined seafloor habitat mapping program currently exists within NPS. Previous mapping studies conducted at the request of NPS have been limited in scope and purpose, primarily performed at the pilot-scale to demonstrate feasibility and practicality of developed maps for management purposes. The ten pilot studies, summarized in Curdts and Cross (2013), also largely focused on the geological component of habitat mapping, with less consideration given to the biological component and the integration of the two. However, there has been growing interest within NPS for seafloor mapping studies and the development of benthic habitat classification maps as their importance and applicability to the effective management of submerged lands is increasingly recognized (Hart et al., 2010; Moses et al., 2010).

In the aftermath of Hurricane Sandy, which occurred in late October 2012, it became further evident to NPS that, unlike its terrestrial lands, there is a clear lack of fundamental information regarding the majority of park submerged lands, including the resources and habitats that exist and their overall condition. Consequently, it was not possible for NPS to fully assess the effects (positive, negative, or neutral) of Hurricane Sandy on its submerged holdings or anticipate future changes. Such changes include those due to natural processes (e.g. storms, sediment deposition and erosion), global climate change (e.g. sea level rise, ocean warming, increased storm events and intensity), resource extraction (e.g. fishing, sand borrow areas for beach nourishment), land-use impacts (e.g. nutrient loading, erosion), and other human activities (e.g. recreation, dredging, facilities construction). In response, NPS funded concurrent studies within four coastal National Parks in the northeast region, which represents the first comprehensive benthic habitat mapping effort undertaken by NPS. The four study locations were: Cape Cod National Seashore in Massachusetts, Fire Island National Seashore (“FIIS”) in New York, Gateway National Recreation Area in New Jersey, and Assateague Island National Seashore in Maryland. The overall objective of these studies was to provide a detailed baseline dataset of submerged lands within the parks, through the inventory, classification, and assessment of biotic and abiotic benthic resources and habitats.

This study focuses on FIIS, one of 10 national seashores within the National Park System in the United States. The primary goal was to develop biotope classification maps to define relationships between macrofaunal communities and their associated environmental characteristics utilizing the CMECS framework for the Otis Pike and Sunken Forest study areas within FIIS. Secondary goals were to understand overall macrofaunal patterns and to assess spatial and temporal changes in seagrass distribution and density within Otis Pike and Sunken Forest, as well as to provide a description of the biotic and abiotic benthic characteristics within East Breach, the area to the east of the new tidal inlet created as a result of Hurricane Sandy. These goals establish a comprehensive baseline dataset to serve as a point of comparison for future data. With this enhanced, multi-disciplinary understanding of ecosystem structure and function, NPS will improve its capacity to anticipate, monitor, and interpret future environmental change. This study will also serve to promote resource stewardship, guide marine spatial planning efforts, and initiate effective, scientifically sound management strategies. From a broader perspective, these habitat mapping studies provide the opportunity to investigate the influence of Hurricane Sandy within the northeastern United States; generate additional examples demonstrating the application of CMECS and further refine its framework; and advance the field of benthic habitat mapping in extremely shallow and often turbid waters.

1.2. Application of the Coastal and Marine Ecological Classification Standard (CMECS)

CMECS provides a common language for organizing and describing scientific information about ecological features in marine and lacustrine environments (FDGC, 2012). The framework is hierarchical and is composed of two settings (biogeographic and aquatic) and four components (Geoform, Substrate, Water Column, and Biotic) to incorporate geological, physical, chemical and biological information into a single structure (Figure 1). The settings and components can also be integrated to define habitats, referred to as biotopes, which reflect ecologically meaningful relationships between biological communities and their associated environments.

The two settings in CMECS provide contextual broad-scale information about the area of interest. The Biogeographic Setting *"identifies ecological units based on species aggregations and features influencing the distribution of organisms."* (FDGC, 2012). This setting is hierarchically organized into three regions: Realm, Province, and Ecoregion. The Aquatic Setting "*distinguishes oceans, estuaries and lakes, and deep and* *shallow waters and submerged and intertidal environments within which more refined classification of geological, physiochemical, and biological information can be organized."* (FDGC, 2012). This setting is divided into System, Subsystem, and Tidal Zone.

The four components are used to describe source or derived data. The Substrate Component describes the composition and characteristics of "*the non-living materials that form an aquatic bottom or seafloor, or that provide a surface (e.g. floating objects, buoys) for growth of attached biota.*" (FGDC, 2012). This component encompasses substrates of geologic, biogenic, and anthropogenic origin. The hierarchical subcomponents are Origin, Class, Subclass, Group, and Subgroup, each of which are based on the dominant substrate type. The Geoform Component describes "*the major geomorphic and structural characteristics of the coast and seafloor. This component is divided into four subcomponents that describe tectonic and physiographic settings and two levels of geoform elements that include geological, biogenic, and anthropogenic geoform features."* (FDGC, 2012). While the Geoform Component sets the geological context, its ultimate purpose is to "*present the structural aspects of the physical environment that are relevant to – and drivers of – biological community distribution.*" (FGDC, 2012). The hierarchical subcomponents are Tectonic Province, Physiographic Province, Origin, and Geoform Level 1 and Level 2. Level 1 of the Geoform subcomponent recognizes large-scale geologic features (>1 sq km; e.g. lagoon, surge platform, delta, flat, moraine, fan), whereas Level 2 is for small-scale surficial attributes (<1 sq km; e.g. sand waves, sand dunes, tidal flat, washover fan). The Water Column Component "*identifies the structures, patterns, properties, processes, and biology of the* *water column relevant to ecological relationships and habitat-organism interactions*." (FDGC, 2012). The subcomponents are Water Column Layer, Salinity Regime, Temperature Regime, Hydrofrom Class and Type, and Biogeochemical Feature. The Biotic Component is a "*hierarchical classification that identifies (a) the composition of floating and suspended biotia and (b) the biological composition of coastal and marine benthos.*" (FGDC, 2012). The hierarchical subcomponents are Setting, Class, Subclass, Group, and Community, each of which is defined by dominance measured in terms of abundance, biomass, or percent cover. For all components, modifiers and co-occurring elements can be used to further define datasets. Modifiers are used "*when additional information is needed to further characterize an identified unit*" and "*allow users to customize the application of the classification in a standardized manner.*" (FGDC, 2012). Modifier types are Anthropogenic, Biogeographic, Biological, Physical, Physicochemical, Spatial, and Temporal, all of which are further divided into more specific categories.

The settings and components within the CMECS framework can be used independently, or they can be combined to develop biotopes. Biotopes provide a more ecologically holistic understanding of areas or features by identifying biotic-abiotic relationships. Specifically, a biotope is defined as "*the combination of abiotic habitat and associated species (Connor 1995, 1997; Connor et al. 2003.).*" (FGDC, 2012). Biotic communities identified in the Biotic Component serve as the basis for defining biotopes and are described in conjunction with other applicable components (i.e. Substrate, Geoform, Water Column) and Settings (i.e. Biogeographic, Aquatic) that characterize the abiotic environment. Biotopes are considered preliminary until the relationships identified are demonstrated to reoccur, i.e. when "*biotic communities are repeatedly associated with unique combinations of the abiotic features.*" (FGDC, 2012).

CMECS offers an extensive database of coded classifiers that are clearly defined to promote the consistent use of terminology. The structure of the framework is flexible in that it does not require every setting and component to be utilized, it is sensor and scale independent, and it can be customized to user needs through the use of modifiers and co-occurring elements. Furthermore, users are free to apply "provisional units" that are consistent with the hierarchy for inclusion with future updates to the framework. These features allow any dataset to be classified, regardless of collection or processing methods, geographic and temporal scales, resolution, density, etc. The dynamic design of CMECS promotes the development of detailed and comprehensive classification outputs; allows for the amalgamation of information from legacy, current, and future datasets; and facilitates the sharing and direct comparison of information more readily across space and time and among a broad range of users.

1.3. Methodology

1.3.1. Study Areas

Fire Island is a barrier island that parallels the south shore of Long Island, New York, separating Great South Bay to the north from the Atlantic Ocean to the south. The island is approximately 52 km (32 mi) in length and ranges from approximately 0.2 km (0.13 mi) to 1.25 (0.78 mi) in width. FIIS encompasses portions of Fire Island and the surrounding marine environment and is one of 10 national seashores within the park system in the United States (Figure 2). FIIS totals nearly 20,000 acres, of which 75% are submerged lands and 25% are terrestrial. The park has 175 km (109 mi) of shoreline and boundaries that extend approximately 1,200 m (3,950 ft) and 300 m (1,000 ft) from shore into the bay and ocean, respectively.

Within and adjoining the bay side of FIIS, three study areas were identified in collaboration with NPS staff. Of greatest priority was the Otis Pike High Dunes Wilderness Area ("Otis Pike"), followed by the Sunken Forest. In addition, the area encompassing the new tidal inlet created as a result of Hurricane Sandy was of high interest, though it was recognized the logistics of collecting data in such an active and uncharted environment would be overly challenging. Instead, it was decided data would be acquired within the most accessible portion of the new inlet – the area to the east ("East Breach"). These data were collected for exploratory purposes and to identify potential changes since Hurricane Sandy.

1.3.2. Data Collection and Processing

The bay side of FIIS is characterized by extremely shallow (< 3 m and averaging 1-1.5 m) and often turbid waters. The Otis Pike, Sunken Forest, and East Breach study areas were accessed using a 8.5 m (28 ft) pontoon vessel customized for shallow water surveying. Acoustic data (sidescan, bathymetry) and ground-truth data (grab samples, sediment profile imagery (SPI)) were acquired within the three study areas over two ten-week periods in the summer and fall of 2014 and the summer of 2015 (Table 1, Figure 3).

Table 1. Summary of data acquired within the Otis Pike, Sunken Forest, and East Breach study areas.

Study Area	Data Collected	Coverage Area or Number of Samples	Supplementary Information	Dates of Collection
Otis Pike (2014)	Sidescan, bathymetry	14.5 km^2 (5.6 mi^2)	Coverage extends from shoreline out to approximately 1,000 m (0.6 mi) beyond FIIS park boundary	17 days between July 10th and September 24th, 2014
	Grab samples	26 sites	Triplicate biology samples (78 total) and single sediment sample (26 total) at each site	6 days between October 14th and 21st, 2014
	SPI images	26 sites	Triplicate deployments (156 images total)	
East Breach (2015)	Sidescan, bathymetry	1.4 km^2 (0.55 mi^2)	Coverage extends just to the east of the newly formed inlet and continues east to Smith Point Bridge	June 11th and 16th, 2015
	Grab samples	7 sites	Single biology sample (7 total) and single sediment sample (7 total) at each site	July 9th, 2015
	SPI images	7 sites	Triplicate deployments (42 images total)	
Otis Pike (2015)	Sidescan, bathymetry	2 km^2 (0.75 mi^2)	Targeted re-survey of five seagrass areas to assess change over time and compare data from two sonar systems	July 13th – 16th, 2015
	Grab samples	15 sites	Triplicate biology samples (45 total) and single sediment sample (15 total) at each site; 9 of the sites were re-sampled from 2014 survey	July 21st – 23rd, 2015

	SPI images	76 sites	Triplicate deployments (456 images total); 15 of the sites followed the grab sample site locations. In addition, 11 transects, consisting of the remaining 61 sites, were designed to cross boundaries identified in the sidescan mosaic	
Sunken Forest (2015)	Sidescan, bathymetry	2.5 km^2 (1 mi^2)	Coverage extends from shoreline out to FIIS park boundary	August 12th and 13th, 2015
	Grab samples	12 sites	Triplicate biology samples (36 total) and single sediment sample (12 total) at each site	August 18th and 19th, 2015
	SPI images	20 sites	Triplicate deployments (120 images total); 12 of the sites followed the grab sample site locations. In addition, 2 transects, consisting of the remaining 8 sites, were designed to cross boundaries identified in the sidescan mosaic	
Total	Sidescan, bathymetry	20.5 km^2 (7.9 mi^2)		
	Grab samples	166 samples at 60 sites		
	SPI images	774 images at 129 sites		

1.3.2.1. Acoustic Surveys

Acoustic data were collected within the three study areas totaling 20.5 km^2 (7.9 mi^2) (refer to Figure 3, Table 1). The 2014 survey within Otis Pike was conducted using a bow-mounted Teledyne Benthos C3D interferometric sonar (220 kHz). The 2015 surveys within Otis Pike, Sunken Forest, and East Breach were conducted using a bow-mounted EdgeTech 6205 Multi-Phase Echo Sounder system with dual-frequency sidescan (550 kHz and 1600 kHz). Both sonar systems are capable of simultaneously acquiring co-located sidescan and bathymetry data and are optimized for shallow water surveying, allowing for increased survey efficiency. The survey was planned in Hypack and designed to acquire full-coverage sidescan data (i.e. 100% coverage with 20-30% overlap). As such, the survey was composed of parallel track lines with line spacing of 35 m - 40 m (115 ft - 130 ft) and a sonar swath range of 50 m (165 ft) to allow sufficient overlap with adjacent lines. At this line spacing, between 25% and 100% bathymetry coverage was anticipated, varying with water depth. For the 2015 survey within Otis Pike, the planned lines and sonar settings from the 2014 survey were used to allow the exact survey to be repeated. Data were collected using GeoDas software developed by Ocean Imaging Consultants (OIC) and monitored topside in real-time to confirm data quality and that full-coverage was being achieved. During acquisition, an Applanix POS MV inertial measurement unit (IMU) system was used for positional accuracy and to correct for vessel motion (pitch, roll, heave).

The raw sidescan and bathymetry records were processed using OIC CleanSweep software. For sidescan, processing involved the standard techniques of bottom-tracking, followed by the application of angle-varying gains (AVG) and look-up tables (LUT) as necessary to correct for water column returns, arrival angle, and refine contrast to produce color-balanced sidescan sonar waterfall images and mosaics. The mosaics were processed to 25 cm pixel resolution and displayed on an inverse gold color scale, with pixel values ranging from zero (dark gold) to 255 (white). The lighter pixels indicate strong acoustic returns and represent hard bottoms, such as coarse sand, cobbles, and boulders, which tend to reflect sound, whereas darker pixels represent softer sediments, which tend to be acoustically absorbent. For bathymetry, data processing followed standard techniques of first correcting for tide, sound velocity, vessel motion, and sonar mount angle, and then applying filters to remove outlier soundings. The resulting mosaic presents water depths of the survey areas at a pixel resolution of 50 cm.

1.3.2.2. Grab Samples

Grab samples were collected using a Van Veen grab sampler for analysis of sediment grain size and benthic macrofauna community structure. In total, 166 grab samples were collected at 60 sites (refer to Figure 3, Table 1). The locations of the 2014 Otis Pike grab sample sites (n=26) follow those previously established by Stony Brook University as part of a long-term seagrass assessment survey being conducted using a tiered monitoring approach. The sample sites were randomly generated by first dividing the sample area into a grid of 198 stratified tessellated hexagons, each 925 m (0.57 mi) in width, and then selecting a random sample site within each hexagon (refer to Neckles et al., 2012). This survey design was chosen due to its ability to generate random sampling sites while ensuring good dispersion of samples (Elzinga et al., 2004). Nine of the 2014 sites were resampled in 2015. The locations of the additional 2015 sample sites (n=6) were strategically chosen to represent the majority of distinct geological bottom types visible in the sidescan data. The sample sites within Sunken Forest (n=12) were generated at random in ArcGIS using the "Create Random Points" tool in the Data Management toolbox. For East Breach, since the objective was more exploratory to gain a better understanding of this dynamic area, grab sample sites were strategically chosen based on interesting features and distinct bottom types identified in the sidescan record that warranted further investigation.

At each site, one grab sample was collected for sediment grain size analysis. A sub-sample was taken from the surface of the grab sample and the remaining material was released. Sediment properties of the sub-sample were characterized using a particle size analyzer (Malvern Mastersizer 2000E), which generated the weight percent of each particle size fraction (e.g. silt, fine sand, coarse sand, etc.) according to the Wentworth classification system (Wentworth, 1922).

At the Otis Pike and Sunken Forest sites, grab samples for analysis of macrofaunal community structure were collected in triplicate to allow for more robust statistical analyses and to account for small-scale spatial variability and the typically complex structure of benthic macrofaunal communities. Single grab samples were taken within East Breach to allow for a broader distribution of sample sites throughout the area. Samples were sieved through a 0.5 mm mesh and captured macrofauna were retained and preserved in a Rose-Bengal solution. All individuals were counted and identified to the species level.

The macrofauna dataset was organized by sample to allow within-site and across-site metrics to be examined, including species abundance, species richness, and community composition. Ordination and multivariate statistical analyses were conducted using the statistical software package PRIMER v7 (Clarke and Gorley, 2015; Clarke et al., 2014; Clarke, 1993), with all routines subjected to a minimum of 999 permutations. To prepare the data for analysis, the triplicate samples at each site were averaged and used to represent benthic community structure. These averaged abundances were 4^{th} root transformed and the Bray-Curtis similarity index was used to create a matrix representing sample site-similarity.

1.3.2.3. Sediment Profile Imagery (SPI)

SPI provides an in-situ perspective of the seafloor and associated characteristics. Specifically, the camera takes a profile photograph of the sediment-water interface, which offers information about the biological and environmental attributes of the surface of the seafloor, the substrate just below the seafloor, and the overlying water column. SPI imagery has been well documented as a primary or ground-truth dataset for ecological studies (refer to Germano et al., 2011; Solan et al., 2003; Germano et al., 1989).

A SPI camera system was used to collect a total of 774 images at 129 sites (refer to Figure 3, Table 1). SPI is especially valuable for collecting imagery in poor visibility conditions, such as the turbid waters of FIIS, which often prevent the effective use of video cameras. Images were taken at each grab sample site (n=60) and also at sites (n=69) comprising a series of transects designed to cross boundaries identified in the sidescan mosaics. All deployments of the camera were done in triplicate. The images were processed and analyzed in Adobe Photoshop CS3. Color and contrast adjustments were applied to enhance the images for detection of features. Geological and biological features were identified and described through expert interpretation of the images, including relative grain size, bedforms, biogenic features, and presence of seagrass and organisms (identified to species or lowest taxonomic level). The imagery data were used to corroborate and complement the acoustic and grab sample data.

1.3.3. Seagrass Distribution and Temporal Variability

Polygons representing seagrass distribution were delineated based on expert interpretation of the sidescan sonar imagery for Otis Pike and Sunken Forest and qualitatively categorized by density. Seagrass has a distinct signature due to its acoustic characteristics, which can be identified by high backscatter intensity returns and a texture that appears as circular features or clusters, and at high densities can resemble heads of cauliflower. SPI was used to identify seagrass according to species. For Otis Pike, changes in seagrass distribution and density over a one-year period was assessed for the five areas surveyed 2014 and again in 2015. For both study areas, seagrass coverage was compared to data collected throughout the southern shore of Long Island in 2002 (NYDOS, 2003). The 2002 dataset classifies seagrass as “continuous” or “patchy” through the examination of aerial imagery and uses a minimum mapping unit of $10m^2$.

1.3.4. Benthic Biotope Classification Maps

Benthic biotope classification maps were developed for the Otis Pike and Sunken Forest study areas. The East Breach study area was excluded since constructing a biotope map for such a dynamic and active environment would be of limited value. The biotope maps were developed following the top-down mapping approach, for which map units are geologically defined based on the presumption that distinct relationships exist between geologic environments or features and biological assemblages. Extensive studies and discussion of the top-down approach and its comparisons to other mapping approaches can be found in Smith et al., 2015; LaFrance et al., 2014; Rooper and Zimmermann, 2007; Eastwood et al., 2006; Hewitt et al., 2004; Brown et al. 2002; and Kostylev, 2001. The resulting biotopes reflect the relationship between macrofaunal communities and geological features of their associated environments within the defined map units. While these biotopes are considered preliminary since the relationships identified have not been repeatedly demonstrated over time, statistical assessments (i.e. ANOSIM, SIMPER, nMDS) provide confidence in the validity of the biotopes.

The first phase of the classification process was to establish map units, as defined by the geologic depositional environments present within the study areas. Following Oakley et al. (2012), the delineation of the map units was primarily based on expert interpretation of the geologic facies visible in the sidescan sonar imagery. Geologic facies are spatially recognizable areas in the sidescan record due to their acoustic characteristics, such as backscatter intensity and texture (Oakley et al., 2012). Additionally, bathymetry, sediment grain size data, and SPI imagery collected in this study, as well as aerial imagery available in Esri ArcGIS and Google Earth platforms were also examined. These secondary datasets were used to assist in data verification and interpretation, particularly with a gradual transition zone occurred between facies, rather than a sharp boundary. The nomenclature of the depositional environments follow the CMECS Geoform and Substrate Component. The Geoform Level 1 subcomponent describes large-scale geologic features (>1 sq km) and Level 2 indicates small-scale surficial characteristics (<1 sq km). The Substrate Component then further refines the Geoform units by describing the average dominant sediment type. Dominance is determined from grain size analysis of the sediment grab samples collected within a given map unit, and reported according to the Wentworth scale (Wentworth, 1922).

The presence of seagrass is an exception to describing map units according to geologic depositional environment. Seagrass was included as a map unit type because CMECS considers it to be a defining feature of the seascape and a unique habitat type from an ecological perspective. Further, exploratory data analyses (e.g. nMDS plot, ANOSIM, SIMPER) indicated there are distinctions in the composition of macrofaunal assemblages within and outside of seagrass areas.

Statistical analyses were performed using PRIMER v7 (Clarke and Gorley, 2015; Clarke et al., 2014; Clarke, 1993). The Analysis of Similarity (ANOSIM) routine was used to assess the strength and significance of the relationship macrofaunal communities exhibit with their accompanying environmental map units. The reported R value reflects the degree of distinction, with a value of 1 indicating that biological communities within each environment type are completely distinct from one other, and a value of 0 indicating there are no differences. The similarity percentages (SIMPER) routine was then used to determine the degree of biological similarity within each map unit type. The routine reports the average percent similarity, as well as the degree to which each individual species contributes to that similarity. Lastly, non-metric multidimensional scaling (nMDS) plots were used to further investigate biotic-abiotic relationships. The plots examined macrofaunal community composition to sediment type, presence of seagrass, presence of worm or amphipod tubes, total organic carbon content (TOC), and distance from shore. An nMDS plot is an ordination plot displaying the level of similarity among samples based on their relative distance from one another on the plot, with shorter distances representing a greater degree of similarity.

A CMECS biotope classification was assigned to the map units found to contain statistically distinct macrofaunal communities. As such, biotopes were classified by their environment type (i.e. geologic depositional environment or seagrass) and the Biotic Component, which was used to describe the biological community based on dominant species. Dominance is defined as the species with the highest abundance combined across all of the macrofaunal samples present within the given map unit. The classification was completed in Esri ArcMap platform by color-coding and labeling each biotope polygon.

1.4. Results

1.4.1. Macrofauna Characterization

In total, the 166 grab samples within the three study areas yielded > 63,200 macrofauna individuals belonging to 8 phyla and 163 species. The vast majority of the recovered macrofauna (91.7% of total number of individuals; 94.5% of total number of species) belonged to three phyla: Arthropoda, Annelida and Mollusca (Table 2). The species with the highest total abundance across the three study areas was *Gemma Gemma*, a small filter-feeding mollusk commonly known as the "Amethyst Gem Clam," comprising 11.8% of all individuals recovered, followed by *Ampelisca vadorum* (9.1%) and *Ampelisca verrilli* (8.2%), both tube-building amphipods (Table 3). Nematode worms were found to be the most spatially distributed, being recovered at 83.0% of the sample sites, followed by the motile deposit-feeding worm *Polygordius jouinae* (81.2%), *A. verrilli* (62.4%), *G. gemma* (60.0%), and *A. vadorum* (44.2%).

Table 2. Summary of phyla composition of macrofaunal samples collected within the Otis Pike, Sunken Forest, and East Breach study areas combined and individually.

Study Area(s)	Phylum	% of Total Individuals	% of Total Species
Otis Pike, Sunken Forest, East Breach Combined	Arthropoda	36.4%	35.0%
	Annelida	30.5%	42.3%
	Mollusca	24.8%	17.2%
	Nematoda	7.6%	0.61%
	Echinodermata	0.32%	1.84%
	Nemertea	0.27%	0.61%
	Cnidaria	0.08%	1.2%
	Platyhelminthes	0.01%	0.61%
Otis Pike 2014	Arthropoda	35.2%	31.9%
	Annelida	30.4%	44.5%
	Mollusca	26.1%	17.6%
	Nematoda	7.8%	0.84%
	Nemertea	0.25%	0.84%
	Cnidaria	0.12%	1.7%
	Echinodermata	0.005%	0.84%
	Platyhelminthes	0.005%	0.84%
Otis Pike 2015	Arthropoda	56.2%	35.5%
	Annelida	24.5%	43.9%
	Mollusca	16.3%	15.9%
	Nematoda	2.6%	0.93%
	Nemertea	0.32%	0.93%
	Cnidaria	0.12%	0.93%
	Echinodermata	0.008%	1.9%
Sunken Forest 2015	Annelida	42.9%	46.9%
	Mollusca	33.3%	13.3%
	Nematoda	13.2%	1.0%
	Echinodermata	8.1%	2.0%
	Arthropoda	2.2%	34.7%
	Nemertea	0.31%	1.0%
	Platyhelminthes	0.02%	1.0%
East Breach 2015	Arthropoda	47.2%	34.8%
	Annelida	22.3%	51.5%
	Mollusca	20.3%	9.1%
	Nematoda	10.1%	1.5%
	Nemertea	0.12%	1.5%
	Cnidaria	003%	1.5%

Table 3. Species contributing 5% or greater to total species abundance within the Otis Pike, Sunken Forest, and East Breach study areas combined and individually. *Note: Asterisk (*) denotes the top three most frequently recovered species.*

Study Area(s)	**Species**	**Description**	**% of Total Individuals Recovered**	**% of Total Samples Recovered Within**
Otis Pike, Sunken Forest, and East Breach Combined	*Gemma gemma*	Mollusca; Amethyst Gem Clam; Filter Feeder	11.8%	60.0%
	Ampelisca vadorum	Arthropoda; Amphipod; Tube Builder	9.1%	44.2%
	Ampelisca verrilli	Arthropoda; Amphipod; Tube Builder	8.2%	62.4%*
	Nematoda	Nematoda; Worm; Burrowing	7.6%	83.0%*
	Polygordius jouinae	Annelida; Polychaete Worm; Motile; Deposit Feeder	7.4%	81.2%*
	Mulinia lateralis	Mollusca; Dwarf Surf Clam; Filter Feeder	7.3%	47.9%
	Leptochelia savignyi	Arthropoda; Amphipod; Tube Builder	6.9%	13.3%
Otis Pike	*Gemma gemma*	Mollusca; Amethyst Gem Clam; Filter Feeder	13.9%	76.2%*
	Ampelisca verrilli	Arthropoda; Amphipod; Tube Builder	10.1%	76.2%*
	Ampelisca vadorum	Arthropoda; Amphipod; Tube Builder	9.2%	43.4%
	Leptochelia savignyi	Arthropoda; Amphipod; Tube Builder	8.5%	17.2%
	Nematoda	Nematoda; Worm; Burrowing	6.5%	75.4%
	Polygordius jouinae	Annelida; Polychaete Worm; Motile; Deposit Feeder	6.1%	78.7%*
Sunken	*Mulinia lateralis*	Mollusca; Dwarf Surf Clam; Filter Feeder	26.6%	91.7%*

Forest	*Polygordius jouinae*	Annelida; Polychaete Worm; Motile; Deposit Feeder	17.2%	94.4%*
	Nematoda	Nematoda; Worm; Burrower	13.2%	91.7%*
	Owenia fusiformis	Annelida; Polychaete Worm; Tube Builder	11.9%	27.8%
East Breach	*Ampelisca vadorum*	Arthropoda; Amphipod; Tube Builder	28.7%	71.4%
	Gemma gemma	Mollusca; Amethyst Gem Clam; Filter Feeder	10.7%	42.9%
	Nematoda	Nematoda; Worm; Burrower	10.1%	100%*
	Mytilus edulis	Mollusca; Blue Mussel; Filter Feeder	9.4%	42.9%
	Lysianopsis alba	Arthropoda; Amphipod; Burrower	6.3%	85.7%*

1.4.2. Seagrass Distribution and Temporal Variability

The SPI imagery and grab samples captured two species of seagrass, *Ruppia maritima* and *Zostera marina*, within Otis Pike and Sunken Forest. *R. maritima* exhibited a wider distribution, being identified at 16 sites, while *Z. marina* was identified at four sites. The two species were not found to co-exist at any of the sites. The 2014 Otis Pike sidescan mosaic revealed seagrass was present throughout the most of the study area with qualitative density categories ranging from sparse to very dense (Figure 4). Comparisons of the five areas surveyed in both 2014 and 2015 show the western and eastern most areas exhibited considerable declines in seagrass distribution and density over the one year period (Figure 5; refer to Figure 2 for study area locations). Seagrass appears to be more stable at the three remaining areas, although they also show evidence of overall decline.

Comparison of the seagrass datasets collected in 2014 (this study) and 2002 (NYDOS, 2003) reveal that there has been substantial changes in seagrass extent and density throughout Otis Pike over the last 12 years (Figure 4). Initial examination of the coverage maps suggests seagrass has expanded northward since 2002, though this is attributed to the different resolutions of the datasets from which the seagrass polygons were delineated; the 2002 aerial imagery data has a minimum mapping unit of $10m^2$, whereas the 2014 sidescan data can identify seagrass on a sub-meter scale. The 2002 data would likely not be able to resolve the “sparse” designation in the 2014 data, causing such areas to be categorized as seagrass “not present.” As such, coverage areas identified as “patchy” or “continuous” in the 2002 data that are now mapped as “sparse” in the 2014 data represent a decrease in seagrass extent and density. Furthermore, there are distinct areas where seagrass existed in 2002, but is no longer present in 2014. Yet, in limited areas, seagrass appears to have expanded. Most notably, along the eastern shoreline and to the west of the dredged channel for Bellport Beach, seagrass was not documented in 2002, but was designated as “dense” or “very dense” in 2014.

Examination of the 2015 Sunken Forest sidescan mosaic indicates seagrass is patchy and infrequent and there has been a substantial decline since 2002 (Figure 6). Seagrass was present within 15.6% the Sunken Forest study area in 2002, though, by 2015, only small patches of seagrass remain, comprising 0.8% of the study area. This change represents a 95% loss over the past 13 years.

1.4.3. Benthic Geologic Depositional Environments

The sidescan mosaics and aerial imagery indicate Otis Pike and Sunken Forest are predominantly sandy environments, the sediment grain size analysis reports the fine, medium, and coarse sand fractions combined comprise greater than 90% of the sediment composition for all but two sample sites, and the bathymetry data confirm the areas are shallow (average depth = 1 m; range = 0.3 m - 3.5 m). These datasets were used to interpret two Geoform Level 1 units (surge platform, lagoon) and five Geoform Level 2 units (sand flat, sand waves, small dunes, bedforms, basin) (Figure 7). The surge platform encompasses the Otis Pike and Sunken Forest study areas extending from the shoreline into Great South Bay where it borders the lagoon bottom that characterizes the remaining portion of the study areas. The Level 2 units suggest Otis Pike and Sunken Forest are active and dynamic areas. This characteristic is evident through the various directions, shapes, and sizes of the bedforms that are present. Otis Pike appears to transition into a less energetic environment as distance from shore/water depth increases and the area becomes defined by lagoon bottom dominated by basin and sand flats comprised of finer sediment.

The Substrate Component further supports and refines the Geoform units, reporting the average dominant sediment grain size across all of the samples within each unit. Two grain-size descriptions were provided when dominance was nearly equal, with the most dominant listed first. For units within which no sediment samples were collected, the Substrate Component was defined as “sand,” based on interpretation of the sidescan and aerial imagery. Both Otis Pike and Sunken Forest are predominately characterized by sand of medium grain size. Specifically, within Otis Pike, four of the six lagoon units are co-defined by medium and fine sand, one unit solely by medium sand, and one unit by fine and very fine sand. The surge platform unit is comprised of coarser sediment overall, being defined by medium and coarse sand fractions. The Sunken Forest units are all characterized by medium sand, with the exception of one lagoon unit that is also co-defined by “fine sediments” (i.e. combined grain size fractions of clay, silt, very fine sand and fine sand).

1.4.4. Benthic Biotope Classification Maps

It would potentially be suitable to combine the data from Otis Pike and Sunken Forest and conduct one series of analyses to develop biotope classification maps. This approach may be justified since the two study areas share similar geological and physical characteristics and are geographically in close proximity to one another (midpoints of study areas are separated by 13 km). However, comparisons using the nMDS and ANOSIM routines indicate Otis Pike and Sunken Forest contain relatively distinct macrofaunal communities and argue the need for maps to be developed independently (Figure 8; R = 0.416; p = 0.001).

Within Otis Pike, ANOSIM reported macrofaunal communities exhibit significant distinctions among map units defined by the Geoform Level 1 Component or the presence of very dense seagrass (R = 0.54; p = 0.001). ANOSIM results incorporating the Geoform Level 2 and/or Substrate Components were not significant. As such, the six lagoon Level 1 Geoform units were merged and the resulting classification map presents three biotopes: *"A. verrilli* on medium to fine sand within lagoon," *"P. jouinae* on medium sand within surge platform containing sand waves" and "*G. gemma* on medium to coarse sand within very dense seagrass" (Figure 9). The SIMPER routine provides an average biological similarity between 46.3% and 51.8% (Table 4). All three biotope-defining species are also most responsible for the within-biotope similarity. Specifically, the deposit-feeding polychaete worm *P. jouinae* contributes 11.5%, the tube-building amphipod *A. verrilli* contributes 11.3%, and the small filter-feeding bivalve *G. gemma* contributes 6.9%.

The nMDS plots reveal patterns in macrofaunal community composition can best be explained as a function of distance from shore and seagrass density (Figure 10). Geographically, sites located nearest to the shoreline separate out to the top and left of the plot, whereas sites further away (up to 2 km from the shoreline) are shown along the bottom left. This result supports defining the map units based on the Geoform Level 1 designation, which are generally spatially distributed as being near shore (surge platform) and offshore (lagoon). Similarly, the presence of very dense seagrass also appears to be driving macrofaunal composition to some degree. Plots investigating the influence of sediment type, amphipod or worm tubes, and TOC revealed no distinct trends.

Table 4. Description of statistically significant biotopes for Otis Pike and Sunken Forest. *Note: Two species define a biotope when both exhibited nearly equal abundances ("*"), or when the most abundant species is the result of a high number of individuals being recovered at one of the sample sites, but another species is found to be the first or second most abundant species at all of the sample sites within the biotope ("**"). Similarly, two substrate types are provided when dominance was nearly equal, with the most dominant listed first. SIMPER identified the average biotope similarity and the species most responsible for biotopes containing more than one macrofaunal sample. The area of each biotope is provided, both as a spatial extent (km^2) and as a percentage of the total study area.*

Study Area	**Biotope**	**Average Dominant Species by Abundance**	**Average Biotope Similarity**	**Species Most Responsible for Similarity (% contri-bution)**	**Area (% of total)**
Otis Pike	*Gemma gemma* on medium to coarse sand within very dense seagrass	*Gemma gemma*	46.3%	*Gemma gemma* (6.9%)	2.58 km^2 (18.1%)
		Leptochelia savignyi		*Prionospio spp.* (6.9%)	
		Nematoda		*Nematoda* (6.8%)	
	Ampelisca verrilli on medium to fine sand within lagoon	*Ampelisca verrilli*	51.8%	*Ampelisca verrilli* (11.3%)	9.10 km^2 (63.9%)
		Mulinia lateralis		*Polygordius jouinae* (7.0%)	
		Ampelisca vadorum		*Spiophanes bombyx* (4.8%)	
	Polygordius jouinae on medium sand within surge platform containing sand waves	*Polygordius jouinae*	50.6%	*Polygordius jouinae* (11.5%)	2.48 km^2 (17.4%)
		Nematoda		*Monoculodes sp.* (7.3%)	

<table>
<tr><td></td><td></td><td>Prionospio spp.</td><td></td><td>Scoloplos robustus (7.2%)</td><td></td></tr>
<tr><td rowspan="14">Sunken Forest</td><td rowspan="3">Mulinia lateralis on medium sand within lagoon containing small dunes (high backscatter intensity)</td><td>Mulinia lateralis</td><td rowspan="3">64.2%</td><td>Polygordius jouinae (11.7%)</td><td rowspan="3">0.40 km^2 (16.7%)</td></tr>
<tr><td>Polygordius jouinae</td><td>Nematoda (10.2%)</td></tr>
<tr><td>Nematoda</td><td>Mulinia lateralis (9.7%)</td></tr>
<tr><td rowspan="3">Mulinia lateralis and Polygordius jouinae on medium sand within lagoon containing sand waves **</td><td>Mulinia lateralis</td><td rowspan="3">64.0%</td><td>Polygordius jouinae (9.2%)</td><td rowspan="3">0.76 km^2 (31.8%)</td></tr>
<tr><td>Polygordius jouinae</td><td>Nematoda (7.7%)</td></tr>
<tr><td>Nematoda</td><td>Mulinia lateralis (5.9%)</td></tr>
<tr><td rowspan="3">Owenia fusiformis on mixture of medium sand and fine sediment within lagoon channel</td><td>Owenia fusiformis</td><td rowspan="3">63.1%</td><td>Owenia fusiformis (7.61%)</td><td rowspan="3">0.13 km^2 (5.4%)</td></tr>
<tr><td>Heteromastus filiformis</td><td>Glycinde solitaire (6.3%)</td></tr>
<tr><td>Polygordius jouinae</td><td>Heteromastus filiformis (6.29%)</td></tr>
<tr><td rowspan="3">Mulinia lateralis and Nematoda on medium sand within surge platform containing bedforms *</td><td>Mulinia lateralis</td><td rowspan="3">n/a</td><td rowspan="3">n/a</td><td rowspan="3">0.55 km^2 (23.0%)</td></tr>
<tr><td>Nematoda</td></tr>
<tr><td>Polygordius jouinae</td></tr>
<tr><td>Polydora ligni on medium sand within surge platform</td><td>Polydora ligni</td><td>n/a</td><td>n/a</td><td>0.02 km^2 (0.84%)</td></tr>
</table>

	containing erosionally exposed peat mixed with seagrass	*Ilyanassa obsoleta*			
	Leptosynapta tenuis and *Nematoda* on medium sand within seagrass bed *	*Leptosynapta tenuis*	n/a	n/a	0.02 km^2 (0.84%)
		Nematoda			
		Nereis arenaceodonta			

Within Sunken Forest, ANOSIM reported there are strong and statistically significant differences in macrofaunal communities map units defined either by geologic depositional environment type, or the presence of seagrass ($R = 0.70$; $p = 0.002$). Note: Map units within which no macrofaunal samples were collected were not included in the statistical analyses and remain classified only by their geologic depositional environment type (i.e. three map units comprising 19.2% of the study area). Of the six resulting map units, five were defined by the Geoform (Level 1 and Level 2) and Substrate Components and one was defined based on the presence of seagrass (Figure 11 and Table 4). The biotopes are biologically diverse, being defined or co-defined by six species belonging to four phyla. The three lagoon-based biotopes are defined or co-defined by three species: the filter-feeding Dwarf Surf Clam, *M. lateralis* (two biotopes), the tube-building polychaete worm, *Owenia fusiformis* (one biotope), and the motile deposit-feeding polychaete worm, *P. jouinae* (one biotope). The surge platform biotope with bedform features is co-defined by *M. lateralis* and Nematoda. The second surge platform biotope is unique in that it contains peat exposed by erosion along the shoreline, as well as patches of seagrass. This biotope is dominated by the deposit-feeding polychaete worm, *Polydora ligni*. The seagrass-defined biotope is also unique, being dominated by the burrowing and deposit-feeding sea cucumber, *Leptosynapta tenuis*. The SIMPER routine, run on the three biotopes that contained more than one macrofaunal sample, shows the average within-biotope biological similarity ranges from 63.1% to 64.2% (Table 4). Considerable overlap exists between the top three species that are dominant and that contribute most to the within-biotope similarity, with contributions ranging from 5.9% to 11.7%.

The nMDS plot indicates three distinct clusters of samples (Figure 12). The two sites that separate out to the bottom right are the only samples collected within seagrass. The site located at mid-distance from the primary cluster contained *Zostera marina* of mediocre health, whereas the furthest site had *Ruppia maritima* that was vibrant and healthy, and is likely the reason it exhibits a greater deviation from the majority of the sites within the study area. The two sample sites that separate out to the top right of the plot contain a substantially higher fine sediment fraction when compared to the other sites. The distance of these two sites on the plot is also meaningful, as it represents the fine sediment fraction, which is 8.3% for the mid-distance site and 27% for the furthest site. The overall pattern also follows distance from shore and water depth, with the two seagrass sites located nearest to shore at a water depth of approximately 1 m, and the two finer sediment sites located furthest from shore in a water depth of approximately 3.5 m. The fact that the nMDS plot reflects the most notable distinctions within Sunken Forest supports defining the biotopes according to the Substrate Component and seagrass presence (in addition to the Geoform Component).

1.4.5. East Breach

Overall, East Breach can confidently be characterized as a sandy environment through the examination of the sidescan mosaic and aerial imagery, as well as from scientific understanding of the physical processes that lead to inlet formation and evolution (e.g. Hayes and Fitzgerald, 2013). The bathymetry shows water depths range from 0.3 m to 1.3 m for most the area, with the exception of the channel, which averages 3 m, though reaches depths of 5 m to 7 m in one location. Strategically selecting ground-truth locations for exploratory purposes, rather than employing a random sampling design, resulted in discoveries that would potentially not have been made otherwise in East Breach. The most notable was the discovery of mature blue mussels, *M. edulis*, present in dense clusters throughout the study area identified following the collection of ground-truth samples within two distinct acoustic signatures visible in the sidescan record. One signature represents substantial mussel reefs in areas of coarse sand and the other represents mussel beds in an area of clay and silt (Figure 13). Other features identified include small clusters of seagrass within fine and medium sand to the northwest, a dense amphipod tube-mat in clay and silt to the northeast, and large-scale sand waves of medium and coarse grain size throughout the study area.

1.5. Discussion

Maps illustrating the distribution and extent of benthic biotopes or habitats are valuable tools for numerous ecological and management purposes, including understanding ecosystem patterns and processes, constructing environmental baselines and monitoring programs, and conducting impact assessments. Such comprehensive information can lead to the development of ecosystem based management strategies that are proactive and readily adaptable to changing conditions, both natural and human-induced. The primary goal of this study was to develop biotope classification maps to define relationships between macrofaunal communities and their associated environmental characteristics utilizing the CMECS framework for the Otis Pike and Sunken Forest study areas within FIIS. Secondary goals were to understand overall macrofaunal patterns and to assess spatial and temporal changes in seagrass distribution and density within Otis Pike and Sunken Forest, as well as to provide a description of the biotic and abiotic benthic characteristics within East Breach, the area to the east of the new tidal inlet created as a result of Hurricane Sandy. These goals establish a comprehensive baseline dataset for FIIS to serve as a point of comparison for future data.

1.5.1. CMECS Biotopes

The classification approach produced biotopes that describe ecologically meaningful biotic-abiotic relationships by establishing well-recognized and statistically distinct macrofaunal communities among the defined map units within both Otis Pike and Sunken Forest. That the CMECS-defined map units were able to characterize the study areas at such a high level indicates the utility of CMECS beyond as a framework for classifying data in the final stages of a study. The success may be attributed to the hierarchical structure of CMECS, which allows for the integration of data across spatial scales, promoting the development of comprehensive units (described by one or multiple components) that can reflect complex environments and conditions. This capability is particularly valuable given that macrofauna are frequently found to be associated with a combination of fine- and broad-scale parameters (e.g. Porskamp et al., 2018; Lecours et al., 2015; De Leo et al., 2014; LaFrance et al., 2014; McArthur et al., 2010; Hale, 2010). Consequently, these integrated units are more ecologically relevant for developing biotopes and identifying biotic-abiotic relationships.

In this study, the incorporation of the CMECS Geoform and Substrate Components to produce geologic depositional environments yielded map units that describe complex processes. While these components present the geological context of the map units, they also reflect physical and hydrodynamic processes that contribute to the structure and shape of the seafloor. For instance, the presence or absence of large- and small-scale geologic features is indicative of different depositional environments and flow regimes (Southard, 1991); e.g., velocities of 0.5 > 1.0 m s^{-1} are required to form and maintain sandwaves (Southard and Boguchwal, 1990). As such, the components are able to describe environmental conditions that are relevant to and influence biological community distribution. Evidence of this influence is seen in the ANOSIM and SIMPER results, as well as the nMDS plot for Otis Pike illustrating that macrofaunal community composition can best be explained by distance from shore. The Geoform Level 1 and Substrate Components within Otis Pike can also be distinguished according to distance from shore. The lagoon units are further from shore and are largely characterized by basins and flats of fine and medium grain size sand, indicative of relatively calm physical conditions (e.g. wave action, hydrodynamics). Conversely, the surge platform unit nearshore is characterized by multi-directional sand waves of various sizes composed of medium to coarse sand, indicating a higher energy regime. Therefore, these geologically-defined CMECS components may be a proxy for physical energy and the level of tolerance and/or preference species have for dynamic versus stable environments.

The biological classification of the biotopes was sufficiently described using the Biotic Component based on dominance with respect to species abundance. The SIMPER results supported and complemented this approach, reporting that the dominant species also tended to be most responsible for the within-biotope similarity. Examination of the raw data also indicated that the dominant species were representative of all the samples within a given biotope, with one exception. For the biotope defined by *M. lateralis* and *P. jouinae* in Sunken Forest, *M. lateralis* was the most abundant species because a high number of individuals were recovered at one of the sample sites. However, *P. jouinae* was found to be the first or second most abundant species across all of the sample sites within the biotope. To address this discrepancy, the biotope was labeled by both species and the reason noted. The flexibility within CMECS allows for this incorporation of additional information into the output. Rather than being restrictive in its classification structure, CMECS provides the opportunity to develop outputs that are comprehensive and best suit the needs of the user, rather than being restrictive or forcing the user to make firm decisions at the expense of removing valuable information.

1.5.2. Biotic-Abiotic Relationships

The biotopes within each study area are ecologically distinct, being characterized by species with differing functional roles. For Otis Pike, the seagrass biotope is defined by the small filter-feeding bivalve *G. gemma*, the lagoon biotope by the tube-building amphipod *A. verrilli*, and the surge platform biotope by the deposit-feeding polychaete worm *P. jouinae*. This pattern is also evident within Sunken Forest, and furthermore, macrofaunal composition similarity was found to be greater within biotopes that share similar geological and sediment characteristics. The three biotopes defined by medium sand and surficial seafloor features (i.e. small dunes, sand waves, bedforms) are dominated or co-dominated by the filter-feeding bivalve *M. lateralis*,. Comparatively, the finer sediment biotope is defined by the tube-building polychaete worm *O. fusiformis*, and the seagrass biotopes are each defined by deposit feeders, the sea cucumber *L. tenuis* and polychaete *P. ligni*.

The biotope classification also highlighted the influence of seagrass on macrofaunal community composition. The two seagrass sites sampled within Sunken Forest were dominated by macrofauna that were found in low abundances (*L. tenuis*) or entirely absent (*P. ligni*) elsewhere throughout the study area. Similarly, species found in high abundances across all sample sites tended to be absent or recovered in low abundances at the seagrass sites, including *P. jouinae*, *M. lateralis*, *Tellina agilis*. Within Otis Pike, very dense seagrass played a role in structuring macrofaunal communities, as evidenced by the abundances of the dominant species within and outside of the biotope. Over 6,400 individuals of *G. gemma* were recovered within the seagrass biotope, compared in a total of 168 and 290 individuals in the surge platform and lagoon biotopes, respectively. Similarly, *L. savignyi* was recovered in samples only located within seagrass biotope (n=4,305), and nematode abundance was substantially higher (n=2000 versus 600).

While there was some distinction in sediment type across the biotopes, the majority of the study areas are either entirely, or partially characterized by sand of medium grain size. An initial examination into the some of the species identified as dominating one or more study areas and/or defining the biotopes indicates the sediment preferences for most of these species are fairly non-specific, with many occupying a broad range of substrates types. For example, high densities of *A. vadorum* and *A. verrilli* can occur in sandy environments ranging from silty sand to coarse sand to sand mixed with gravel and shell (Dickinson et al., 1980). *M. edulis* can colonize substrates ranging from mud to cobbles (Maddock, 2008). Other species tend to be more restricted, for example, *P. jouinae* is prefers medium to very coarse grain sand (Ramey, 2008), *O. fusiformis* inhabits fine to coarse grain sand (Pinedo et al., 2000), and *G. gemma* prefers sand flats comprised of medium sand or well-sorted grain sizes (Weinberg and Whitlatch, 1983). As such, while the sediment type can be used to refine biotope boundaries and descriptions, it should not be relied upon as the sole discriminating factor. Further, sediment type will play a more substantial role in defining some macrofaunal species/communities than others. These overall conclusions are frequently identified in benthic studies (LaFrance et al., 2014; Raineault et al., 2012; McArthur et al., 2010; Hale, 2010; Snelgrove 1999; Snelgrove and Butman, 1994) and reiterates the need to consider factors in addition to sediment type in determining benthic macrofauna community structure characteristics.

1.5.3. Comparing Otis Pike and Sunken Forest Study Areas

Despite the apparent similarities of Otis Pike and Sunken Forest, including their close proximity to one another, location along the bayside of FIIS within Great South Bay, and similar geological and sediment structures, the two areas are reasonably different. Most notably, the study areas do not have any biotopes in common. Geologically, Otis Pike and Sunken Forest share only broad-scale similarities, exhibiting some common Geoform and Substrate designations, but not in combination. Otis Pike is a more diverse and dynamic environment, containing areas of multi-directional bedforms and sand waves of various sizes, as evident in the sidescan and aerial imagery. These features indicate Otis Pike is more influenced by physical and hydrodynamic processes (e.g. currents, tide, wave action, wind). Similarly, while both areas are dominated by sand, analysis of the sediment samples collected within Otis Pike reveal the area is essentially void of finer sediments, further indicating it is an active areal; whereas finer sediment is present within Sunken Forest.

Biologically, the two study areas are characterized by different dominant phyla and species. For example, Arthropoda dominate Otis Pike due to overwhelming abundances of tube-building amphipods, though it is the least dominant phylum found within Sunken Forest. Further, the biotopes in both areas are classified by different species, with the exception of *P. jouinae*, which defines and co-defines one biotope within Otis Pike and Sunken Forest, respectively. On a functional level, the two study areas exhibit greater similarity, each having biotopes defined by a small filter-feeding bivalve, tube-building macrofauna (amphipod in Otis Pike, polychaete in Sunken Forest), and deposit feeding macrofauna (polychaete in Otis Pike, polychaetes and sea cucumber in Sunken Forest).

1.5.4. Influence of the New Tidal Inlet

The opening of the new inlet has led to an influx of ocean water into Great South Bay, resulting in substantial environmental changes caused by alterations in circulation and flushing patterns, including increases in salinity, water clarity, and light availability, as well as reduced water temperatures (NPS staff, Pers. Comm). All of these factors have been found to be drivers for the distribution of seagrass and benthic species and communities (McArthur et al., 2010; Hale, 2010; Snelgrove, 2001). The data collected in this study found East Breach contained a diverse range of distinct benthic communities and habitat types, evidence that the inlet is having a positive influence on the immediate area. For example, emerging patches of healthy seagrass in sandy substrate were noted, as was a dense tube-mat in an area of clay-silt substrate (with nearly 1,000 *A. vadorum* individuals recovered in one grab sample). Mature, dense mussel beds being supported in both coarse sand and clay-silt sediment were also discovered throughout the study area. The extensive presence of mussels within East Breach and near absence within Otis Pike and Sunken Forest represent a distinction in ecosystem structure that is not believed to have existed prior to Hurricane Sandy. The mussel beds and reefs seem to be stable, as it would require between one and three years for mussels to reach the growth stage (3-5 cm) that was observed (Rodhouse et al., 1986).

The degree to which Otis Pike and Sunken Forest were similar (e.g. physically, geologically, biologically) before the breach occurred and the inlet formed cannot be evaluated directly due to a lack of historical data in the area. However, the two study areas do exhibit some clear distinctions in dominant macrofauna, seagrass extent and density, and surficial sediment characteristics, which can sensibly be attributed to the distance of each study area from the inlet. Seagrass, in particular, appears strongly linked to the influence of the inlet. Seagrass has increased within Otis Pike since 2002 in areas located in close proximity to the new inlet (~2-4 km) and is also emerging in the immediate vicinity of the inlet in the East Breach study area. The altered conditions within Great South Bay caused by the inlet are believed to be promoting this growth in seagrass. Conversely, seagrass extent and density appears to decline along a gradient with increasing distance from the inlet. Such a trend is evident within the Otis Pike area and continues moving further west to Sunken Forest, located approximately 19 km from the inlet, within which total seagrass coverage in 2015 is 5% of what was present in 2002. Also, seagrass within Sunken Forest in 2015 exists in very small, fragmented patches that do not overlap much with the 2002 extent, suggesting seagrass might have expanded at one time before declining. The causes for such a considerable decline are attributed to poor water quality conditions, such as elevated water temperature and nutrient levels, and reduced light availability. There are several lines of evidence to suggest that light availability is potentially the most significant factor controlling seagrass distribution within Sunken Forest. First, the majority of the seagrass that persists is located in the shallowest portions of the study area. Second, the healthy seagrass site sampled during the ground-truth survey is located in shallower water than the less healthy site. Third, unsuccessful attempts to gather video footage due to high turbidity reveal that visibility is often limited to less than 0.3 m, and therefore light availability is also limited.

1.5.5. Implications for management

A fundamental understanding of the ecological function and value of the biotopes identified within Otis Pike and Sunken Forest is needed to fully appreciate these submerged lands and guide scientifically sound and adaptive management decisions. Table 5 begins to address this need by noting the ecological value for select species that define the biotopes and/or dominate the study areas, and therefore, could be of interest from a management and regulatory perspective. For example, the filter-feeding bivalves, *M. lateralis*, *G. gemma*, and *M. edulis*, are an important and well-documented source of food for various waterfowl that winter in the region. Waterfowl that consume both *M. lateralis* and *G. gemma* include the Surf Scoter (Perry et al., 2007), Lesser Scaup, and Long-tailed Duck (Baldassarre, 2014). The diet of the America Black Duck partially consists of *G. gemma* and *M. edulis*, and *M. edulis* is a preferred for the Common Eider (Baldassarre, 2014). Similarly, both *A. verrilli* and *A. vadorum* are amphipods believed to be important food sources for some species of finfish, including several commercially important species (Dickenson et al., 1980). These amphipods, along with the polychaete worm, *O. fusiformis*, are tube-building organisms that can create very dense, abundance-rich tube-mats that alter the structure of the seafloor. The tubes may stabilize the sediment and increase small-scale environmental heterogeneity (Pinedo et al., 2000).

Another example is the motile deposit-feeding polychaete worm, *P. jouinae*, which can be an indicator of changing sediment conditions (Ramey, 2008).

Table 5. Description of select species identified within FIIS. *Note: These species tended to be dominant in at least one of the three study areas and/or define one or more biotope. Description includes reason species may be of interest with respect to management, and additional notes relevant to this study.*

Species	Reason(s) for Interest / Management Considerations	Relevant from this study
Ampelisca vadorum (Arthropoda / Amphipoda)	Important food source for some fish species, including being the primary food source for juveniles of several commercially important species[1]	Findings from this study confirm that *A. vadorum* is present in environments dominated by medium and fine sand and can occur in high densities. The majority of individuals were recovered within Otis Pike, with the exception of one site within East Breach. The greatest abundance recovered at one site was 964. Though, as few as 1 individual was recovered at other sites.
Ampelisca verrilli (Arthropoda / Amphipoda)	Important food source for some fish species, including being the primary food source for juveniles of several commercially important fish species[1]	Findings from this study confirm that *A. verrilli* is present in environments dominated by medium and fine sand. The vast majority of individuals were recovered within Otis Pike. *A. verrilli* is a dominant species within Otis Pike and is responsible for defining one of the Otis Pike biotopes. The species can occur in high densities, with the greatest abundance recovered at one site was 504 individuals. Though, as few as 1 individual was recovered at other sites.
Mytilus edulis (Mollusca / Bivalvia)	Important food source for some wintering waterfowl (e.g. American Black Duck, Common Eider)[2]; Has a role in healthy functioning of marine ecosystem; Filter particles from the water column; Provide food source; Enhances biodiversity in sediment-	Findings from this study confirm that *M. edulis* is present in environments dominated by medium and fine sand. Where the species is present in Otis Pike and East Breach, it tends to occur in high densities. At 5 of the 6 samples sites it was recovered within, 161 to 566 individuals were counted.

	dominated environments[3]	
Gemma Gemma (Mollusca / Bivalvia)	Important food source for some wintering waterfowl (e.g. Lesser Scaup, American Black Duck, Surf Scoter; Long-tailed Duck)[2]; Naturally occurring species from Nova Scotia to Texas[4]. Is an invasive species along the West Coast of the United States, though generally considered non-threatening[5]	Findings from this study confirm that *G. gemma* is present in environments dominated by medium and fine sand. The vast majority of individuals were recovered within Otis Pike. *G. gemma* is a dominant species within Otis Pike and is responsible for defining one of the biotopes. The species can occur in high densities, with the greatest abundance recovered at one site being 1,944 individuals. Though, as few as 1 individual was recovered at other sites. Investigation of this species in its natural habitat may provide insights of its role in benthic communities, which may assist invasive species management strategies on the West Coast.
Mulinia lateralis (Mollusca / Bivalvia)	Important food source for some wintering waterfowl (e.g. Lesser Scaup[2], Long-tailed Duck[2], Surf Scoter[6]); Potential significantly contribute to benthic production and benefit commercially important fish species[7]	Findings from this study confirm that *M. lateralis* is present in environments dominated by medium and fine sand. *M. lateralis* is a dominant species within Sunken Forest and is responsible for defining or co-defining three of the Sunken Forest biotopes. The species is also fairly common within Otis Pike. *M. lateralis* can occur in high densities, with the greatest abundance recovered at one site was 737 individuals. Though, as few as 1 individual was recovered at other sites.
Polygordius jouinae (Annelida / Polychaeta)	Potential to have a major impact on sediment biogeochemistry; Potential indicator of changing sediment conditions[8]	Findings from this study confirm that *P. jouinae* is present in environments dominated by medium and fine sand. *P. jouinae* is a dominant species within Sunken Forest and Otis Pike. The species is also responsible for defining one of the Otis Pike biotopes and co-defining one of the Sunken Forest

		biotopes. The greatest abundance recovered at one site was 195 individuals. Though, as few as 1 individual was recovered at other sites.
Owenia fusiformis (Annelida / Polychaeta)	Lives within the tube it builds by cementing sediment granuals together with a saliva-like secretion; Tubes play a role in stabilizing sediment and increase small-scale environmental heterogeneity[9]	Findings from this study confirm that *O. fusiformis* is present in environments dominated by medium and fine sand. *O. fusiformis* is a dominant species within Sunken Forest and is fairly common within Otis Pike. The species is responsible for defining one of the Sunken Forest biotopes. The greatest abundance recovered at one site was 400 individuals. Though, as few as 1 individual was recovered at other sites.

[1]*Dickinson et al., 1980;* [2]*Baldassarre, 2014;* [3]*Maddock, 2008;* [4]*Abbott, 1974;* [5]*Global Invasive Species Database, 2007;* [6]*Perry et al., 2007;* [7]*Walker et al., 1984;* [8]*Ramey, 2008;* [9]*Pinedo et al., 2000*

The concept of ecological value can also be applied to seagrass. Seagrass and seagrass meadows have long been recognized as areas that are highly productive, biologically diverse, and provide numerous valuable ecological functions and services. Seagrass offers critical habitat and nursery grounds for various species of finfish and shellfish (Lefcheck et al., 2017; Gurbisz et al., 2016; Dennison et al., 1993), some of which are economically valuable species for recreational and commercial fishing (Hyndes et al., 2016, Orth et al., 2006); is a food source for waterfowl (Dennison et al., 2003); plays an important role in nutrient cycling and sediment stability (Gurbisz et al., 2016; Hyndes et al., 2016; Orth et al., 2006; Dennison et al., 1993); and provides shoreline protection through the attenuation of waves and currents (Lefcheck et al., 2017). Seagrass is also considered an indicator species of ecosystem health (Barrell et al., 2016; Neckles et al. 2012; Dennison et al., 1993).

Based on the ecological value given to the defining macrofaunal species and seagrass, the biotopes within the Otis Pike and Sunken Forest study areas can be prioritized relative to one another with respect to ecological value (Figure 14). The highest priority area corresponds to the biotope classified by seagrass and *G. gemma* (i.e., waterfowl food source) within Otis Pike and, as it is the only area to be characterized by two components considered to be of high ecological value. Areas assessed as medium priority were biotopes defined by species identified to be important food sources for either waterfowl or fish, or by seagrass. Only one biotope, within Sunken Forest, was assessed as relatively low priority, though the tubes built by the defining species, *O. fusiformis*, do have the potential to stabilize sediment and increase small-scale environmental heterogeneity. The maps presented here focus attention on areas that should be of greatest interest and concern to resource managers and regulators, and, as such, they can be valuable tools for guiding management decisions.

The analyses and biotope maps produced in this study indicate Otis Pike and Sunken Forest differ in several respects, despite the apparent similarities of the two study areas, such as their close proximity to one another along the bayside of Great South Bay and their similar geological and sediment structures. Differences identified between the two study areas include that Otis Pike and Sunken Forest do not share any identical biotope classes; Otis Pike appears to be a more dynamic environment and more influenced by physical and hydrodynamic processes; and Otis Pike is dominated by tube-building amphipods, whereas these species are among the least abundant within Sunken Forest. This finding is a reminder to be cautious in assuming that specific findings from one study area are relevant for another area, even on a local-scale.

The findings from this study cannot be directly compared to pre-Hurricane Sandy conditions due to the lack of historical data available, particularly with regard to biotope maps and macrofaunal data. However, there is sufficient evidence that the increased influx of ocean water into Great South Bay due the opening of new tidal inlet is having positive ecological effects. This finding is particularly evident within the East Breach study area, as demonstrated by the presence of mature blue mussels in dense concentrations and the emergence of seagrass beds.

The mapping approach used in this study was able to produce biotopes that describe ecologically meaningful biotic-abiotic relationships and establish statistically distinct macrofaunal communities among the defined map units within both Otis Pike and Sunken Forest. The biotope maps provide a well-defined depiction of the areas at a given moment in time. However, because they are a static temporal representation of an ever-changing marine realm, these maps are most effective when they are updated as new data become available. Updated habitat maps can also be used to monitor change over time and capture the dynamism, resiliency, and vulnerability of an area or biotopes. As such, the implementation of a monitoring within FIIS should be of critical priority. A monitoring program would ensure that biotic and abiotic conditions are documented on a regular basis using comparable protocols, allow for continual understanding of the biotopes within FIIS and associated biotic-abiotic relationships, document spatial and temporal changes, and allow patterns to be more readily identified and attributed to their cause (e.g. human activity, storm event, climate change).

1.5.6. Future Research Needs

The findings from this and other studies within FIIS and Great South Bay warrant the continuation of such research to further understand the changes that have occurred and anticipate the changes that may occur. Future benthic research should take the form of a well-defined monitoring program. The program should follow a tiered-structure approach, such that various datasets are collected over appropriate time and spatial scales. It is in these capacities that benthic mapping studies have the greatest value for developing management strategies. Additional sediment and macrofauna data could be used to refine the map unit boundaries, develop finer-scale biotopes with greater distinction (e.g. achieve a higher ANOSIM R value), and achieve a more complete understanding of ecosystem structure and the specific relationships between benthic macrofaunal communities and their associated environments. Furthermore, in incorporation of water quality data, such as light penetration, temperature, and salinity, could be used to better determine the distribution potential of seagrasses and anticipate changes over time. Perhaps of highest priority is to continue to understand the influence of the new tidal inlet on benthic habitats and species. Studies could examine the growth and distribution of seagrass and blue mussels, changes in species dynamics (e.g. composition, interaction, and potential species shifts) of macrofaunal communities, and the physical alteration of the seafloor due to changes in sediment transport. To accomplish this, efforts should focus on collecting and/or incorporating data from all three study areas (i.e. Sunken Forest, Otis Pike, East Breach) to allow for patterns associated with distance from the inlet to be adequately assessed.

1.6. Conclusion

The classification approach produced biotopes that describe ecologically meaningful biotic-abiotic relationships by establishing well-recognized and statistically distinct macrofaunal communities among the defined map units within both Otis Pike and Sunken Forest. This study demonstrates value of benthic habitat mapping and CMECS for FIIS from an ecological and management perspective and argues the critical need for continued monitoring. Establishing a monitoring program that is both cost-effective and efficient can be accomplished using a subset of the technologies and methodologies applied in this baseline study. Such a program would allow for further understanding of the biotopes within FIIS and the associated biotic-abiotic relationships, and would document the dynamism, resiliency, and vulnerability of the area and each biotope. This knowledge is required to implement adaptive, science based management actions in a timely manner, before they become too ineffective or costly. In this capacity, benthic mapping and continued monitoring offers a proactive approach towards resource stewardship and management.

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1.8. Figures

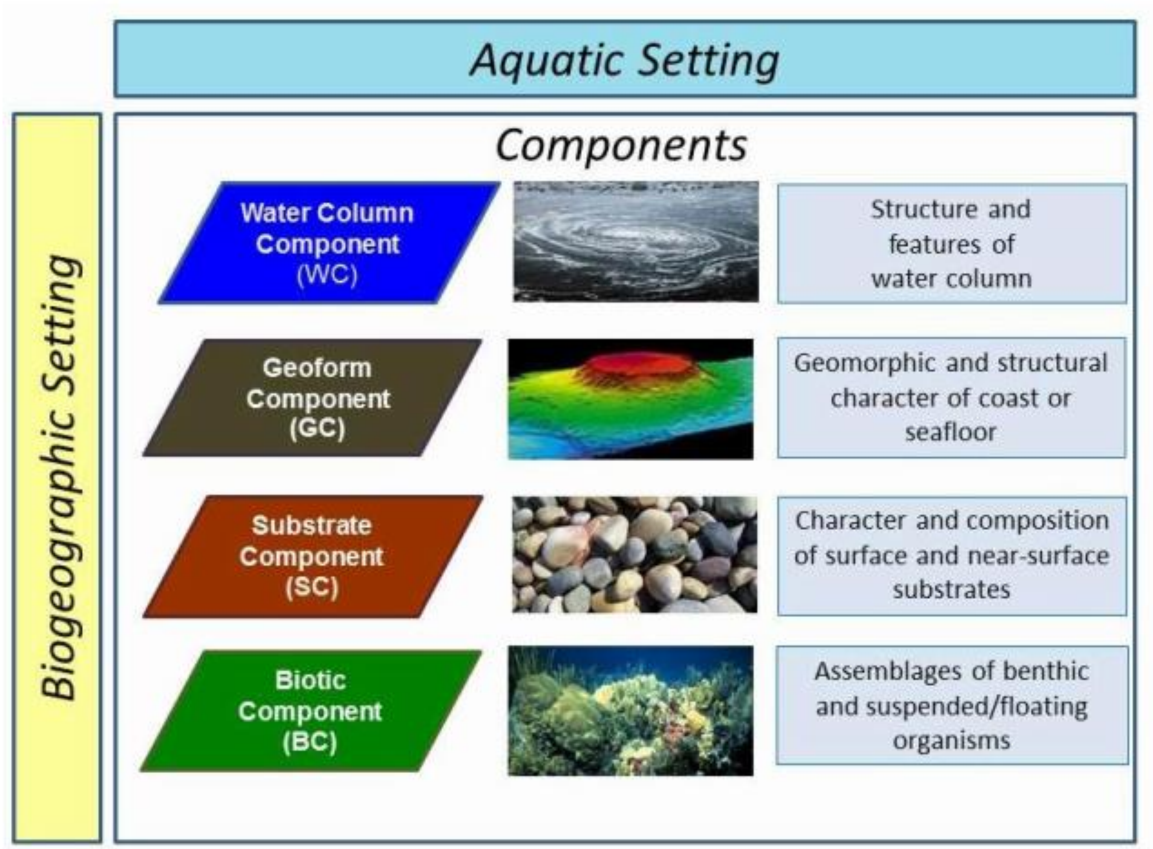


Figure 1. Structure of the Coastal and Marine Ecological Classification Standard (CMECS) framework.

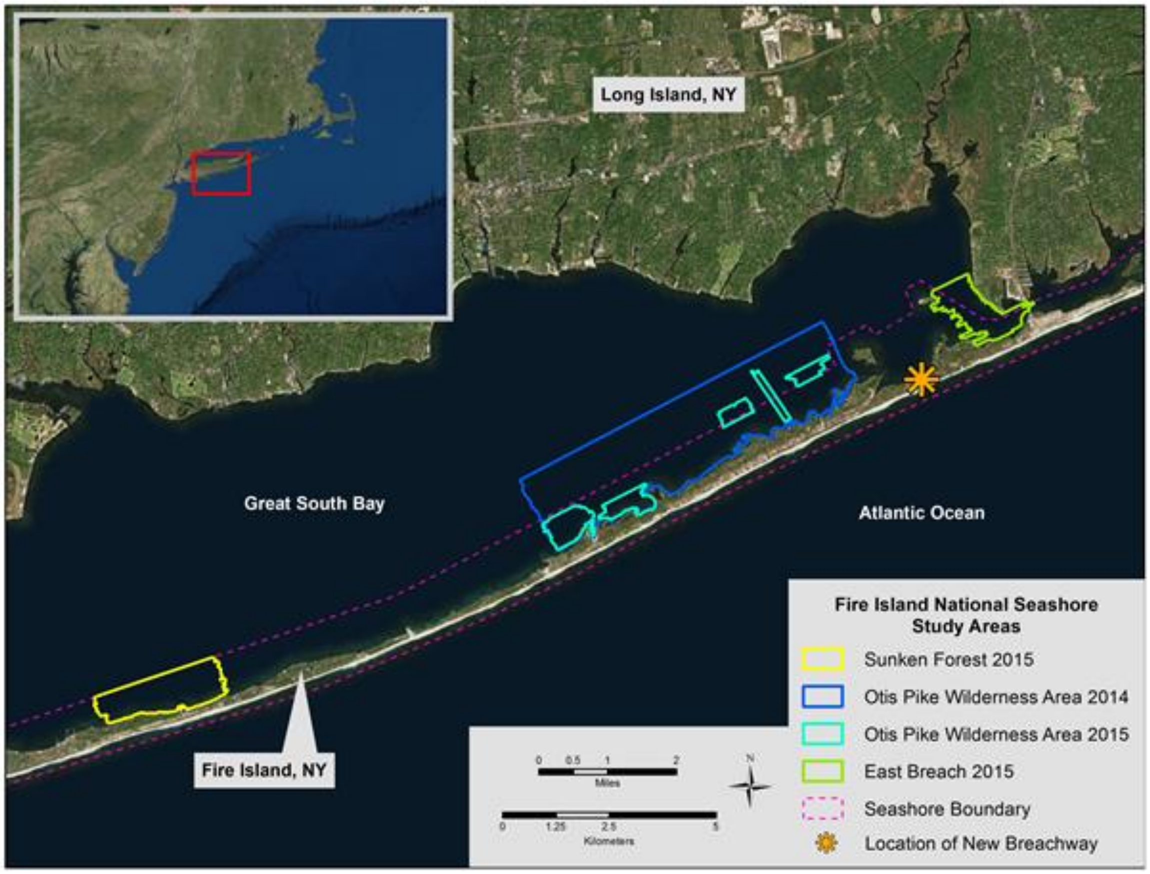
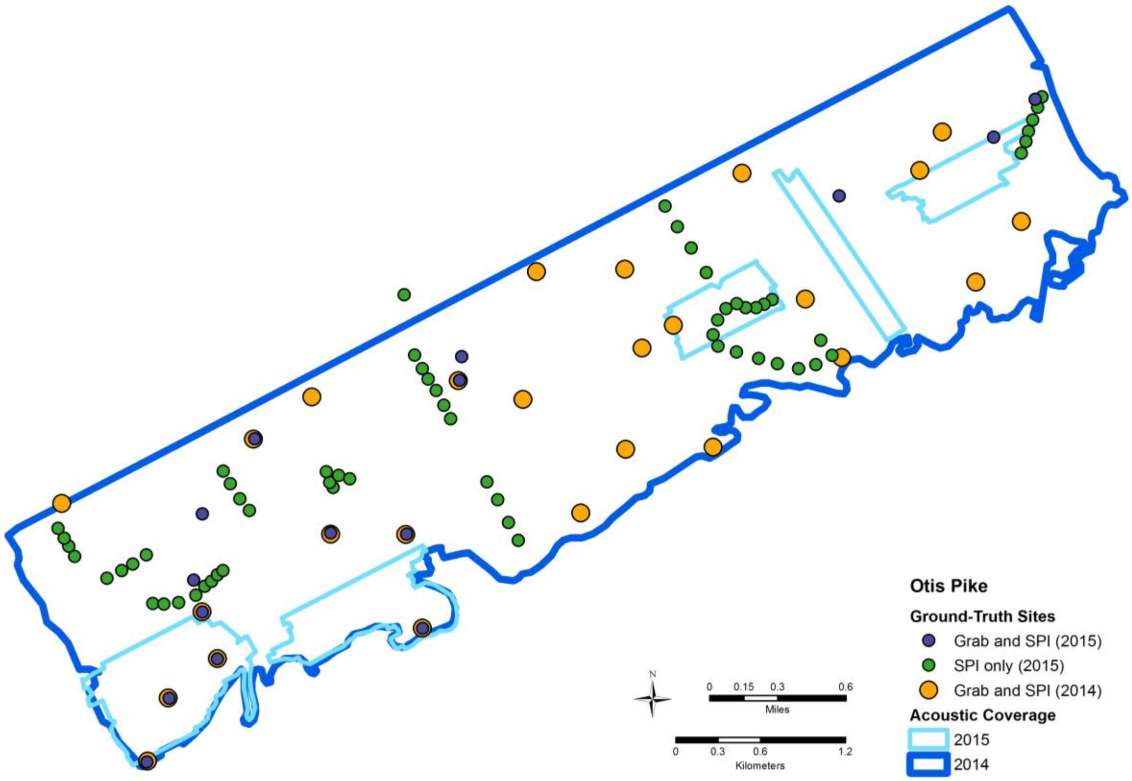
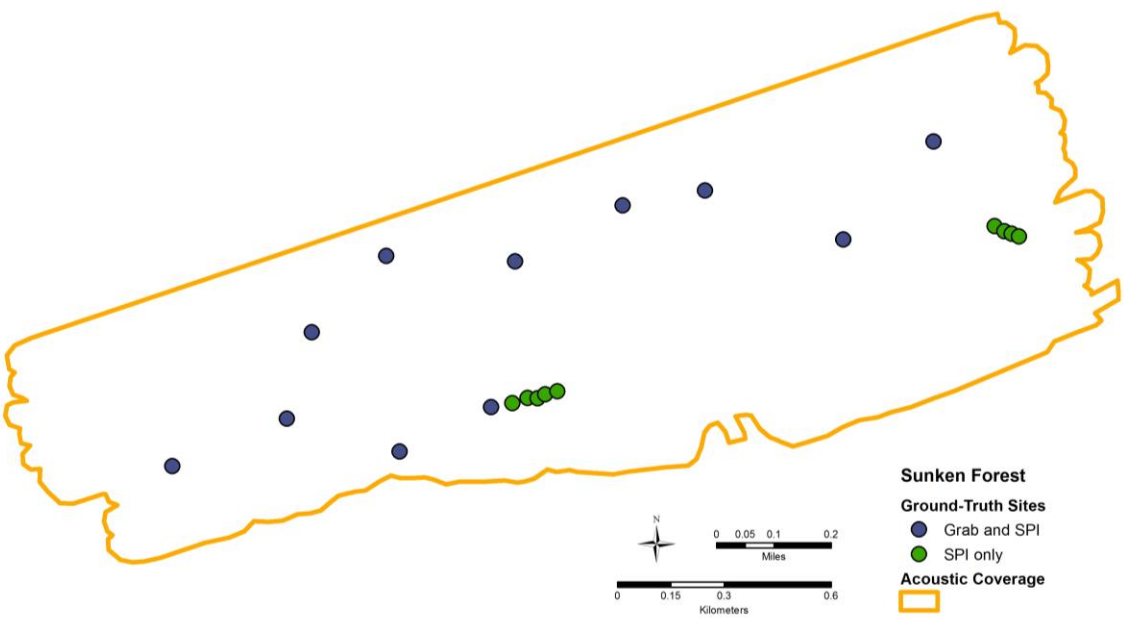


Figure 2. Map of Fire Island National Seashore, New York, and associated study areas.


Otis Pike
Ground-Truth Sites
Grab and SPI (2015)
SPI only (2015)
Grab and SPI (2014)
Acoustic Coverage
2015
2014
N
0 0.15 0.3 0.6
Miles
0 0.3 0.6 1.2
Kilometers


Sunken Forest
Ground-Truth Sites
Grab and SPI
SPI only
Acoustic Coverage
N
0 0.05 0.1 0.2
Miles
0 0.15 0.3 0.6
Kilometers

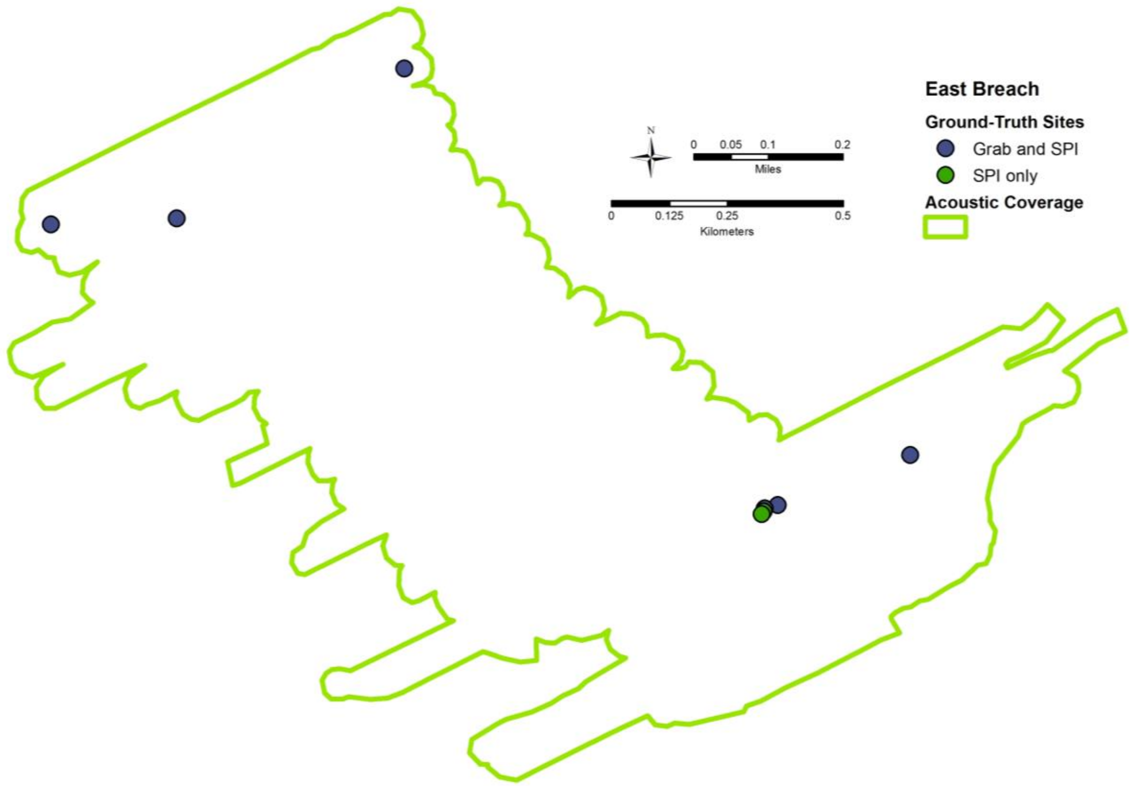


Figure 3. Acoustic survey coverage and ground-truth survey sample locations for the Otis Pike, Sunken Forest, and East Breach study areas.

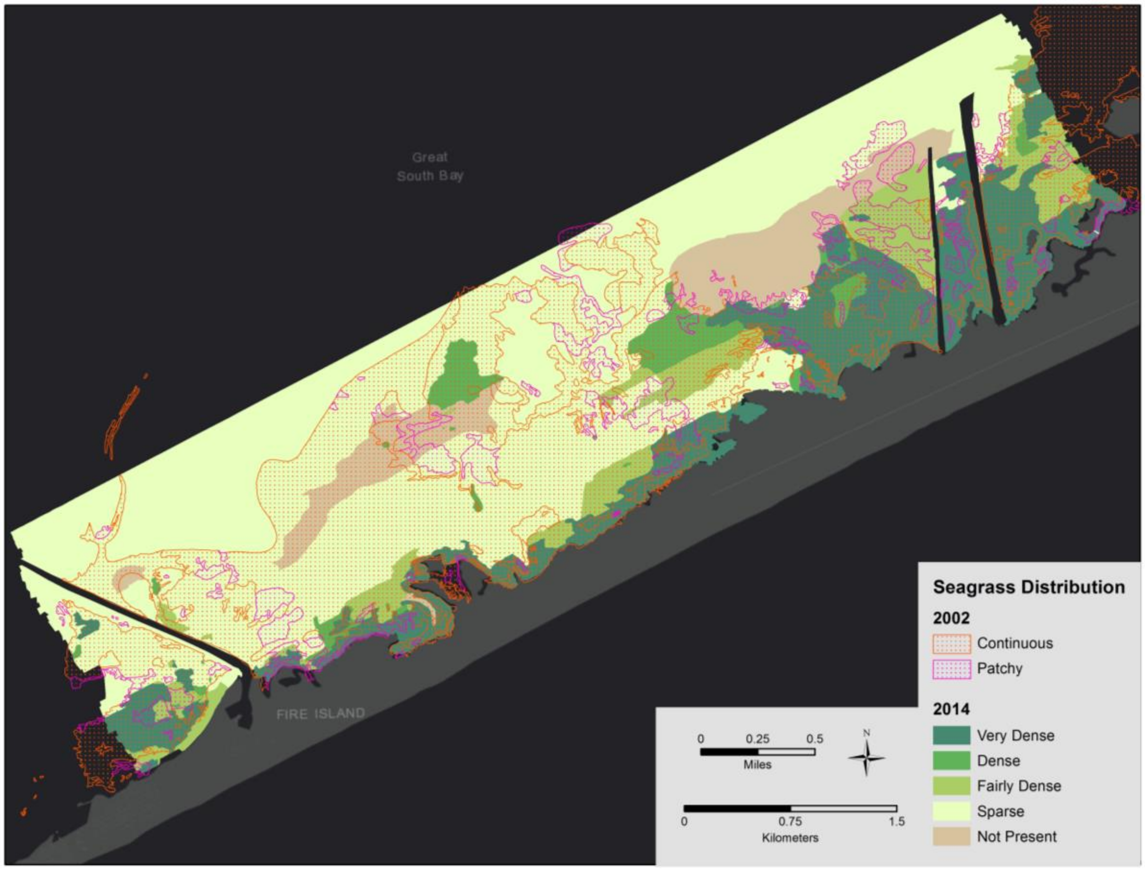
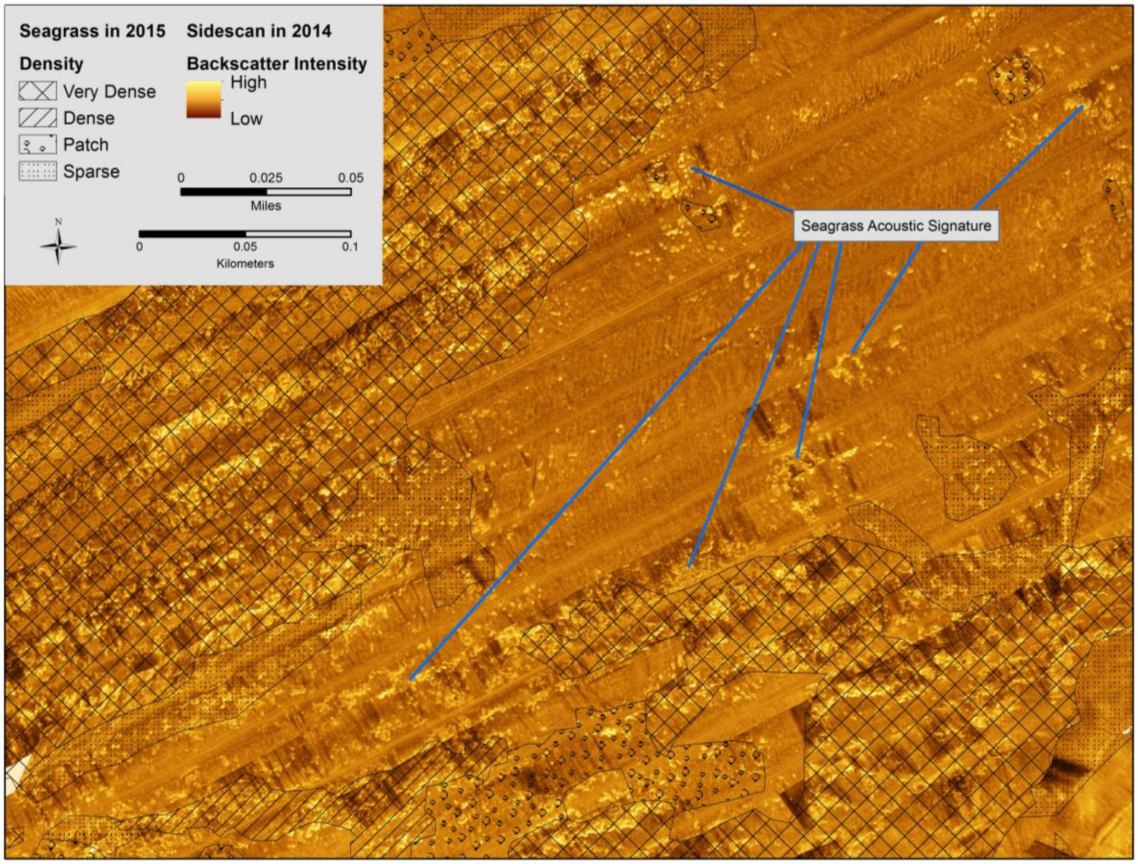


Figure 4. Maps comparing seagrass distribution and extent for Otis Pike in 2002 and 2014. *Note: Over the 12 year period, seagrass has declined substantially in the western portion of the study area, but appears to have expanded in the eastern portion.*


Seagrass in 2015
Sidescan in 2014
Density
Very Dense
Dense
Patch
Sparse
Backscatter Intensity
High
Low
0
0.025
0.05
Miles
0
0.05
0.1
Kilometers
N
Seagrass Acoustic Signature

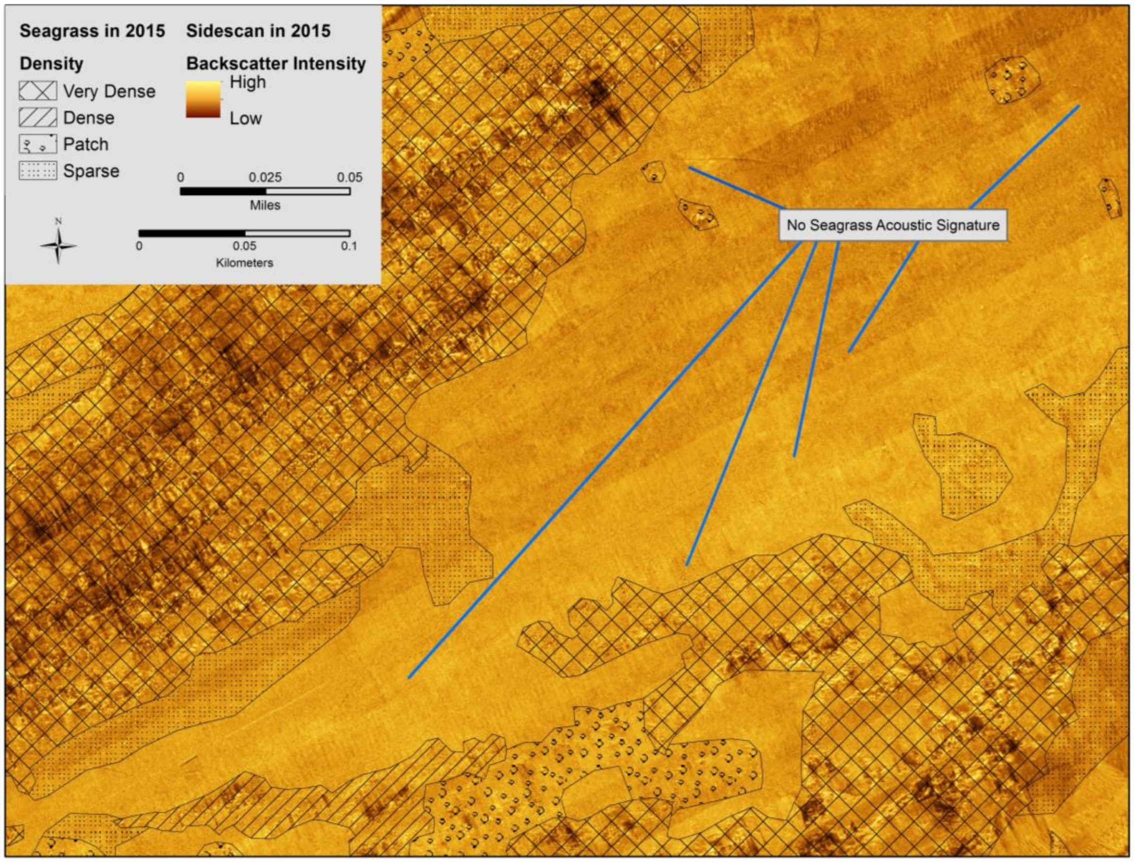


Figure 5. Western boundary of the Otis Pike study area showing (a) 2014 sidescan mosaic and (b) 2015 sidescan mosaic, both superimposed with polygons delineating 2015 seagrass extent and density. *Note: Blue lines are examples of where seagrass is visible in the 2014 sidescan record, but is no longer present in the 2015 record.*

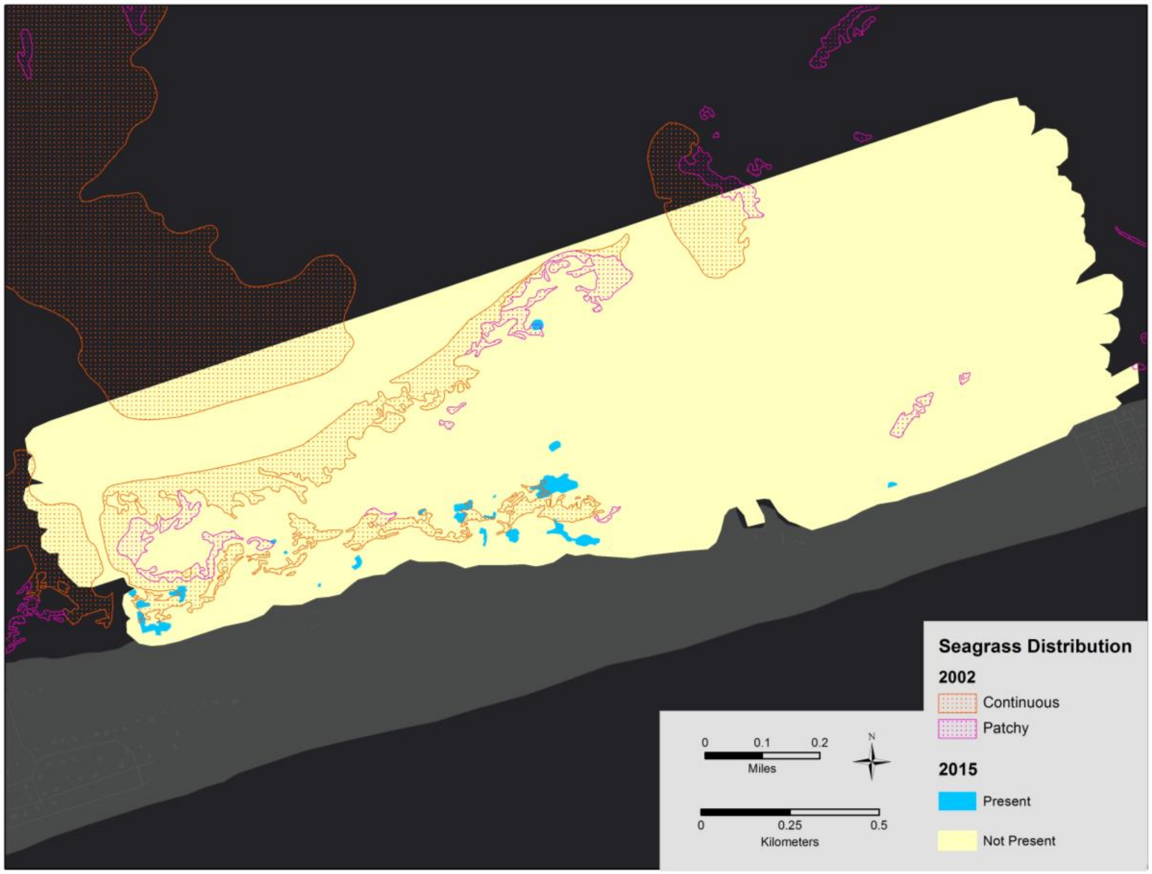
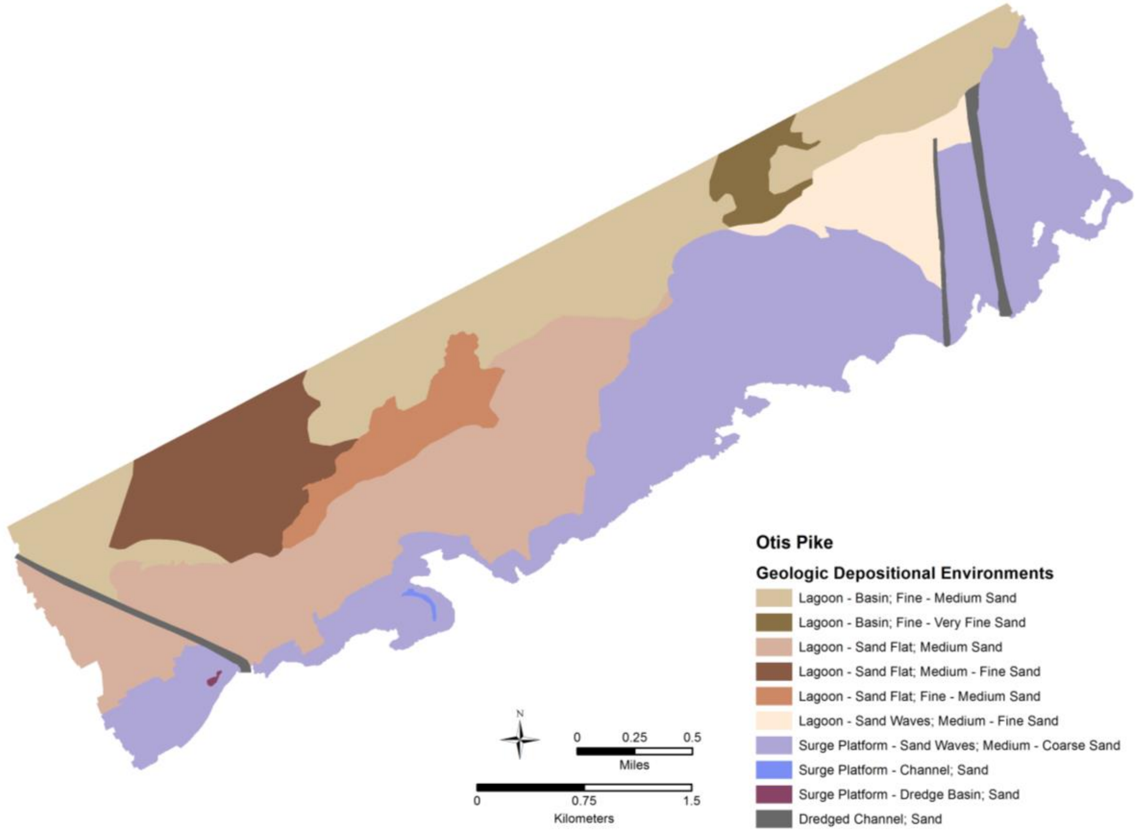


Figure 6. Maps comparing seagrass distribution and extent for Sunken Forest in 2002 and 2015. *Note: The area has experienced a 95% decline in seagrass over the 13 year period.*


Otis Pike
Geologic Depositional Environments
Lagoon - Basin; Fine - Medium Sand
Lagoon - Basin; Fine - Very Fine Sand
Lagoon - Sand Flat; Medium Sand
Lagoon - Sand Flat; Medium - Fine Sand
Lagoon - Sand Flat; Fine - Medium Sand
Lagoon - Sand Waves; Medium - Fine Sand
Surge Platform - Sand Waves; Medium - Coarse Sand
Surge Platform - Channel; Sand
Surge Platform - Dredge Basin; Sand
Dredged Channel; Sand
N
0 0.25 0.5
Miles
0 0.75 1.5
Kilometers

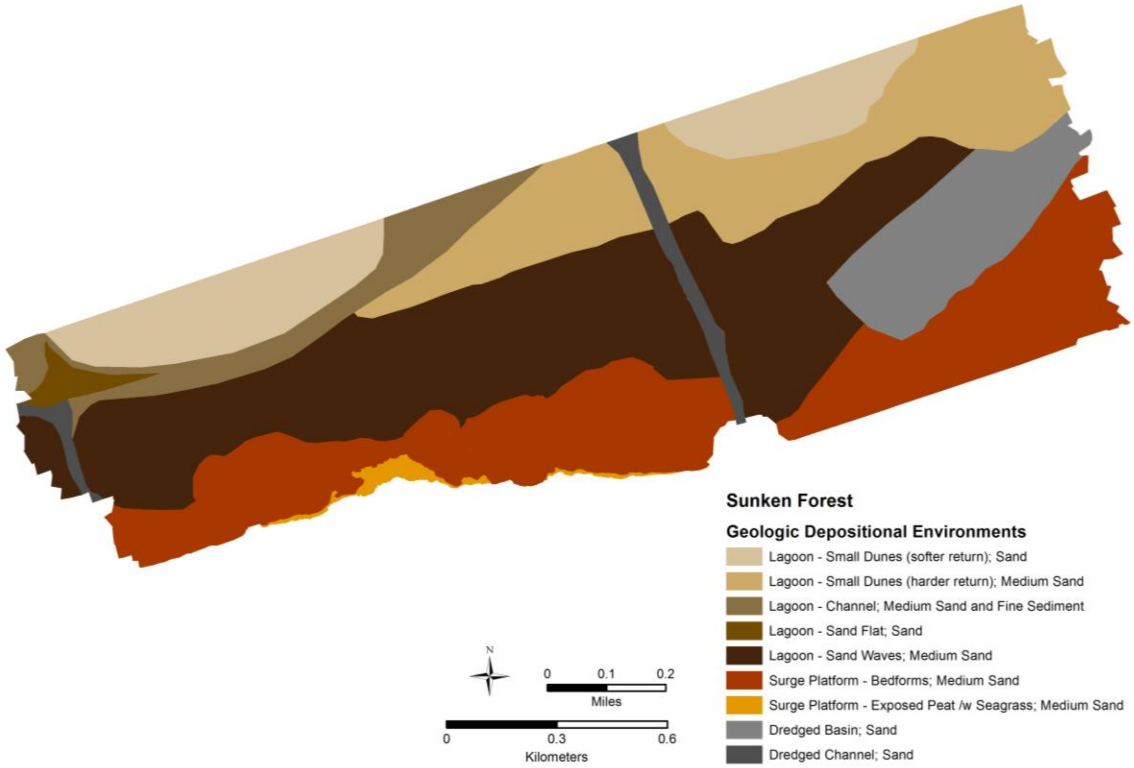


Figure 7. Geologic depositional environment classification maps of a.) Otis Pike and b.) Sunken Forest. *Note: The map units are labeled according to the Geoform and Substrate Components within the CMECS framework. "Fine Sediment" refers to the combined clay to fine sand grain size fractions.*

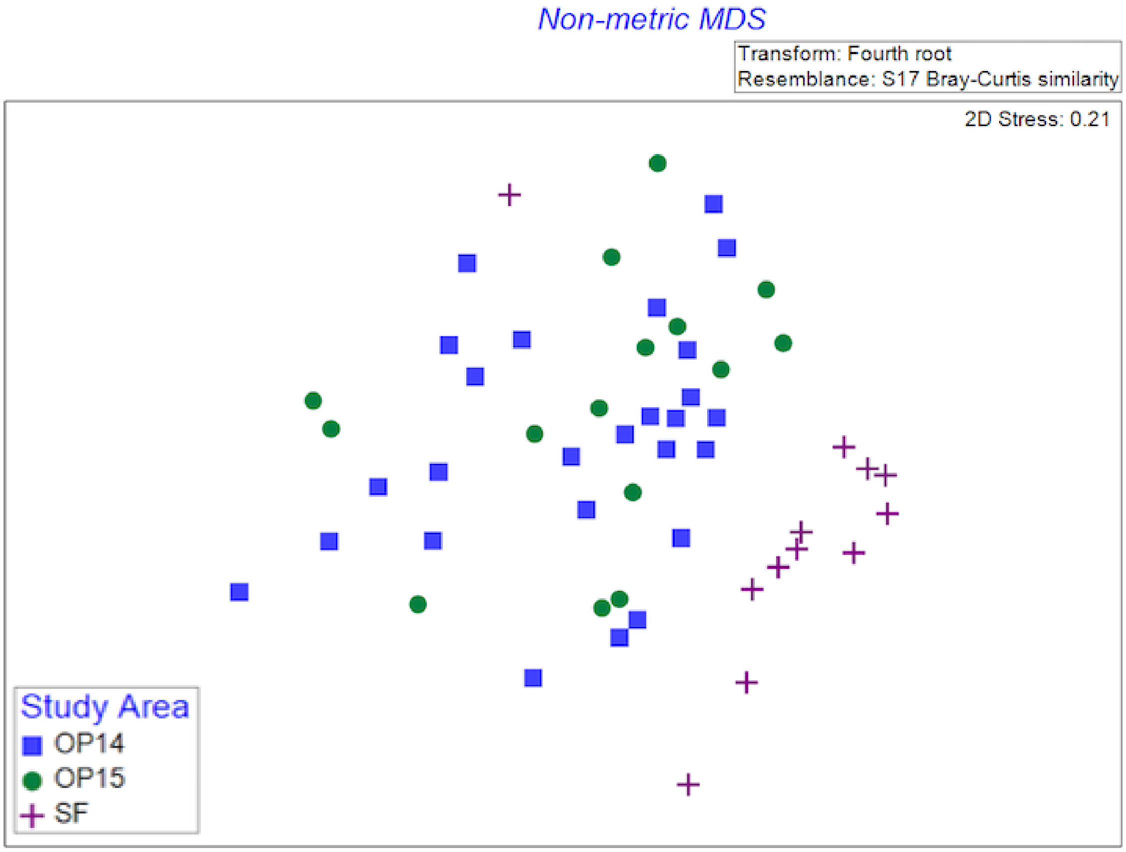


Figure 8. The nMDS plot of samples collected within the Otis Pike and Sunken Forest study areas. *Note: The plot shows benthic macrofaunal samples separate out according to study area, indicating Otis Pike and Sunken Forest contain relatively distinct benthic communities.*

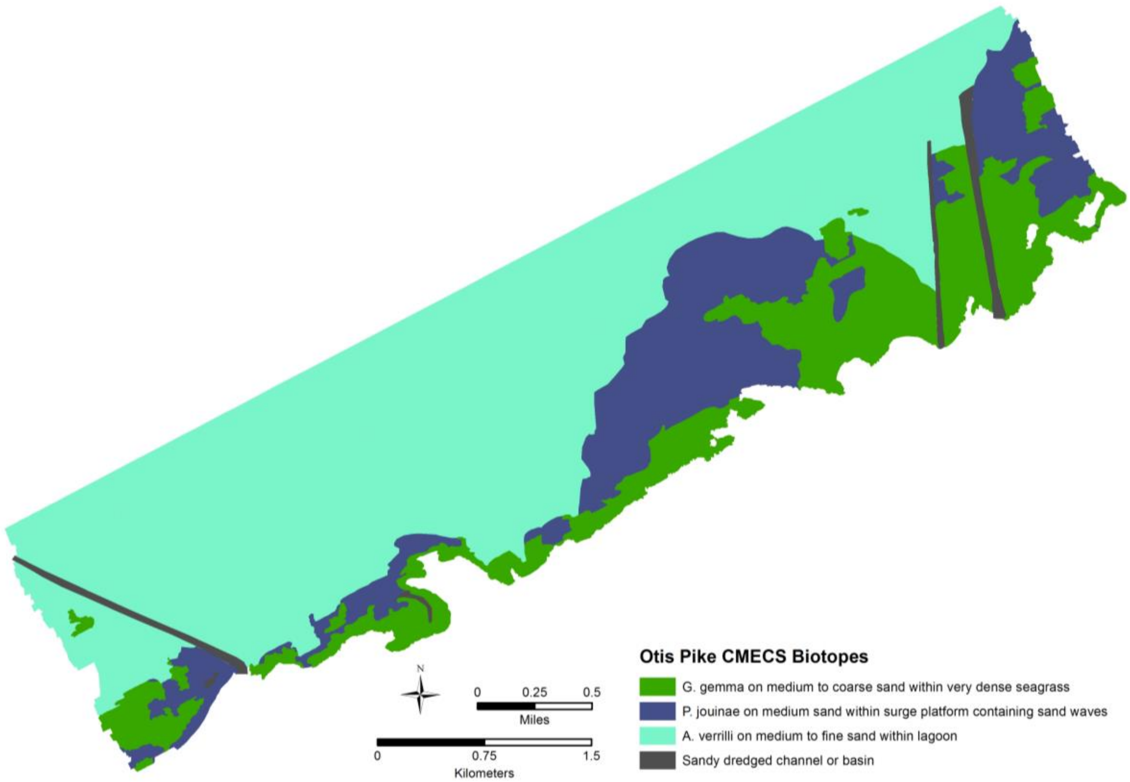
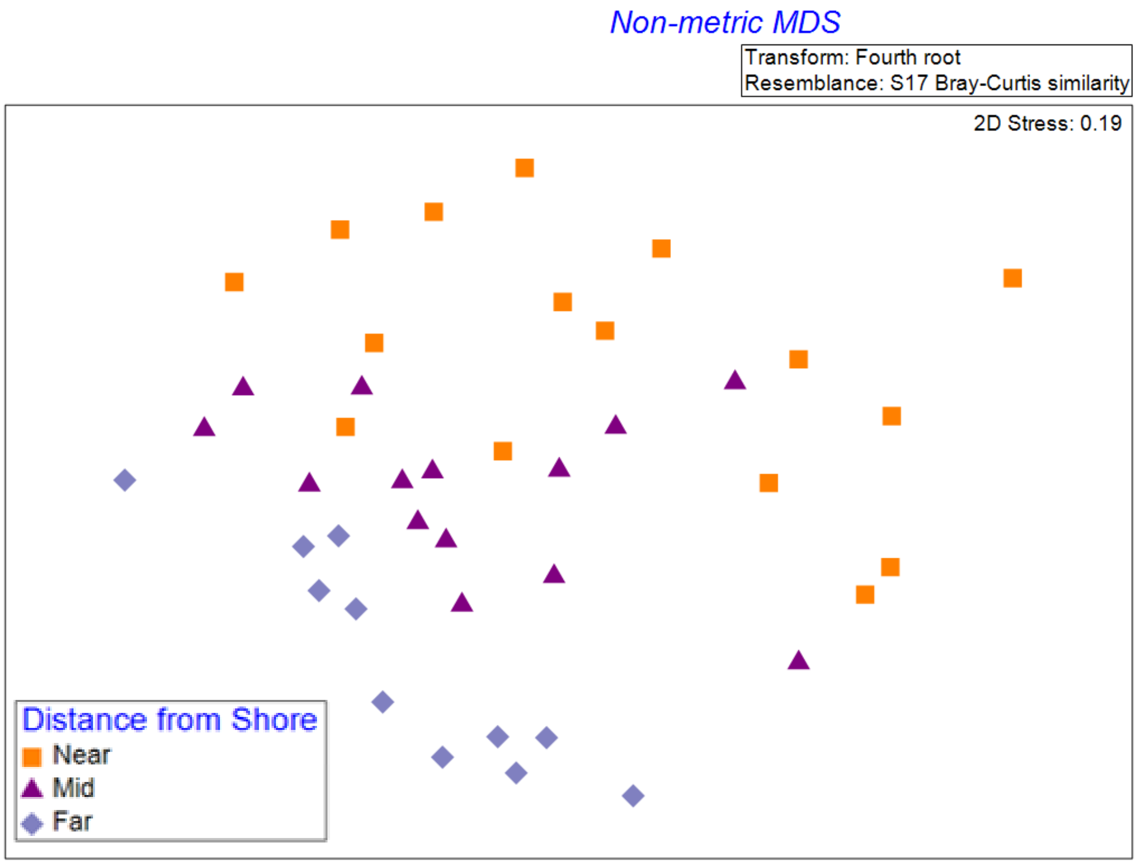


Figure 9. CMECS biotope classification map of the Otis Pike study area. *Note: ANOSIM indicates the macrofaunal communities within the defined map units are significantly different (R = 0.54; p = 0.001). See Table 4 for further description of each biotope.*


Non-metric MDS
Transform: Fourth root
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0.19
Distance from Shore
Near
Mid
Far

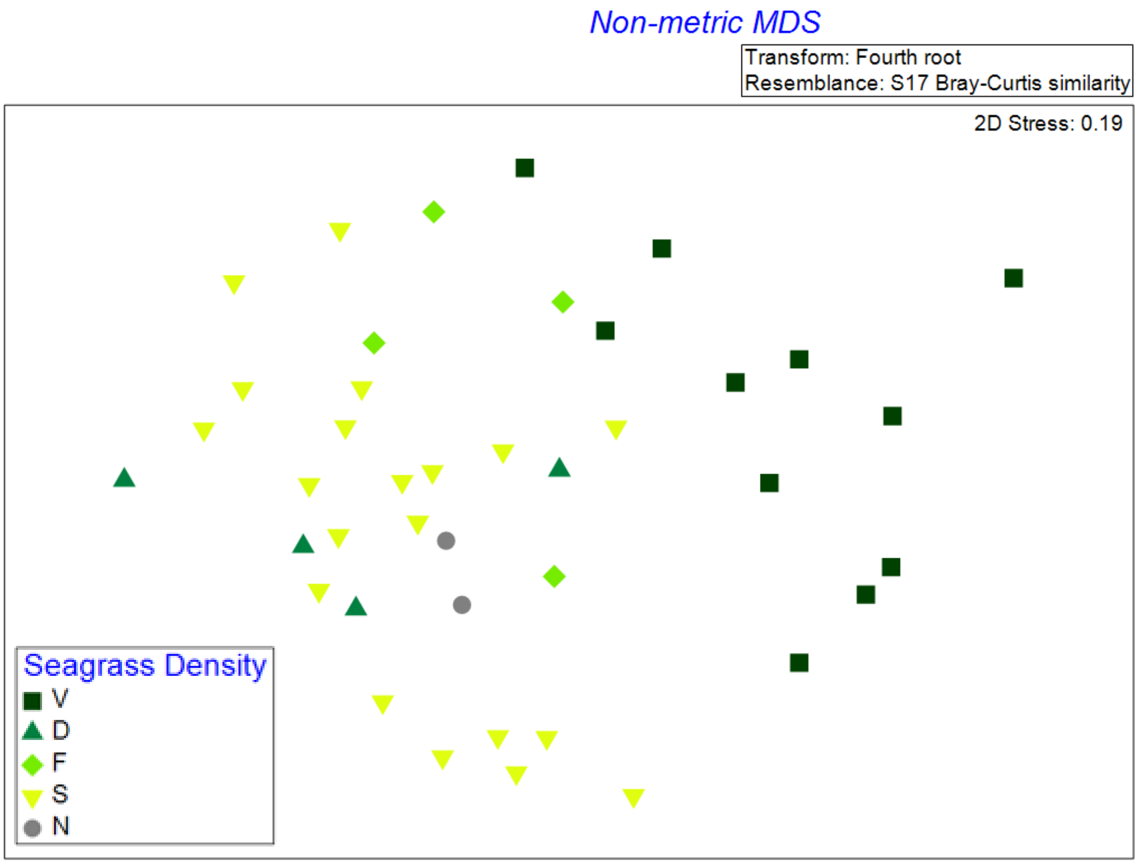


Figure 10. nMDS plots for benthic macrofaunal samples collected within Otis Pike in 2014 and 2015 with respect to (a) distance from shore and (b) seagrass density. *Note: Triplicate samples at each site were averaged.*

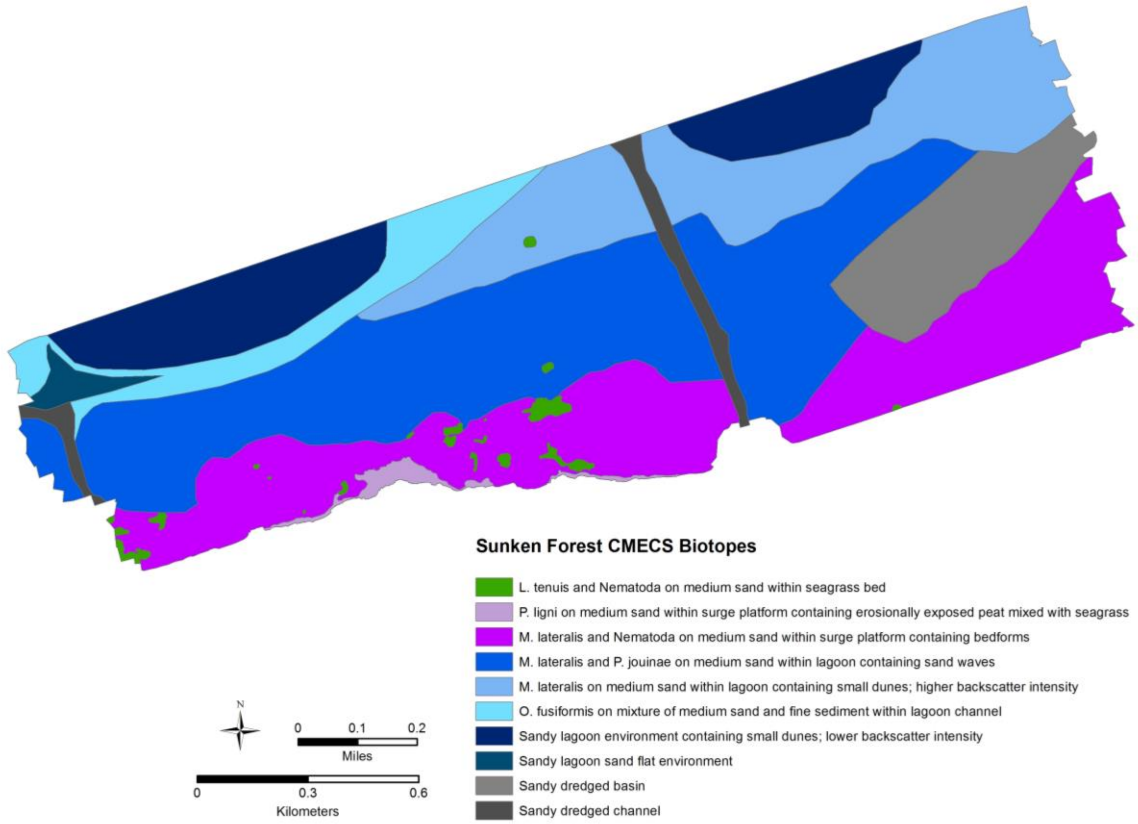
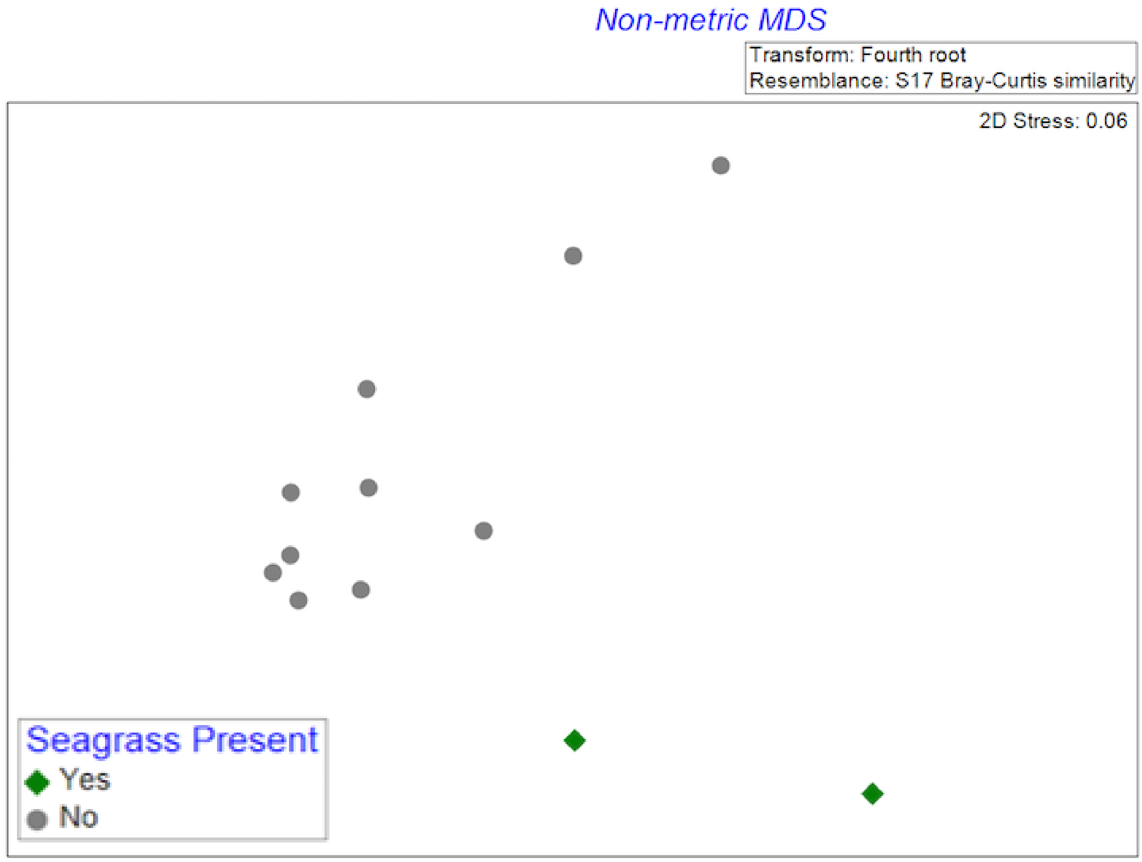


Figure 11. CMECS biotope classification map of the Sunken Forest study area. *Note: ANOSIM indicates the macrofaunal communities within the defined map units are significantly different (R = 0.70; p = 0.002). See Table 4 for further description of each biotope.*


Non-metric MDS
Transform: Fourth root
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0.06
Seagrass Present
Yes
No

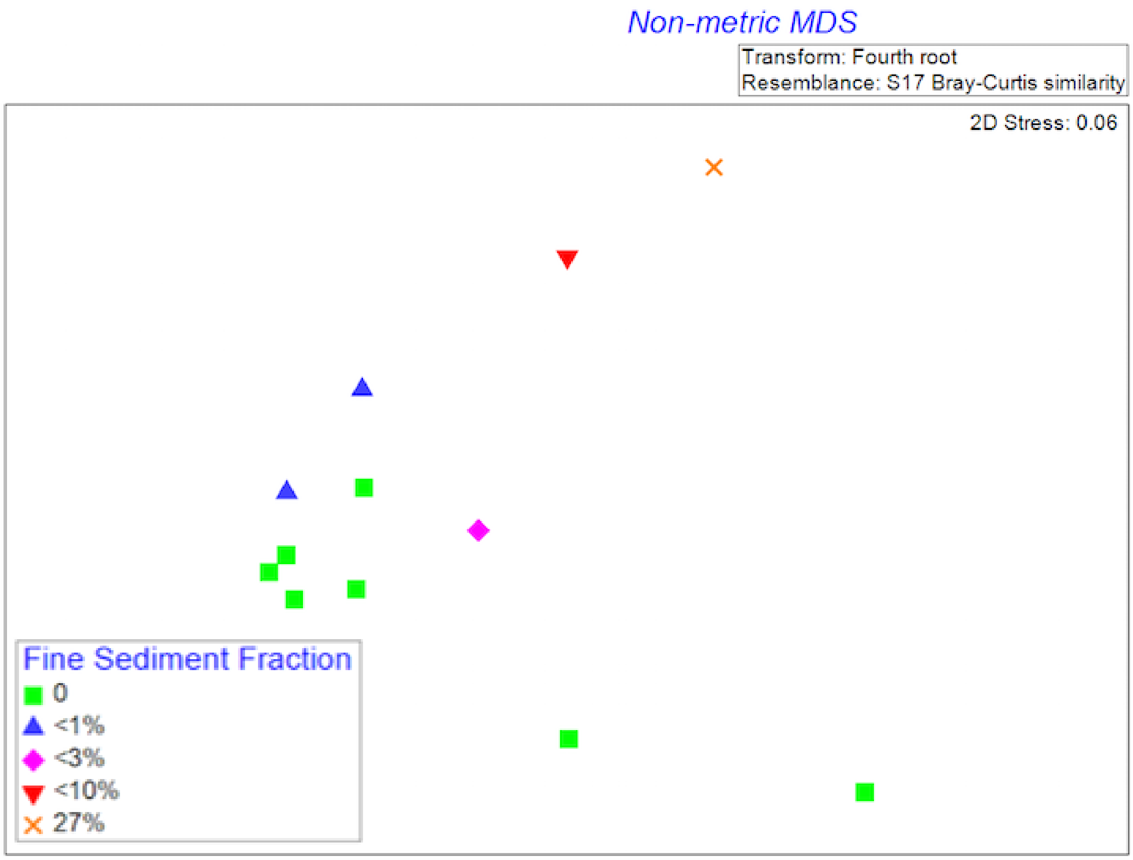
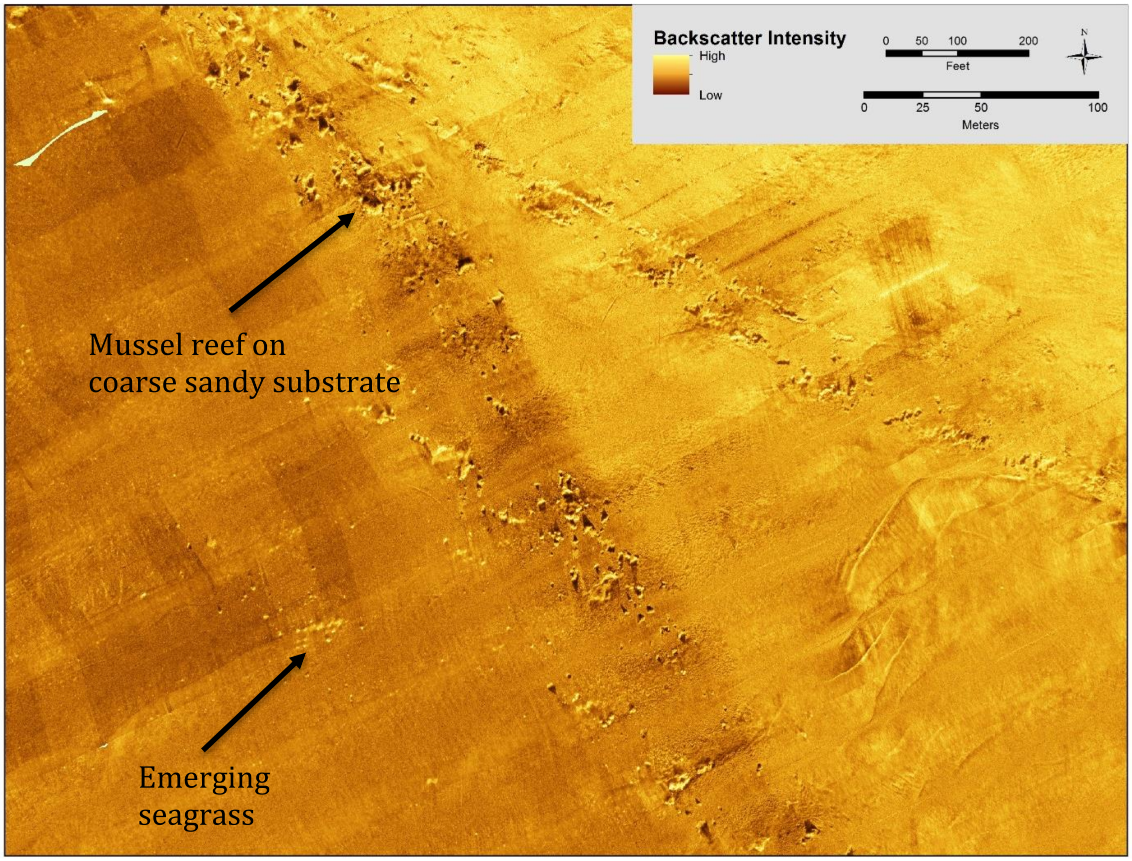
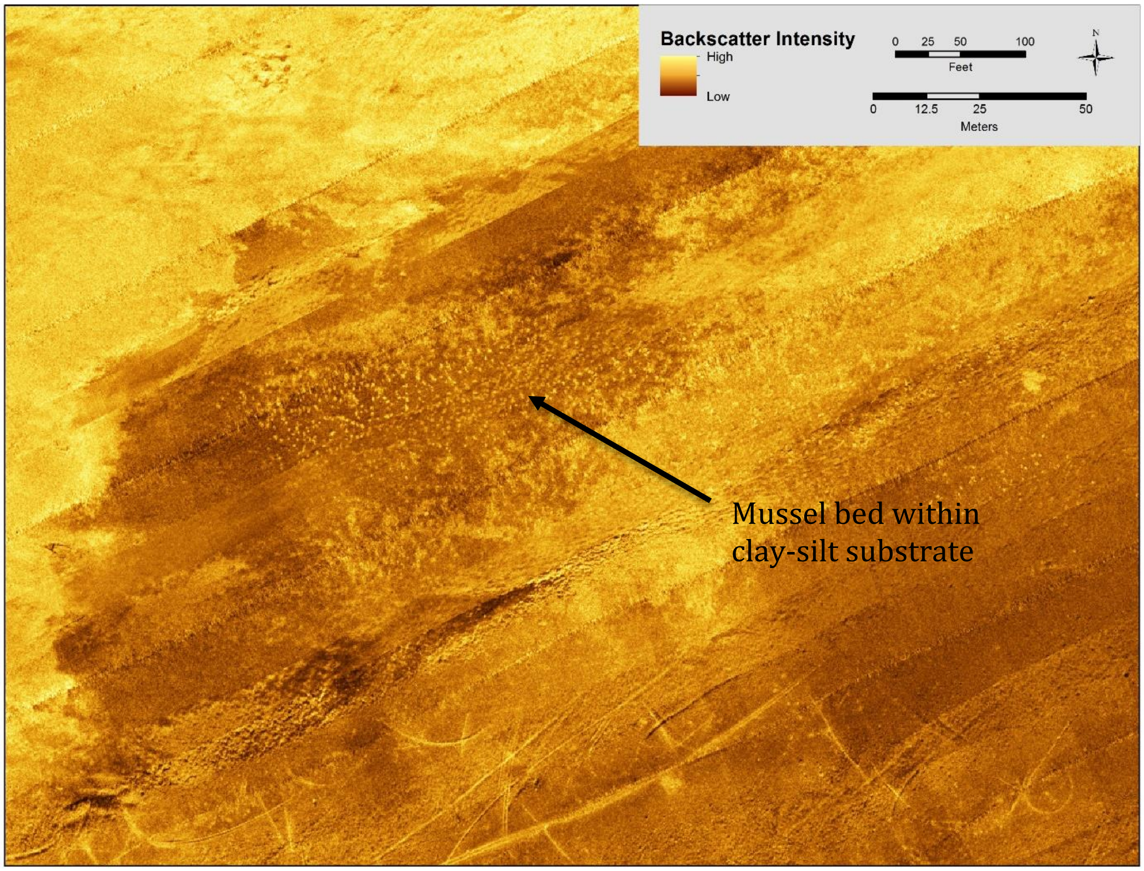


Figure 12. nMDS plots for benthic macrofauna samples collected within Sunken Forest in 2015 examined by (a) presence of seagrass and (b) combined grain size percentage of fine sediment. *Note: Triplicate samples at each site were averaged.*


Backscatter Intensity
High
Low
0 50 100 200
Feet
0 25 50 100
Meters
N
Mussel reef on
coarse sandy substrate
Emerging
seagrass


Backscatter Intensity
High
Low
0 25 50 100
Feet
0 12.5 25 50
Meters
N
Mussel bed within
clay-silt substrate

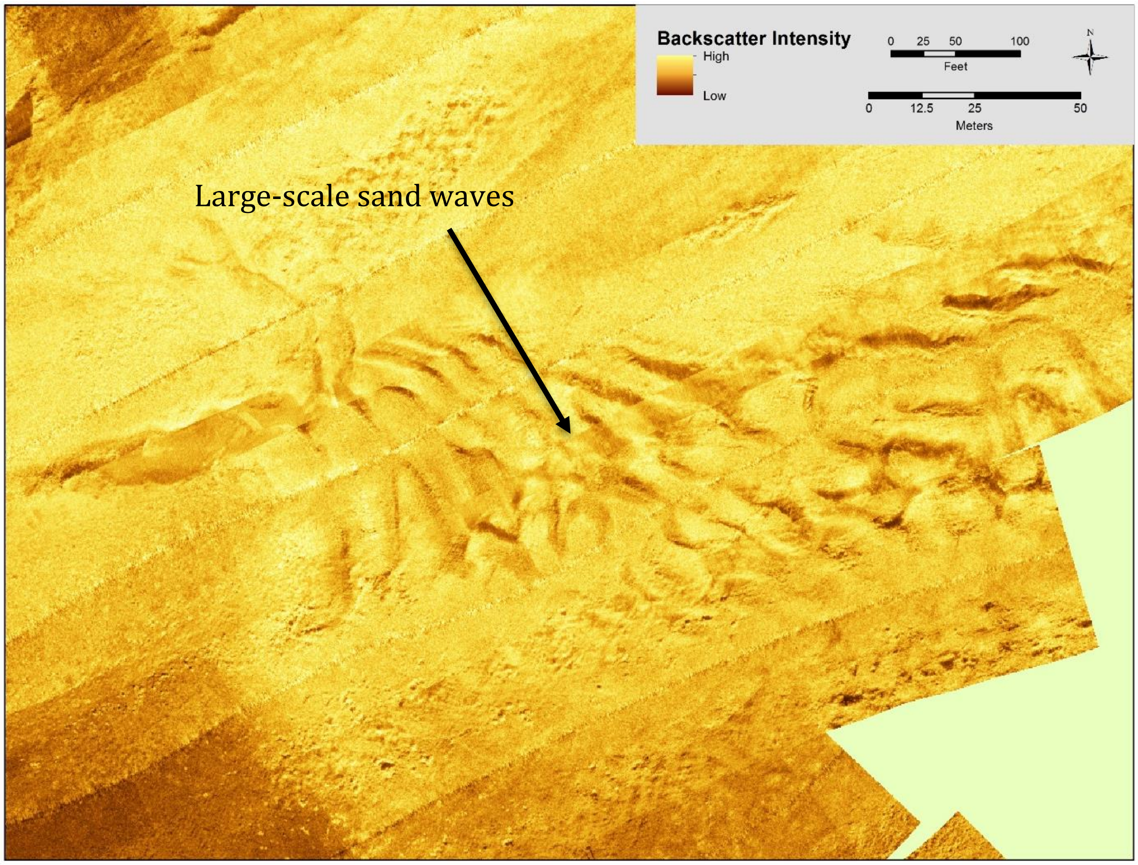
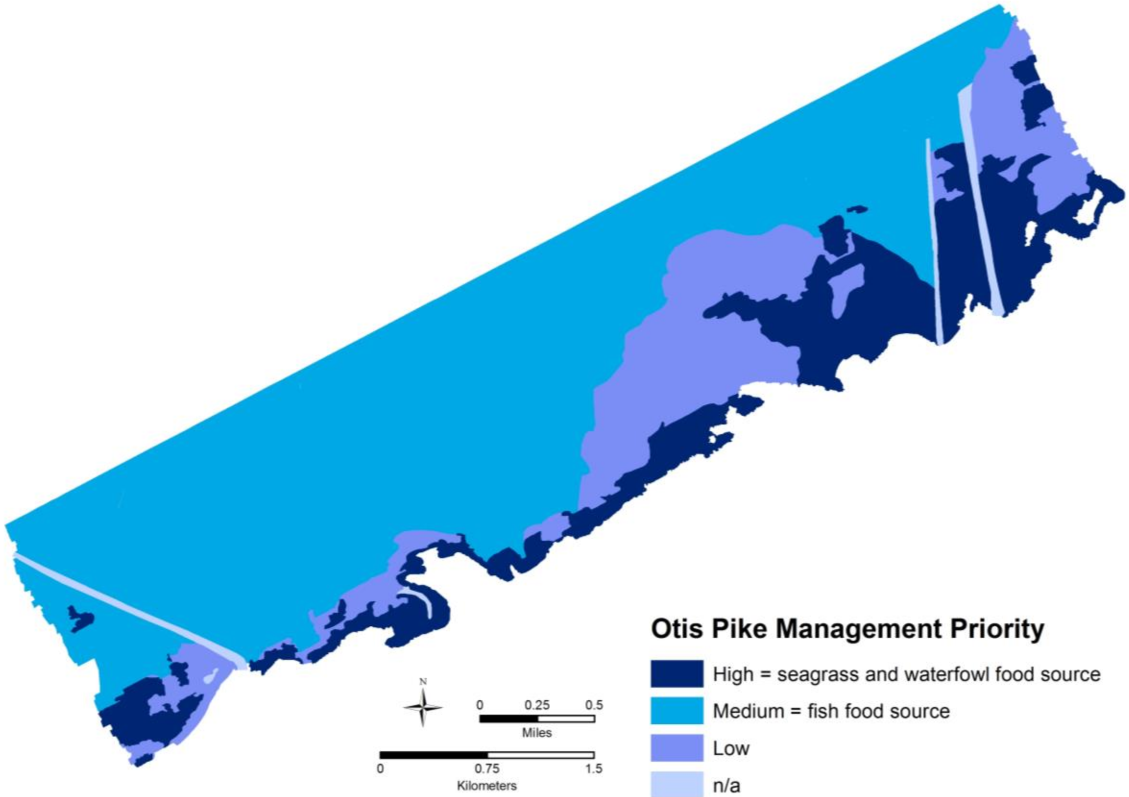


Figure 13. Sidescan sonar mosaic highlighting features within the East Breach study area. *Note: a.) Mussel reef built on sandy seafloor and small patch of seagrass in northwestern portion of study area; b.) mussel bed in clay-silt environment in southern portion of study area; and c.) large-scale sand waves in southeastern portion of study area.*



Otis Pike Management Priority
High = seagrass and waterfowl food source
Medium = fish food source
Low
n/a
N
0
0.25
0.5
Miles
0
0.75
1.5
Kilometers

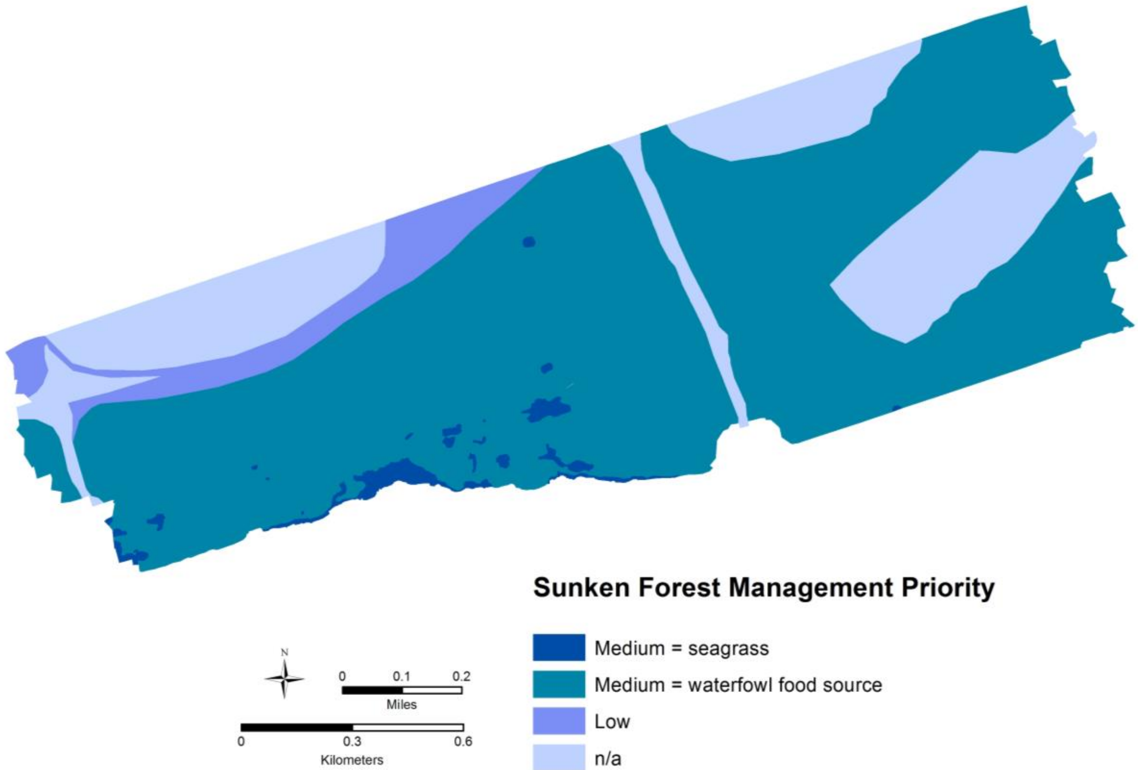


Figure 14. Otis Pike and Sunken Forest study area biotopes prioritized with respect to relative ecological value.

MANUSCRIPT 2: Benthic monitoring to assess near-field changes at the Block Island offshore wind farm

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Abstract

The Block Island Wind Farm, located in the northeast Atlantic Ocean, is the first offshore facility in the United States. The primary objectives for this two-year study were to investigate near-field alterations in benthic macrofaunal communities, sediment composition, and organic enrichment among turbine and control areas, as a function of distance from the turbine foundations. At three turbines, grab sample and imagery data were collected within the footprint of the jacket foundations and 30m – 90m from the center point under the foundations. No appreciable differences were detected in either abiotic or biotic variables, with the exception of substantial changes exhibited within the footprint of one turbine. The variable spatial and temporal pattern over which changes are occurring poses challenges for predicting future conditions and highlights the complexity of attempting to do so. Monitoring efforts should continue to be focused on documenting alterations from offshore development and understanding the complex abiotic-biotic interactions that cause such alterations.

2.1. Introduction

The Block Island Wind Farm (BIWF) is the first commercial offshore wind farm in the United States. The five-turbine, 30-megawatt facility is located within state waters 4.5 km from Block Island, Rhode Island, in the Atlantic Ocean (Figure 15). BIWF construction began in July 2015 and was completed in a phased manner by the end of November 2016. During Phase I, five steel jacket foundations were installed from July 26 to October 26, 2015. Phase II was initiated in January 2016 and it included installation of the turbines on the foundations and laying of the submarine power transmission cables. Operational testing of the facility was conducted from August through November 2016 and the initial operations commenced on December 2, 2016.

A benthic monitoring study was conducted with the primary objectives being to investigate any alterations in benthic macrofaunal communities, surficial sediment composition, and sediment organic enrichment caused by the BIWF facility. Data were analyzed between turbine and control areas, among and within turbine areas, and as a function of distance from the turbine foundationss. While long-range and large-scale changes in benthic conditions are not expected from the presence of the five turbines, localized alterations to seabed characteristics near the foundations are anticipated, though the specifics of those changes and the rate at which they will manifest are unclear. Alterations in benthic conditions may occur because of the presence of the turbine structures, which can modify local hydrodynamic conditions and sediment grain size distribution (Coates et al., 2014; Brabant et al., 2012; Schröder et al. 2006; Leonhard, 2006). The structures also provide substrate for the growth of marine organisms, which may result in localized sediment enrichment due to increases in the deposition of organic detrital material to the seafloor from biomass continually being eroded from the structures (Schröder, 2006) and excretion of organisms (Dewsbury and Fourqurean, 2010). The contribution of organic material from epifouling organisms can be substantial. Within approximately the first year of operation of the FINO1 platform, 3.6 tons of biomass was predicted to have accumulated on the jacket structure (Schröder, 2006).

This study is unique, as it represents the first benthic monitoring of offshore wind platforms within the Atlantic Ocean along the northeast coast of the United States. Further, while there are numerous offshore wind facilities in Europe, turbines typically have monopile foundations (e.g. Bockstigen, Utgrunden I) or gravity-based foundations (e.g. Thornton Bank, Kårehamn). The BIWF foundations are jacket structures and have a larger footprint, which may influence the degree and extent of alterations to the benthos. Currently, there is a lack of monitoring data for these foundation types and impacts on benthic ecology are generally poorly understood, and therefore, this study presents the opportunity to meaningfully contribute to the understanding of the specific construction and operational effects of jacket foundation structures on the benthos. Additionally, required monitoring of benthic habitats within offshore wind facilities in Europe has primarily focused on large-scale effects, with no significant impacts detected (e.g. Bergman et al., 2015; Vandendriessche et al., 2015; Lock et al., 2014; Coates, 2014; Vandendriessche et al., 2013; Coates et al. 2012; Coates and Vincx, 2010; Reubens et al., 2009; Degraer et al., 2009). As a result, the potential small-scale spatial and temporal changes to the benthos in the area of offshore developments are not well understood. This study establishes a comprehensive dataset documenting near-field conditions over two years that can serve as a point of comparison for measuring future alterations in macrofaunal and sediment characteristics at the BIWF, whether a result of human activity or natural processes.

The monitoring study was conducted under the United States (U.S.) Department of Interior's Bureau of Ocean Energy Management's (BOEM) Real-Time Opportunity for Development Environmental Observations (RODEO) Program. The purpose of the RODEO Program includes to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and/or initial operations of selected proposed offshore wind facilities. Findings from this on-going program will identify the near-field spatial and temporal extent and magnitude of impacts that can be anticipated. While it is recognized that spatial and temporal patterns that are identified will be most relevant on a regional scale, the results from this and future studies at BIWF will be broadly relevant and add to existing observations on the potential short-range ecological influences of offshore development. Such information is relevant since additional offshore wind facilities are planned for the U.S. east coast in the future and knowledge of associated effects can guide scientifically sound management decisions by either proactively mitigating or avoiding impacts in areas where necessary.

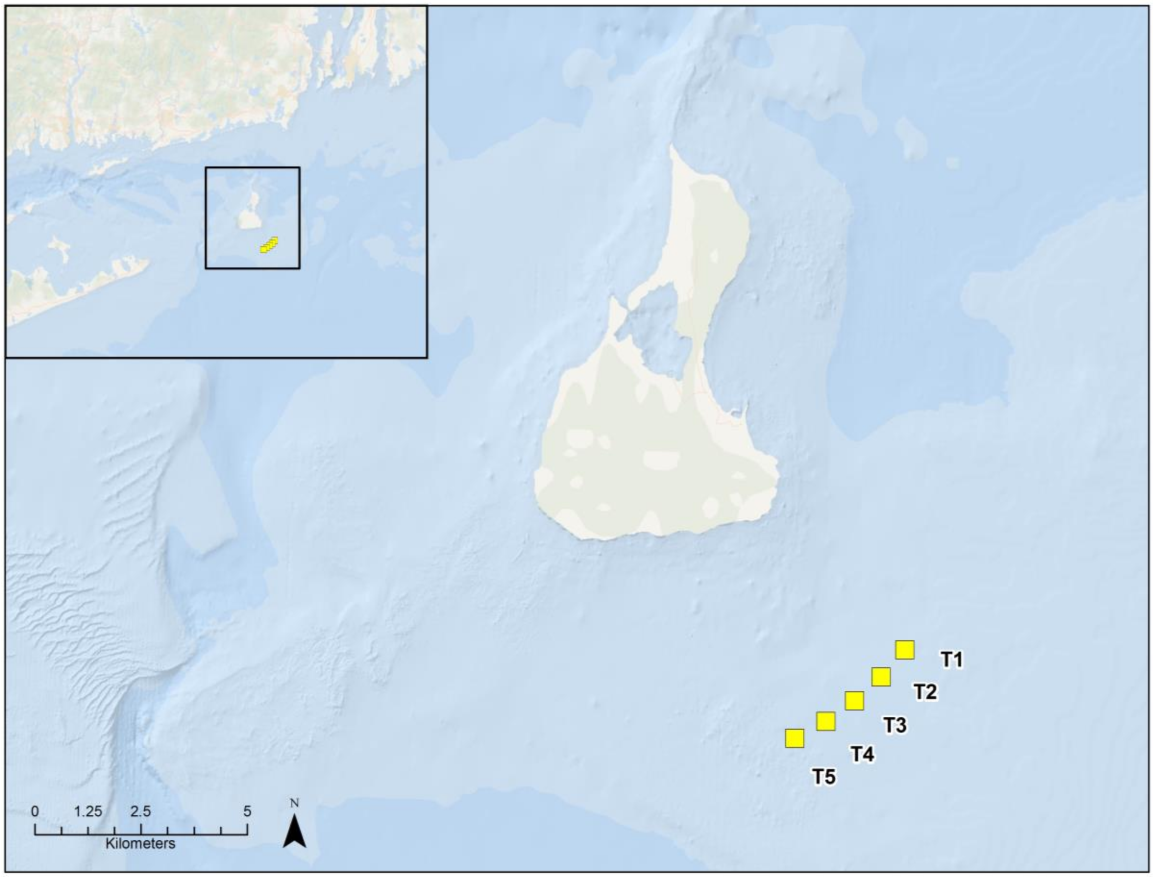


Figure 15. Block Island Wind Farm (BIWF) study area.

2.2. Methods

2.2.1. Survey Design

Data were collected over two sampling periods, referred to as "Year 1" (2016–2017) and "Year 2" (2017–2018). Sample stations were planned at three of the five turbines (T1, T3, and T5) and within three control areas (C1, C2, C3) (Figure 16). Turbines 1, 3 and 5 were selected for sampling because between them they offer the broadest representation of the biotopes present in the study area, as previously defined by LaFrance et al. (2014). This sampling strategy permits pre- and post-construction comparisons to be made and is valuable for understanding the responses of macrofaunal communities to potential changes across a range of biotope types. The control areas were selected at locations outside of the predicted influences of the construction and operation of the BIWF. These areas were also comparable in substrate and depth conditions to that of the turbine areas (LaFrance et al., 2014). Data from the control areas allow for the assessment of benthic change attributable to the BIWF against baseline conditions.

A new array of sample stations was planned within the turbine and control areas each year, i.e., Year 1 stations were not reoccupied in Year 2. Data acquired at each sample station consisted of grab samples for analysis of sediment grain size, organic content, and macrofaunal community composition, paired with seabed video to provide broader contextual information of the surrounding area. In addition, high-resolution seabed photography was acquired along transects within each of the turbine and control areas using a Lagrangian floating remote digital stereoscopic still-image camera.

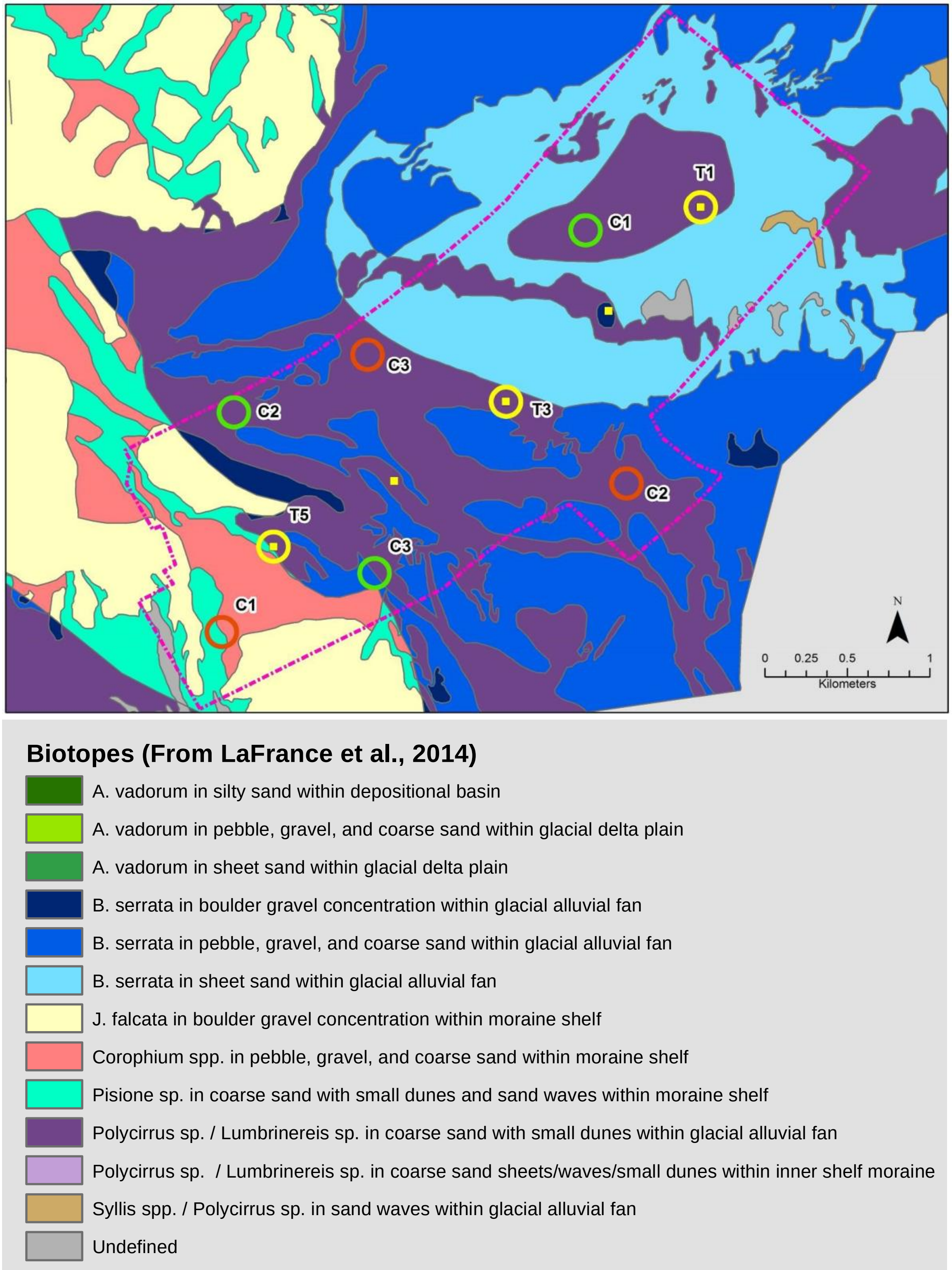


Figure 16. Distribution and extent of classified seabed biotopes in relation to the BIWF.

2.2.2. Data Collection and Preparation

2.2.2.1. Vessel-based Grab Samples

Within the turbine and control areas, surficial samples of the seafloor ("grab samples") were collected using a Smith McIntyre grab sampler (~ 620 cm^2 sample area). Survey operations took place on board a 13 m research vessel. Three grab samples were collected at each station following a cluster sampling strategy. These samples are not considered true replicates due to the difficulties of collecting three co-located samples in offshore conditions in water depths averaging 30 m. The collection of three cluster samples allows for more robust statistical analyses of the biological communities; accounts for the small-scale spatial variability and complex structure of benthic macrofaunal communities; and generally provides a more comprehensive understanding of the sample stations and the study areas.

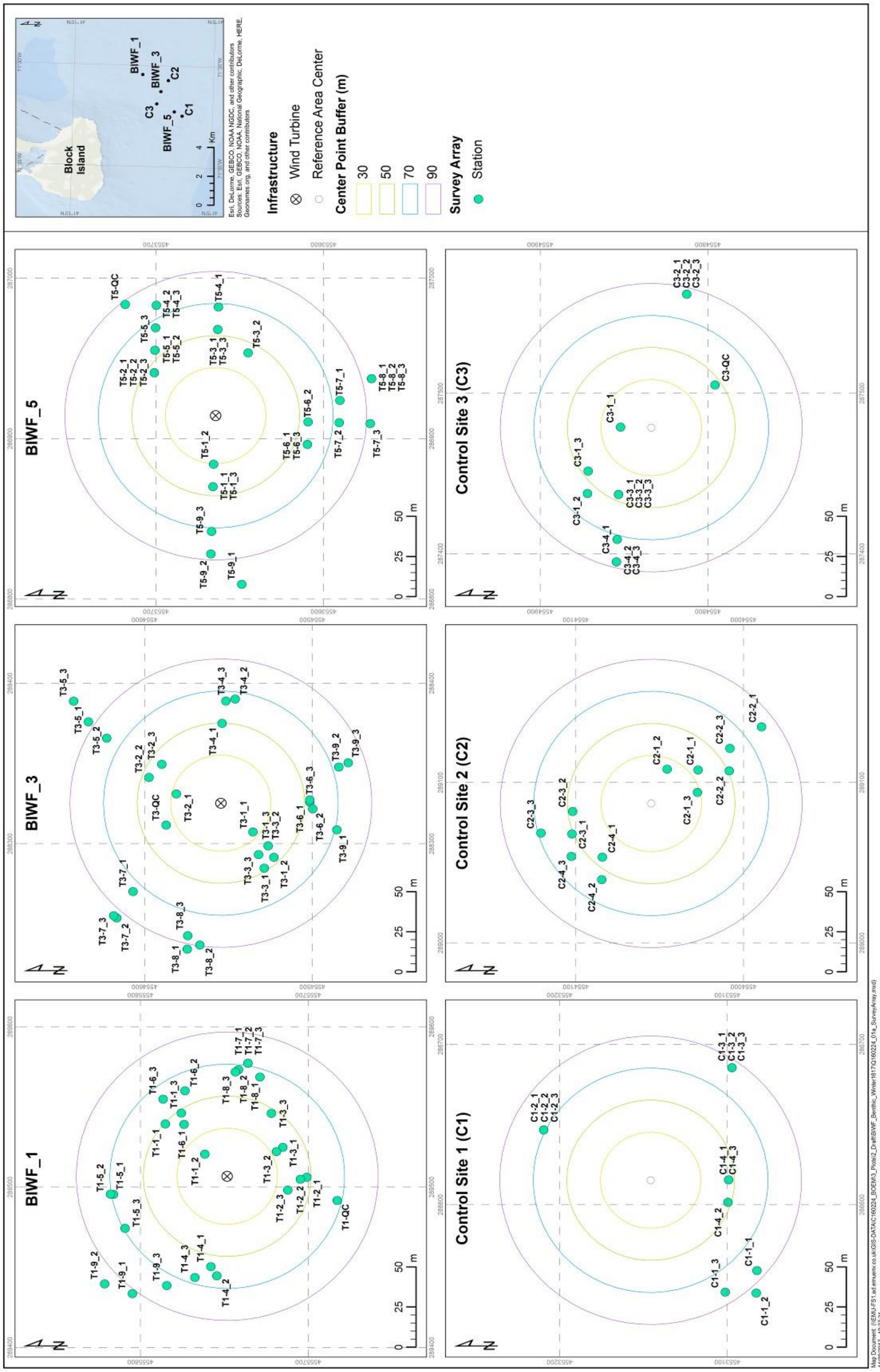
Each year, nine sample stations were randomly positioned within each turbine area, resulting in 27 samples per turbine (81 samples total) (Figure 17, Table 6). The turbine areas were modified to exclude any construction-related disturbance features identified in side scan sonar and bathymetry data before samples were positioned. Specifically, the following features were excluded: 1) the locations of the pin piles on the seabed; 2) seabed disturbance from the placement of the spud legs of the jack-up rig; and 3) seabed disturbance from the jetting of trenches of the inter-array cables and the placement of scour protection material over portions of the cable (in the form of concrete mats). Furthermore, within each turbine area, the random sampling process was stratified to position three sampling stations within three pre-determined distance bands such that samples were collected at increasing distances from the turbine foundation. This strategy was intended to provide adequate spatial coverage to detect any changes based on prior observations (Schröder 2006, Coates et al. 2012 and 2014). These distance bands were equal to 30–49 m, 50–69 m, and 70–90 m from the center point under the foundation structure.

Cluster samples were also collected at randomly positioned stations within the control areas, which were relocated each year (refer to Figure 17, Table 6). While distance bands were not used, sampling was restricted to within a 90 m radius of the established center point to mimic the coverage area of the turbines. In Year 1, each control area contained four sample stations, resulting in 12 samples per area and 36 samples total. The Year 2 sampling strategy differed slightly based on experiences from Year 1. Specifically, the number of sample stations within the control areas was reduced to three because the Year 1 design was determined to be unbalanced in a way to which significance testing procedures are sensitive. In Year 1, the sample size for the control areas was 36, whereas the sample size for each of the turbine areas was 27; removing one station allowed for the sample size to be 27 for both the turbine and control areas.

In total, 117 vessel-based grab samples were collected at 39 stations within the turbine and control areas in Year 1. Data acquisition occurred over three days: December 20th, 2016 for Turbines 1 and 3; January 20th, 2017 for Turbine 5 and Controls 1 and 2; and March 21st, 2017 for Control 3. The delay between sample days was caused by inclement weather. However, completing the sampling over this time period is not considered a concern, as data from previous studies supports that this region is stable and that there are minimal seasonal effects (LaFrance et al., 2014; Steimle, 1982; Savard, 1966; Pratt, Pers. Comm). Also, all sampling occurred in the winter season, and therefore, conditions were constant throughout the data collection period. Additionally, four quality control samples were collected at each turbine on March 21st 2017 and were found to be comparable to the samples collected in December 2016 and January 2017, further supporting the observation that there are minimal seasonal changes in this area. Any remaining concerns regarding time between sampling days were abated in Year 2, as all 108 samples at 36 stations were collected over two consecutive days: November 30th and December 1st, 2017.

Table 6. Summary of Benthic Survey Sampling Effort. Note: Grabs samples and seabed video footage were simultaneously collected for the vessel-based stations. A single grab sample was collected at each diver-based sample station.

	Turbine 1	**Turbine 3**	**Turbine 5**	**Control 1**	**Control 2**	**Control 3**
Year 1 (vessel-based data collection)						
Sample stations within 30–49 m distance band	3	3	3	4	4	4
Sample stations within 50–69 m distance band	3	3	3			
Sample stations within 70–90 m distance band	3	3	3			
Total sample stations per area	9	9	9	4	4	4
Total samples per area (cluster samples = 3 per station)	27	27	27	12	12	12
Total (grabs and video)	117 samples at 39 stations					
Float camera transects	3	3	4	2	1	2
Year 2 (vessel-based data collection)						
Sample stations within 30–49 m distance band	3	3	3	3	3	3
Sample stations within 50–69 m distance band	3	3	3			
Sample stations within 70–90 m distance band	3	3	3			
Total sample stations per area	9	9	9	3	3	3
Total samples per area (cluster samples = 3 per station)	27	27	27	9	9	9
Total (grabs and video)	108 samples at 36 stations					
Float camera transects	2	2	2	2	2	2
Year 2 (diver-based data collection)						
Sample stations within footprint of turbine structure (single sample per station)	5	5	5	--	--	--
Total (grabs only)	15 samples at 15 stations					
Towed camera transects	1	1	1	--	--	---


BIWF_1
BIWF_3
BIWF_5
Control Site 1 (C1)
Control Site 2 (C2)
Control Site 3 (C3)
Block Island
Infrastructure
Wind Turbine
Reference Area Center
Center Point Buffer (m)
30
50
70
90
Survey Array
Station

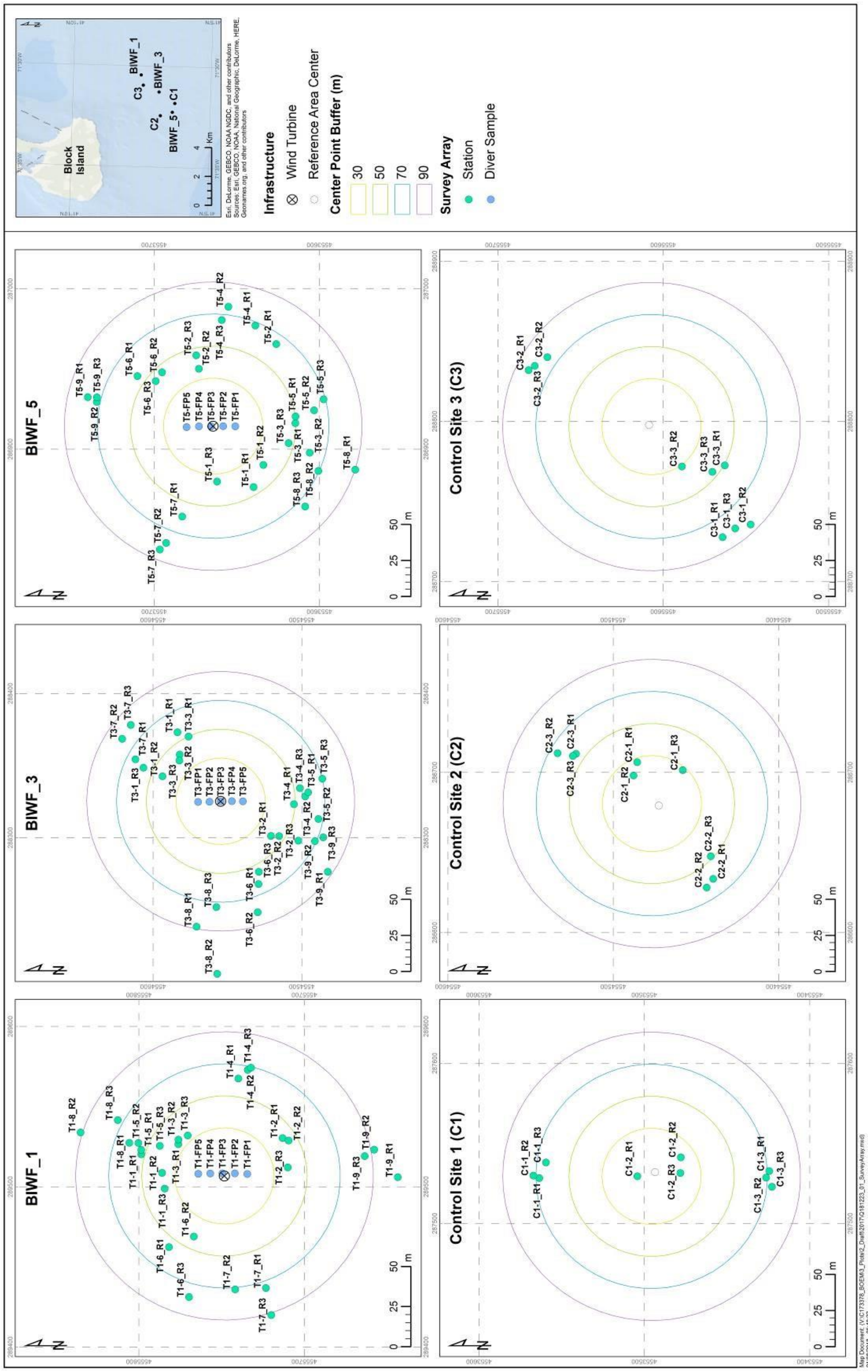


Figure 17. Location of the vessel-based grab samples and seabed video collected within the BIWF study area for Year 1 and Year 2.

A sub-sample from every grab sample was collected for analysis of sediment particle size distribution (PSD) and organic content. A muffle furnace was used to determine total organic matter (TOM) and total organic carbon (TOC) following the Loss-On-Ignition method of Dean (1974). A Malvern Mastersizer 2000E was used to characterize sediment properties by generating the weight percent of each particle size fraction according to the Wentworth classification system (Wentworth 1927). Therefore, sediment analyses were performed on grain sizes ranging from 0 to 2,000 μm (i.e., clay to very coarse sand). While sediment larger than 2,000 μm (e.g., gravel, cobble, and boulder) were not quantitatively assessed, qualitative data on larger material was collected. Within the grab samples, the recovery of gravel and cobbles was noted in Year 1, while this material was retained in Year 2. Also, in the seabed video, the presence and overall concentrations of gravel, cobble, and boulder were noted for both years. The remaining material in each grab sample was sieved through a 1mm aperture mesh sieve and retained for macrofaunal analysis. All individuals recovered were counted and identified to the species level or lowest possible taxonomic group.

2.2.2.2. Diver-collected Grab Samples

The Year 2 sampling effort was also modified to include the collection of grab samples located within the footprint of each of the three turbine structures (refer to Table 6; Figure 17). The samples were added in recognition that the sampling design in Year 1 may not have been adequate to detect changes that may be occurring in the very near field, i.e., on the order of meters, from the turbine structure. The footprint of the foundation structure on the seafloor takes the shape of a square that is 24.5 m on each side. As such, within the closest distance band, samples were collected at a minimum distance of 15 m from the outer perimeter of the structure and 30 m from the center point under the structure (Figure 18). Further, the Year 1 sampling strategy was not designed to consider changes that could be occurring within the footprint of the jacketed structures, despite that this is a sizable area of approximately 600 m^2.

The five diver-collected grab samples were located at equal distances (i.e., 7.5 m) under each turbine structure along a transect spanning from the southern leg to the northern leg (i.e., 30 m total). A compass was used to navigate course and a measuring tape was used to determine distance between samples. These samples were collected as single samples, not in clusters of three. The sample size was intended to be comparable to that of the Smith McIntyre grab sampler, both with respect to sample area and depth. Data acquisition took place over three days: May 17th 2018 for Turbine 3; June 7th 2018 for Turbine 5, and June 8th 2018 for Turbine 1. Sediment grain size, organic content, and biological analyses of the diver-collected samples follow those of the vessel-based samples.

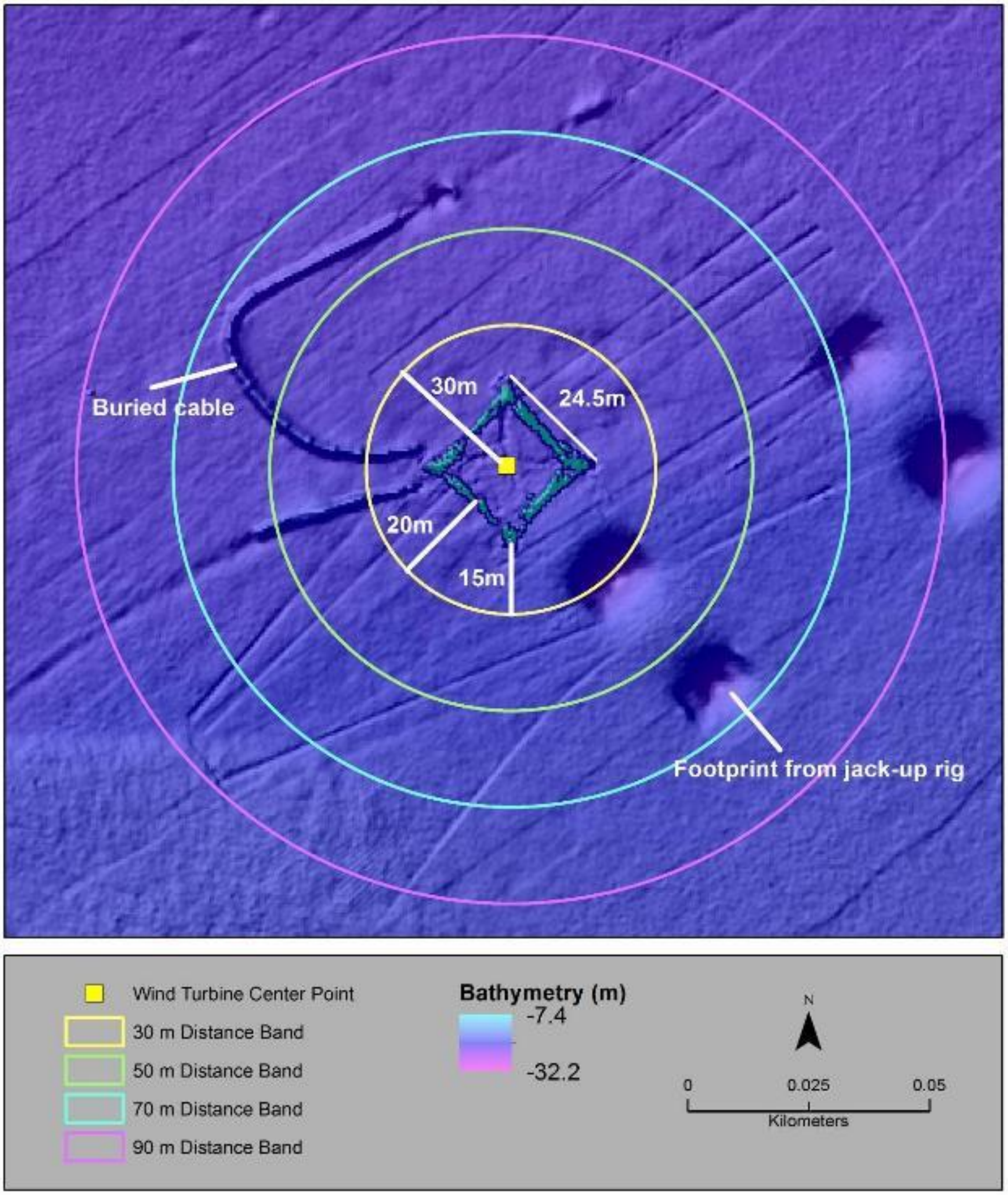


Figure 18. The relationship between the distance bands and footprint of the foundation structure. Turbine 5 is shown here and is also representative of Turbines 1 and 3. *Note: Multibeam data provided by Fugro USA Marine, Inc (Fugro, 2017).*

2.2.2.3. Seabed Imagery

Video was acquired using a GoPro camera outfitted with lights that were attached to the frame of the Smith McIntyre grab sampler, allowing for grab samples and video footage with identical spatial and temporal attributes (refer to Figure 17, Table 6). Such co-located datasets reduce uncertainties associated with returning to an area for sampling. In addition, high-resolution seabed photography was acquired using a Lagrangian floating remote stereoscopic digital still-image camera. The camera system is free-floating, i.e., its trajectory follows that of the bottom currents, though is tethered to a surface buoy to allow for easier recovery and to note general location and drift pattern. The camera was programmed to follow the seabed at a constant altitude of approximately 2.2 m for durations ranging between 15 and 30 minutes, with photographs collected every 3-4 seconds. In Year 1, between one and four camera transects were completed within each of the turbine and control areas (15 total) over two days (June 28th and August 9th, 2017) (refer to Table 6). Data acquisition occurred over three days in Year 2 (May 17th, June 12th, and June 15th of 2018), during which two transects were completed within each area (12 total). Also in Year 2, the camera system was modified to be towed along by a diver to acquire images within the footprint of the three turbines. The divers mimicked the south-north transect along which the grab samples were collected. Each transect was then extended beyond the structure out to 90 m to ensure photographs were obtained across the three distance bands. These surveys were completed over two days (June 15th and 17th, 2018). The raw photographs were color corrected to account for lighting artifacts and small variations in altitude. The rapid rate at which the camera operates typically results in a continuous series of overlapping photographs that can then be mosaicked.

The seabed video and still imagery was collected to complement the grab sample data by acquiring data in a non-disruptive manner that provides contextual information over a broader scale and allows for the degree of spatial heterogeneity of the surrounding environment to be assessed. As such, the imagery was reviewed to identify bedforms, coarse surficial material concentrations (e.g., boulders, cobble, gravel), and general sediment composition. With respect to biology, noting observations of the blue mussel, *Mytilus edulis*, within the imagery was of highest priority due to the species overwhelmingly dominance as a fouling organism colonizing the turbine structures. The imagery was also examined for the presence of other conspicuous epifaunal species, particularly those that are mobile or occur in low densities (e.g., crabs, starfish, sponges, algae) and so tend to not be captured by the grab sampler.

2.2.3. Data Analysis

Statistical analyses were carried out using the statistical software package PRIMER v6.0 (Clarke and Gorley, 2015; Clarke et al., 2014; Clarke, 1993), unless otherwise noted. A variety of univariate measures were calculated, including number of species (S), number of individuals (A), and a range of diversity indices, including Shannon Index of diversity (H'), Margalef's Richness (d), Pielou's Eveness index (J') and Simpson's Dominance (λ). Prior to multivariate analyses, macrofaunal data were square root transformed to reduce the influence of any highly abundant taxa allowing less abundant species a greater role in driving the emergent multivariate patterns. The transformed data were then subjected to hierarchical clustering to identify sample groupings based on the

Bray-Curtis index of similarity. Categorical information were also prepared regarding the survey design and data provided by the grab samples and seabed video to investigate potential relationships with observed macrofaunal patterns. These categories can be used as factors or to define sample groups and include sampling period (i.e., Year 1, Year 2), study area (i.e., Turbine 1, 3, 5, Control 1, 2, 3), sample clusters (i.e. the three samples collected at one station), distance from turbine (i.e., near, mid, far), dominant sediment type (e.g., coarse sand, medium sand), general concentration of gravel, cobble and boulders, and the presence of biological features (i.e., shell hash, mussels). The geologic depositional environment types, as defined by LaFrance et al. (2010, 2014), were also considered in analyses.

nMDS (non-metric Multi-dimensional Scaling) plots were used to examine patterns in macrofaunal community composition in relation to the categorical factors. As defined, an nMDS plot is an ordination plot for which samples are represented as points and the similarity/dissimilarity between samples is based on their relative distance from one another on the plot (Clarke and Gorley 2015). Therefore, in this study, each point on the plot represents the benthic community composition for one sample and points that are closer together on the plot represent samples that are more similar in composition than those that are farther apart. The representativeness of this 2-dimensional plot, in comparison to the multi-dimensional array, is indicated by a stress level. The closer this stress level is to zero, the better the representation. A stress level of 0.20 or less is considered acceptable.

SIMPER (Similarity Percentages) is a quantitative complement to nMDS plots and examines data based on user-defined sample groups. SIMPER analysis was used to rank macrofaunal species in terms of their contribution to both the within-group similarity and "between" group dissimilarity. SIMPER compares groups of samples by examining the degree to which individual species contribute to the within-group similarity of the sample groups and reporting the average overall within-group percent similarity. SIMPER also reports the average percent dissimilarity of the sample groups between all pairs of groups and how individual species contribute to this dissimilarity (Clarke and Gorley 2015). For example, SIMPER can be used to assess similarity of macrofaunal samples at each study area and the level of dissimilarity between each study area. Sample groups can also be defined according to sampling period, cluster station, etc. As such, SIMPER can assist in determining the relative distinctiveness of each sample group and the identification of the characterizing taxa.

The ANOSIM (Analysis of Similarity) routine was used to test the null hypothesis that there are no differences between biological communities among different user-defined sample groups (e.g., study area, geologic depositional environment types). ANOSIM reports an R value, for which a value of 0 would indicate that there are no differences in the biological communities within the defined groups, while an R value greater than 0 would reflect the degree of the difference, with a value of 1 indicating that the biological communities within each group are completely distinct from one other.

Differences between sample groups were also tested using the Permanova+ module within PRIMER (Anderson et al. 2008). While ANOSIM and Permanova+ were essentially used to perform similar functions in this study, Permanova+ is able to encompass and compare multivariate datasets between increasing numbers of spatial and temporal factors and also appears to perform well with heterogeneous data compared to

ANOSIM (Anderson & Walsh, 2013). The PermDisp function was performed in parallel with Permanova+. These results express observed homogeneity/heterogeneity of the macrofaunal data dispersions for selected groups and were used to assess the variability of macrofaunal communities between turbines and control areas and between sampling periods.

The Microsoft Excel Real Statistics Tool Pack was used to conduct significance testing on selected abiotic and biotic variables using two-way Analysis of Variance (ANOVA). This technique tests for differences between means of groups of three or more samples and identifies whether the means within the group are consistent or if one or more is significantly different. The advantage of testing group means, as opposed to undertaking a series of pairwise tests, is that the latter approach increases the risk of committing a Type 1 error, i.e., concluding a significant result when none was present. The ANOVA output is an F ratio, which is the ratio of the variability between the groups relative to the variability within the groups. Where the "within" and "between" variability is the same, the F ratio will be 1. However, as the "between" increases relative to the "within" variability, the F ratio becomes larger. The p value is obtained with reference to "look up" tables of the F distribution and the degrees of freedom. ANOVA tests for differences within the entire group of samples but does not identify where those differences occur. Thus, on detection of statistical differences, post-hoc comparison between pairs of groups was undertaken using a Holm Sidak test, a multiple comparison procedure.

The ANOVA test requires normally distributed data and comparable variances between groups, which was tested using both the Shapiro-Wilks and Levene tests prior to performing the analyses. Data which did not fulfil the variance and normality assumptions were analyzed using the analogous non-parametric methods Welch's ANOVA and Tukey Honestly Significant Difference (HSD) test. With this approach, data are compared on medians only, not means and only for one data set.

Note that for Year 1, the use of four sample stations at each of the three control areas led to an unbalanced design for the ANOVA (i.e., 36 total control samples, but 27 samples for each turbine). Thus, for ease of interpretation and power of analysis, one sample station (containing three cluster samples) was randomly removed from each control area. This change reduced the sensitivity of the ANOVA to unequal standard deviations (if present) and improved the power of the test.

2.3. Results

2.3.1. Turbine and Control Areas

2.3.1.1. Surficial Sediment Composition

The sediment PSD analysis, video footage, and still photographs all confirm that the turbine and control areas are environments dominated by sand of medium to very coarse grain size and contain various concentrations of gravel and/or cobble present throughout. The PSD analysis reports all samples are dominated by medium or coarse sand, and that these fractions, combined with very coarse sand, comprise between 90% and 100% of the sediment composition at 112 of the 117 samples in Year 1 and at 105 of the 108 samples in Year 2. Clay and silt sized particles were recorded within 14 samples for Year 1 and two samples for Year 2, though these fractions accounted for less than 1%

of total sediment composition within each sample. Control 1 in Year 1 was exceptional in that it also exhibited areas with boulders.

While broadly similar, further examination of the data reveals the study areas vary with respect to sand grain size and the degree of bedforms present. Specifically, grain size increases along a gradient moving from Turbine 1 to Turbine 5. The PSD results report Turbine 1 exhibits the highest fractions of fine and medium sand, and, conversely, the lowest fractions of coarse and very coarse sand. Turbines 3 and 5, Year 1 Control 1, and the Year 2 control areas all share similar characteristics, exhibiting higher levels of coarse and very coarse sand and less fine and medium sand, relative to Turbine 1. The Year 1 Controls 2 and 3 fall mid-way along this spectrum. This pattern is also apparent within the video and still imagery. Additionally, the imagery confirm the seabed is naturally mobile within the study areas, as evidenced by the presence of sand waves and sand ripples, resulting in the constant winnowing and erosion of fine sediment particles from the seabed. However, the degree to which this process occurs varies among the turbines. Extensive and well-defined sand waves and ripples are visible in the video collected at all the Turbine 5 stations, whereas at the Turbine 1 stations there are either sand ripples of very low relief, or no visible bedforms present. Turbine 3 falls in the middle of this gradient.

These sedimentary environment characteristics for each turbine area is consistent from Year 1 to Year 2. The PSD analysis reports the proportion and distribution patterns of each grain size fraction were highly similar for both sampling years (Table 7). The minor temporal fluctuations evident in sediment composition in the samples collected within the turbine areas were largely reflected in the control samples, indicating the change was caused by natural variations. Visual examination of the video and still imagery corroborate these findings, and also show bedform features are comparable from year to year.

The PSD and imagery data provided no evidence for sediment composition being related to distance for any of the turbine areas. Further, regression plots (not shown) of the levels of combined clay, silt and fine sand for all turbine samples plotted against distance from the center of its corresponding turbine foundation revealed no correlations for Year 1 or Year 2. The exception was a weak inverse relationship ($R^2 = 0.1912$) of increasing fine sediment levels with decreasing distance to Turbine 1 found in Year 1, though the relationship did not continue in Year 2.

Table 7. Mean of each sediment grain size fraction according to the Wentworth scale for vessel-based sediment samples collected within each study area in Year 1 and Year 2.

Sampling Period	Study Area	Mean Fraction of:					
		Clay and Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand
Year 1	Turbine 1	0.0%	0.0%	5.5%	49.6%	41.6%	3.4%
	Turbine 3	0.0%	0.1%	0.7%	29.0%	55.3%	17.9%
	Turbine 5	0.01%	0.1%	1.6%	25.9%	50.3%	22.1%
	Control 1	0.02%	0.1%	0.1%	25.7%	60.4%	13.6%
	Control 2	0.22%	0.3%	4.5%	34.7%	48.8%	11.5%
	Control 3	0.07%	0.0%	4.2%	43.9%	45.9%	6.0%
	Range	0 - 0.98%	0 – 1.8%	0 – 17.9%	2.9 – 62.2%	28.8 – 64.0%	0.5 – 42.3%
Year 2	Turbine 1	0.0%	0.0%	6.2%	49.6%	43.4%	0.9%
	Turbine 3	0.0%	0.0%	1.5%	37.8%	55.0%	5.7%
	Turbine 5	0.0%	0.0%	0.6%	29.6%	61.0%	8.8%
	Control 1	0.0%	0.0%	2.7%	32.6%	58.0%	6.7%
	Control 2	0.0%	0.0%	0.7%	31.0%	59.3%	9.0%
	Control 3	0.1%	0.07%	1.3%	37.0%	57.4%	4.1%
	Range	0 - 0.9%	0 – 0.6%	0 – 14.4%	16.3 – 57.3%	29.1 – 69.6%	0 – 30.3%

2.3.1.2. Sediment Organic Content

The sediment samples contained minimal levels of TOM and TOC with no appreciable change evident between Year 1 and Year 2. Specifically, mean levels of TOM ranged between 0.33% and 0.52% for each study area across both years, and mean TOC ranged between 0.17% and 0.22%. Regression plots (not shown) comparing the TOC level for each sample and distance from the center point of its respective turbine foundation found no correlations in Year 1 or Year 2 for any of the turbine areas. Additionally, ANOVA tests revealed no statistically significant differences ($p>0.05$) between study areas, distance bands, or sampling years.

2.3.1.3. Epifauna from Imagery Analysis

The imagery revealed there has been a substantial increase in the distribution of *M. edulis* from Year 1 to Year 2 within the turbine areas. In the video footage from Year 1, the only evidence that *M. edulis* is present in the vicinity was provided by empty shells visible at six sites near Turbine 3 and one site near Turbine 5. In Year 2, *M. edulis* was much more prevalent throughout, with individuals and/or clusters of individuals noted at 13 sample sites near Turbine 3, 11 sites near Turbine 1, and 3 sites near Turbine 5 (although a designation of living or non-living could not be confidently determined from the video). In addition, empty shells were noted at 18 sites, mostly near Turbine 5. In contrast, *M. edulis* was not recorded in any of the video collected within the control areas for Year 1 or Year 2, with the exception of a few individuals at one site (Year 2 Control 2). This overall finding is also evident within the still imagery. The increased occurrence of *M. edulis* in Year 2 throughout all the turbine areas strongly suggests the species has increased in abundance and/or distribution. Further, that this increase did not also occur within the control areas indicates the change is caused by colonization of the turbine structures, rather than natural variation.

Other epifaunal species were visible within the imagery for all study areas, except Turbine 3 for both Year 1 and Year 2. Specific species include the barnacle *Balanus amphitrite* on cobbles and small boulders, sea stars of the genus *Asterias*, bivalves of the genus *Astarte*, the sponge *Polymastia robusta*, and the spider crab *Libinia emarginata*. The most notable difference between Year 1 and Year 2 was the absence of sea stars, although the majority of the recorded sightings were in Year 1 in Control 1, which was not representative of the turbine areas and was not resampled in Year 2. Similarly, the bivalve *Astarte*, was largely absent in Year 2, though their presence seemed to have been a localized occurrence near Turbine 5.

2.3.1.4. Macrofaunal Analysis

Comparison of Sampling Years

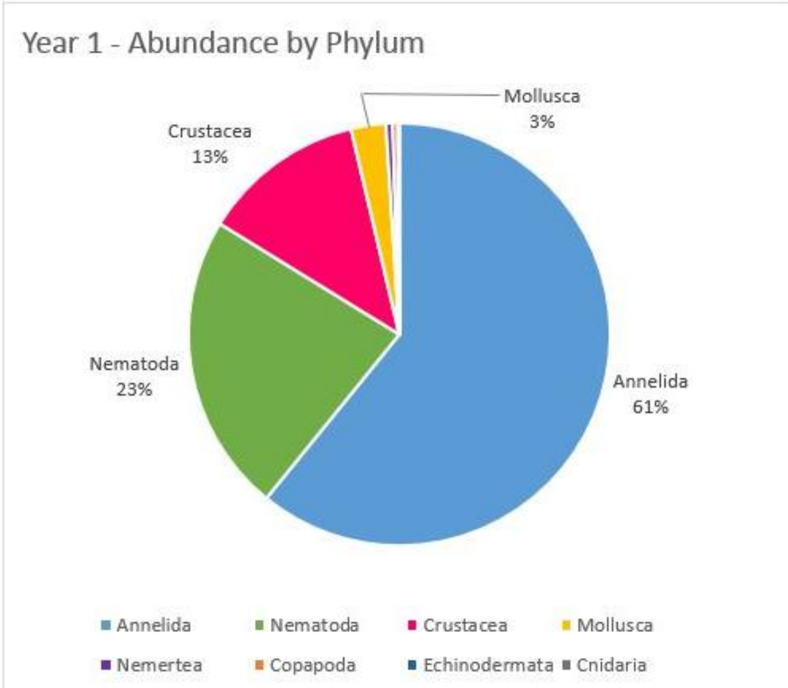
In Year 1, a total of 17,804 individuals represented by 139 species were recovered from the 117 grab samples (Table 8). From the 108 grab samples collected in Year 2, there was a total of 61,835 individuals belonging to 131 species. The large discrepancy in total abundance between the Year 1 and Year 2 is primarily attributed to nematodes increasing by a factor of 10 (4,120 individuals in Year 1 to 41,802 individuals in Year 2). Both the cause of this increase in nematodes and which of the two years is more representative of the typical condition within the study area are currently unknown. Year 1 and Year 2 total abundances are more comparable when considered without nematodes, although there is still a noticeable increase of 4,605 individuals over the three turbine areas in Year 2. ANOVA found this difference in total species abundance between turbines and years to be significant ($F_{(7,192)} = 46.31$. $p = 5.3x10^{38}$). The Tukey HSD test confirmed abundances were significantly higher at all three turbine locations and at the control stations in Year 2 compared to Year 1.

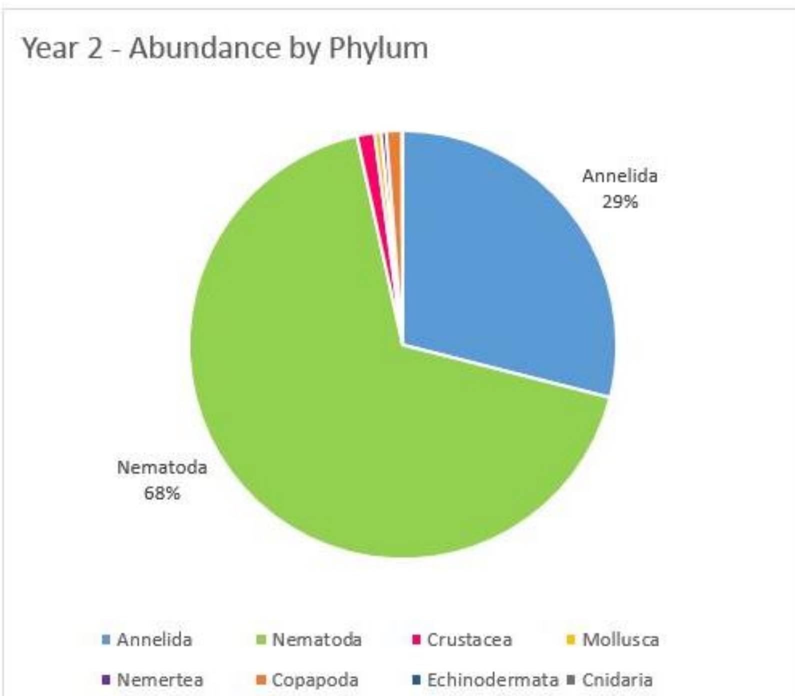
With regards to species richness, a combined total of 175 species were identified across all of the Year 1 and Year 2 samples. (Note that nematodes were not resolved to the species level, and, therefore, do not contribute to the number of species count.) Of the 175 species, 93 were recovered in both years, while 45 and 37 species were present solely in Year 1 and Year 2, respectively. Of the 82 unique species, only 15 had a total abundance greater than 10 individuals (12 had between 19 and 60 individuals, and the remaining species had abundances of 70, 154, and 241). These results indicate that the species unique to each year have minimal influence on overall macrofaunal community composition. Rather, it is the 93 species (or likely a subset of) common to both years that are ecologically meaningful. Furthermore, total richness by phylum was highly similar between Year 1 and Year 2 (Figure 19), indicating the number of species within each phylum remained consistent over time, despite the fact that there were unique species present in each year.

Table 8. Summary of species abundance and species richness for all vessel-based macrofaunal samples collected within the turbine and control areas for Year 1 and Year 2.

	Year 1			Year 2		
Study Area	**Species Richness (all species)**	**Species Abundance (all species)**	**Species Abundance (Nematoda excluded)**	**Species Richness (all species)**	**Species Abundance (all species)**	**Species Abundance (Nematoda excluded)**
All Study Areas Combined	139	17,804	13,684	131	61,835	20,033
Turbine 1	78	1,939	1,677	86	4,896	2,056
Turbine 3	64	5,182	3,838	75	21,924	5,710
Turbine 5	79	4,925	3,424	70	16,752	5,778
Turbine Areas Combined	--	12,046	8,939	--	43,572	13,544
Control 1	76	2,212	1,844	61	3,304	1,542
Control 2	69	2,092	1,686	57	11,213	3,383
Control 3	66	1,454	1,215	45	3,746	1,564
Control Areas Combined	--	5,758	4,745	--	18,263	6,489

By phylum, the Year 1 and Year 2 abundance data are broadly comparable, with both overwhelmingly dominated by annelids (i.e. polychaetes) and nematodes, accounting for 83.8% of the total in Year 1 and 96.6% in Year 2 (Figure 19). Also, the phyla Molluska, Echinodermata, Nemertea, Cnidaria, and Copepoda offer minimal contributions with no appreciable change between years. The greatest distinction between Year 1 and Year 2 is that annelids were just over twice as abundant as nematodes in Year 1, whereas the reverse is true in Year 2. While the change is largely a result of a ten-fold increase in nematode abundance, the number of polychaetes recovered also increased from 11,147 individuals in Year 1 to 17,905 in Year 2. Examination of the macrofaunal data indicates that the overall increase is largely due to increased abundances for 9 of the 15 most dominant polychaete species from Year 1 to Year 2. The greatest increase occurred for the spionid worms, *Parapionosyllis longicirrata* (+1,893) and *Sphaerosyllis erinaceus* (+1,430); the eunicid worm, *Parougia caeca* (+920); the small interstitial worms, *Pisione* sp (+899) and *Polygordius* sp (+736); and the terebellid worm, *Polycirrus eximius* (+663). Further, two species that were not dominant in Year 1 showed noticeable increases in abundances, namely *Syllides longocirratus* (+391) and *Travisia carnea* (+141). Two polychaete species, *Lumbrinereis acuta* and *Lumbrinereis fragilis,* maintained constant abundances. The remaining four polychaetes dominant in Year 1 experienced a decline, the greatest being the calcareous tube dwelling worm, *Spiroris borealis* (-715), followed by the sand tube dwelling worm, *Sabellaria vulgaris* (-562), although these species exhibited a patchy distribution in Year 1. In particular, *Spirobis borealis* were recovered only in samples collected within Control 1, which was not resampled in Year 2.


Year 1 - Abundance by Phylum
Mollusca
3%
Crustacea
13%
Nematoda
23%
Annelida
61%
Annelida
Nematoda
Crustacea
Mollusca
Nemertea
Copapoda
Echinodermata
Cnidaria


Year 2 - Abundance by Phylum
Annelida
29%
Nematoda
68%
Annelida
Nematoda
Crustacea
Mollusca
Nemertea
Copapoda
Echinodermata
Cnidaria

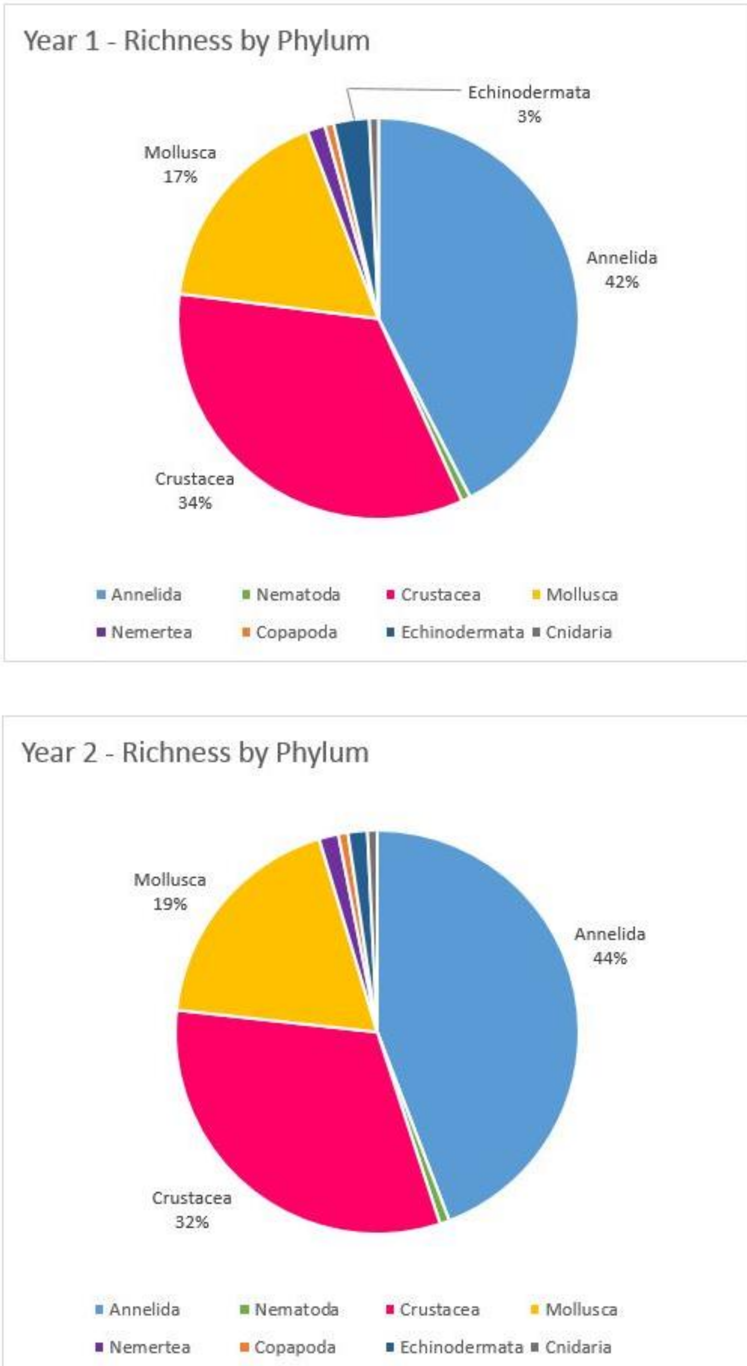


Figure 19. Proportion contribution of macrofauna identified in vessel-based grab samples characterized by phylum to the total abundance and total species richness for Year 1 and Year2. *Note: Percent labels are not shown when a phylum has a total contribution of less than 1.5%.*

The Year 1 and Year 2 samples have comparable spatial distribution and species dominance patterns. Polychaetes, nematodes, crustaceans, and mollusks were broadly distributed, being recovered within all or nearly all of the samples within the turbine and control areas. In Year 1, Polychaetes and/or nematodes dominate or co-dominate all of the 81 samples collected within in the turbine areas, with two exceptions. One sample near Turbine 1 was dominated by the barnacle, *Amphibalanus amphitrite*, and one sample near Turbine 5 is co-dominated by the amphipods *Gammaropsis maculata* and *Erichthonius rubricornis*. Also near Turbine 1, Amphipods (primarily *Unciola irrorata*) and barnacles also co-dominate seven and three samples, respectively. In Year 2, nematodes overwhelmingly dominate 66 samples, followed by polychaetes present in much smaller abundances. Nematodes co-dominate with polychaetes in nearly equal abundances for 10 samples and with nemertea for one sample. The two samples for which nematodes are present, but do not dominate were located near Turbine 1; one sample is dominated by the polychaete, *Polygordius* spp., and the other is co-dominated by *Polygordius* spp. and the amphipod, *Unicola irrorata*. The two turbine samples that did not contain nematodes were located near Turbine 5 and were dominated by polychaetes; one sample is co-dominated by *Parougia caeca* and *Pisione* sp. and the other sample is co-dominated by *Polygordius* spp. and *Polycirrus eximius*.

The majority of the most conspicuous species from Year 1 continue to be present in Year 2 (Table 9). Of the ten most abundant and most frequently occurring species identified each year, six are common to both years: Nematodes, *Polycirrus eximius*, *Polygordius spp*., *Pisione spp*., *Lumbrinereis acuta*, and *Goniadella gracilis*. Of those, the top three most abundant species are consistent from year to year. The same is true for the top five most frequent species, although the first and second ranking species are switched. The primary distinction between years is that three of the most abundant species in Year 1 exhibit a highly patchy and localized distribution, being collected primarily within a few samples (i.e. *Spirorbis*, *Amphibalanus amphitrite, Sabellaria vulgaris*). This pattern is not present in Year 2. Rather, species that are most abundant are also the most widely distributed across the study areas, being found in at least 79 of the 108 samples collected. Overall, the Year 1 samples were found to be more variable, whereas the overall macrofaunal community composition for Year 2 is more cohesive (Figure 20).

Table 9. Top 10 most abundant and frequently occurring species for vessel-based grab samples across all study areas collected in Years 1 and 2. *Note: Asterisk denotes species listed in both years.*

Year 1 - Most abundant			
Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=121)**
Nematode*	Nematoda	4,196	119
Polycirrus eximius*	Polychaete	1,959	77
Polygordius spp*	Polychaete	1,806	112
Lumbrinereis acuta*	Polychaete	1,361	102
Pisione spp.*	Polychaete	1,325	76
Goniadella gracilis*	Polychaete	918	108
Spirorbis	Polychaete	726	6
Sabellaria vulgaris	Polychaete	568	40
Amphibalanus amphitrite	Barnacle	483	27
Unciola irrorata	Amphipod	458	77

Year 2 - Most Abundant			
Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=108)**
Nematode*	Nematoda	41,802	105
*Polycirrus eximius**	Polychaete	2,622	79
Polygordius spp*	Polychaete	2,542	108
Pisione spp*	Polychaete	2,224	81
Parapionosyllis longicirrata	Polychaete	2,186	103
*Lumbrinereis acuta**	Polychaete	1,775	104
Sphaerosyllis erinaceus	Polychaete	1,553	91
Parougia caeca	Polychaete	1,037	88
*Goniadella gracilis**	Polychaete	724	105
Aricidea catherinae	Polychaete	676	84

Year 1 - Most frequent			
Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=121)**
Nematode*	Nematoda	4,196	119
Polygordius spp*	Polychaete	1,806	112
Goniadella gracilis*	Polychaete	918	108
Lumbrinereis acuta*	Polychaete	1,361	102
Parapionosyllis longicirrata*	Polychaete	293	82
Unciola irrorata*	Amphipod	458	77
Polycirrus eximius	Polychaete	1,959	77
Pisione spp.	Polychaete	1,325	76
Maldanidae spp.	Polychaete	259	70
Kirkegaardia baptisteae	Polychaete	140	69

Year 2 - Most frequent			
Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=108)**
Polygordius spp*	Polychaete	2,542	108
Nematode*	Nematoda	41,802	105
*Goniadella gracilis**	Polychaete	724	105
*Lumbrinereis acuta**	Polychaete	1,775	104
*Parapionosyllis longicirrata**	Polychaete	2,186	103
Sphaerosyllis erinaceus	Polychaete	1,553	91
Parougia caeca	Polychaete	1,037	88
*Unciola irrorata**	Amphipod	431	86
Aricidea catherinae	Polychaete	676	84
Monticellina baptisteae	Polychaete	240	83

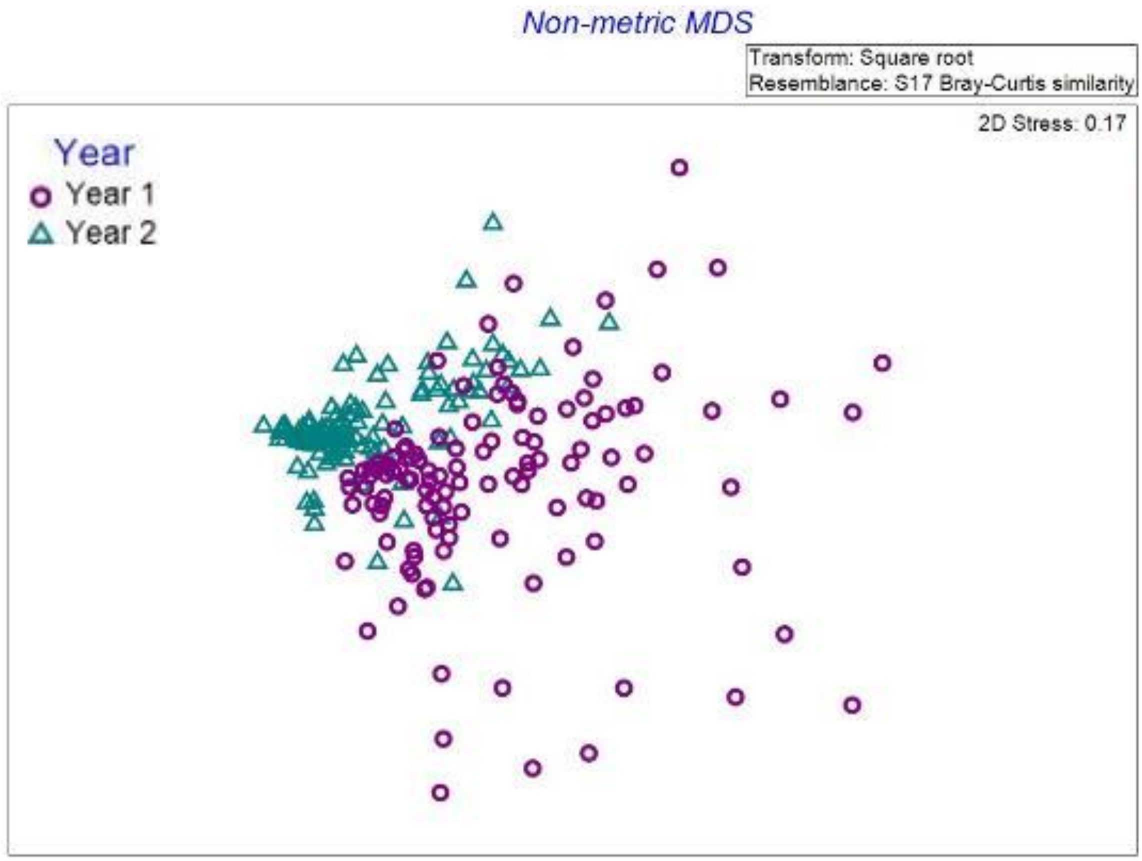


Figure 20. Non-metric MDS plot of vessel-based grab samples collected in Years 1 and 2.

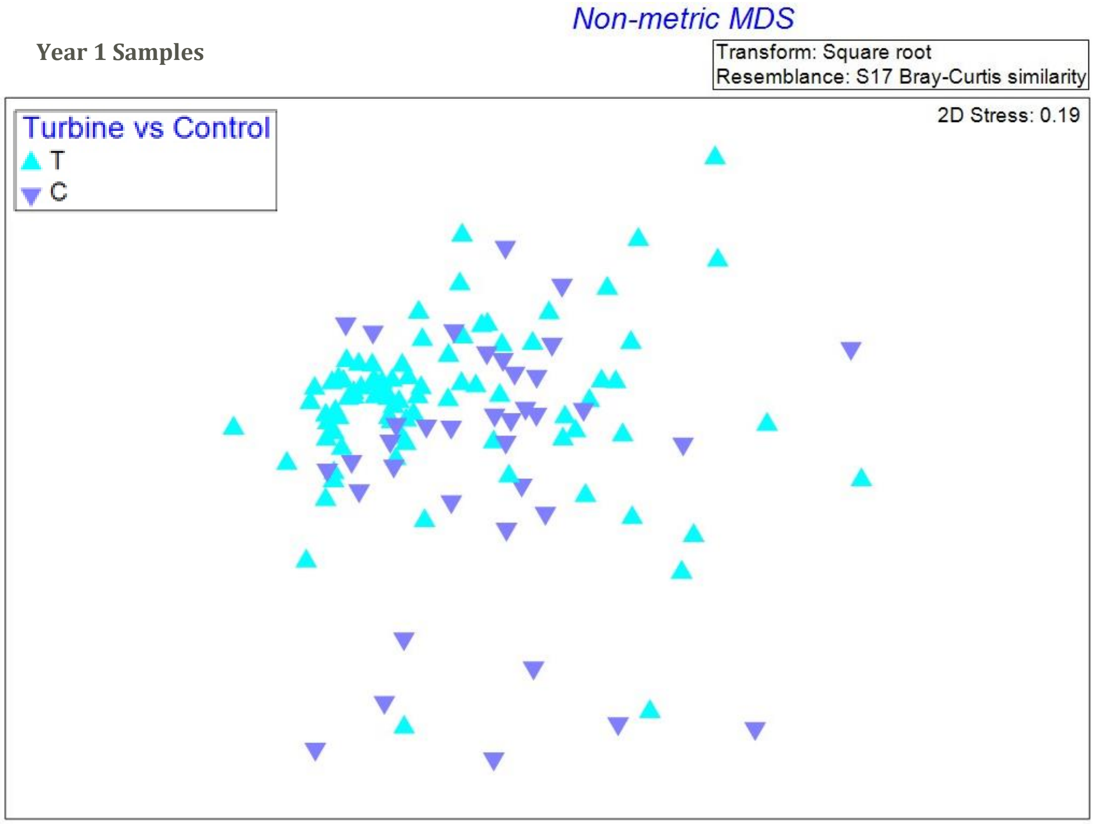
Comparison of Grouped Turbine and Control Areas

The data strongly indicate that there are no appreciable differences between the macrofaunal communities within the turbine and control areas when considered as two general groups in Year 1 or Year 2. The univariate measures of species richness, species abundance, the Shannon Index of diversity (H'), and Margalef's Richness (d) show no clear distinctions between groups. Examination of community composition using nMDS plots for each year and for both years combined further show there is no clear separation between the turbine and control areas (Figure 21). The ANOSIM results support this finding, having an R value of 0.18 ($p=0.001$) for Year 1 samples and an R value of 0.13 ($p=0.001$) for Year 1 and Year 2 samples combined, indicating the two areas exhibit minimal distinction with respect to one another. The ANOSIM result for Year 2 was not significant. Additionally, the SIMPER analysis shows the average similarity for the turbine and control samples combined is high for Year 2 (54.95%) and relatively high for Year 1 (38.92%) (Table 10). SIMPER also reports that for both years the same species are responsible for the average similarity within each group, namely nematodes and polychaetes.

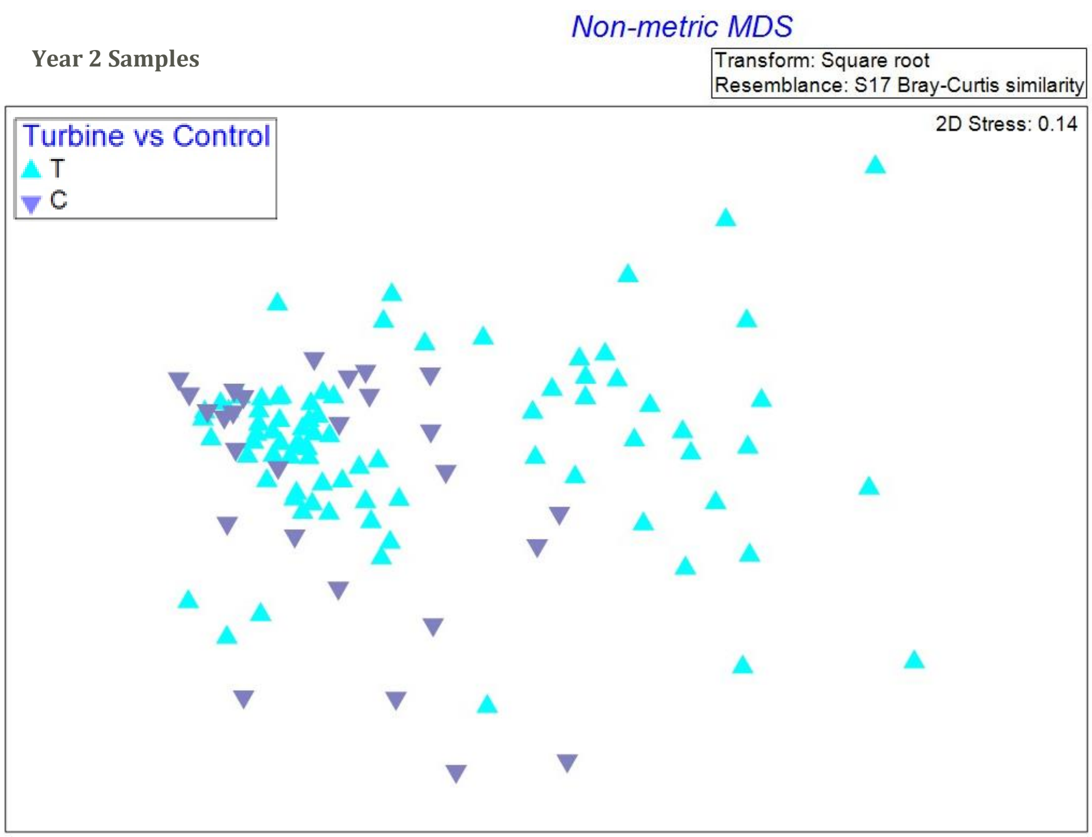
Table 10. SIMPER results showing average similarity and top contributing species (70% cut-off) across all vessel-based grab samples collected in Year 1 and Year 2.

	Average Similarity	**Contributing Species (70% cut-off)**
Year 1	38.92%	Nematoda (20.98%)
		Polygordius (13.38%)
		Lumbrineries acuta (10.26%)
		Goniadella gracilis (9.26%)
		Polycirrus eximius (7.87%)
		Pisione sp. (7.06%)
		Parapionosyllis longicirrata (4.07%)
Year 2	54.95%	Nematoda (30.44%)
		Polygordius (10.62%)
		Parapionosyllis longicirrata (7.24%)
		Lumbrineries acuta (7.19%)
		Goniadella gracilis (5.83%)
		Polycirrus eximius (4.49%)
		Pisione sp. (4.36%)

Year 1 Samples



Year 2 Samples



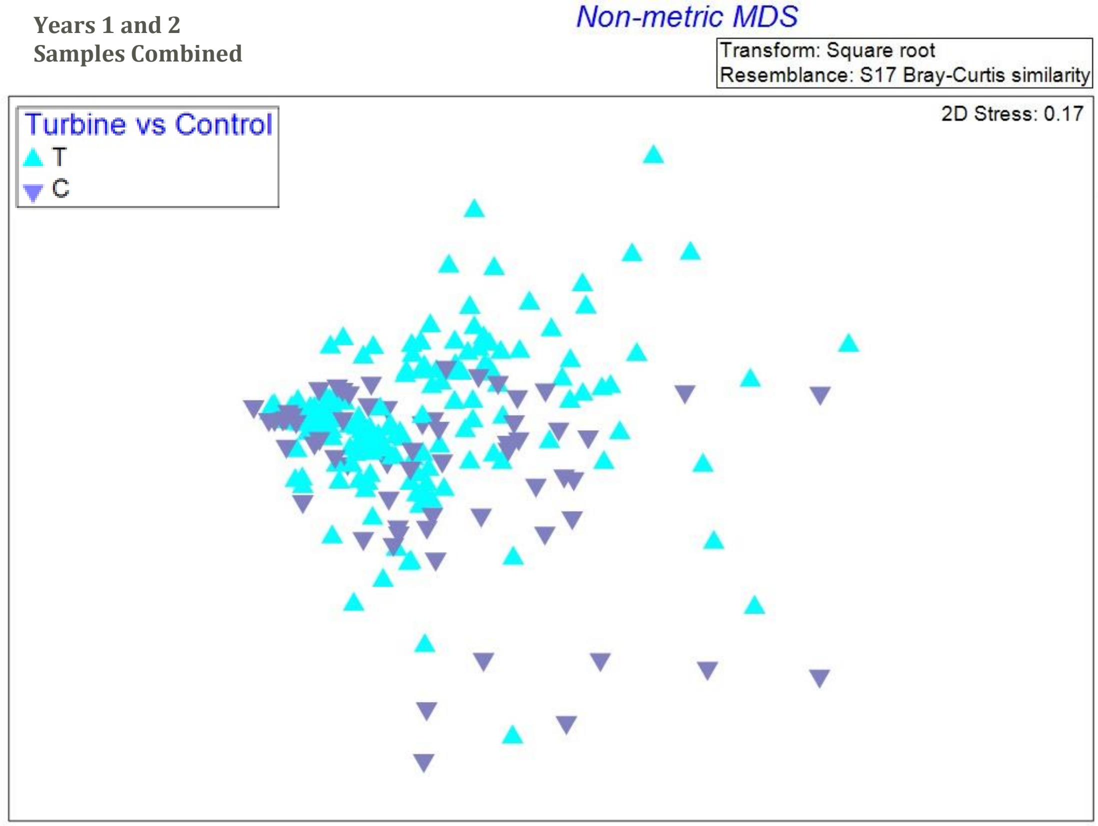


Figure 21. Non-metric MDS plot of Turbine (T) versus Control (C) areas for vessel-based grab samples collected in Year 1, Year 2, and both years combined.

Comparison of Individual Turbine and Control Areas

The data indicate that the macrofaunal communities within the individual turbine and control areas are largely comparable and that there are no appreciable differences from Year 1 to Year 2. The primary distinction between the turbine areas is that Turbines 3 and 5 exhibit a higher degree of similarity in macrofaunal community characteristics and Turbine 1 is relatively distinct for both years. Overall differences that were identified were largely partitioned on the basis of variations in abundances of the characterizing fauna rather than the existence of distinct assemblages. The control samples are generally representative of the turbine samples, suggesting that all of the study areas are reflecting natural conditions associated variability. The discrepancy of samples in Control 1, particularly in Year 1, likely reflects a more distinct macrofaunal community structure because that control area is located on the edge of a glacial moraine and exhibits different environmental characteristics relative to the other study areas, most notably the presence of boulders and coarser substrates and shallower water depths, rather than activities associated with the BIWF project. Further details are presented below in support of these findings.

The univariate calculations report that the mean number of species and mean species abundance (excluding nematodes) increased within the turbine and control areas from Year 1 to Year 2 (Figure 22 and Table 11). The data also show that Turbine 1 is more distinct, reporting the lowest values for both years. This difference is especially pronounced with respect to mean species abundance, for which Turbines 3 and 5 exhibited similar mean abundances that were approximately 2.5x and 3x the mean abundance of Turbine 1 in Year 1 and Year 2, respectively. The Tukey HSD test found species abundance at Turbine 1 to be significantly lower than those at Turbines 3 and 5 ($p < 0.05$). Mean species abundance for the control areas are comparable to those calculated for the turbine areas for each year. Though the pattern changes from Year 1 to Year 2, having a lower value than Turbines 3 and 5 in Year 1 and a higher value in Year 2. Comparatively, the mean number of species was highest for the control areas in both years. While the mean number of species and species abundance values are useful interpretations of the data, it is recognized that the variance around the mean fluctuates considerably for both datasets (refer to Figure 22).

The Shannon Index of diversity (H') and Margalef's Richness (d) results are similar across all of the turbine areas and mean values for the control areas are in the range of those calculated for the turbine areas (Figure 22 and Table 11). Slightly lower values of the Shannon Index (H') were reported at Turbine 5 in Year 1 and at Turbine 3 in Year 2. Also, despite the overall increases in mean numbers of species in Year 2, mean diversity (H') values were comparatively lower. Mean values of Margalef's were consistent for both years, with the exception of the relatively higher value for the control areas in Year 1.

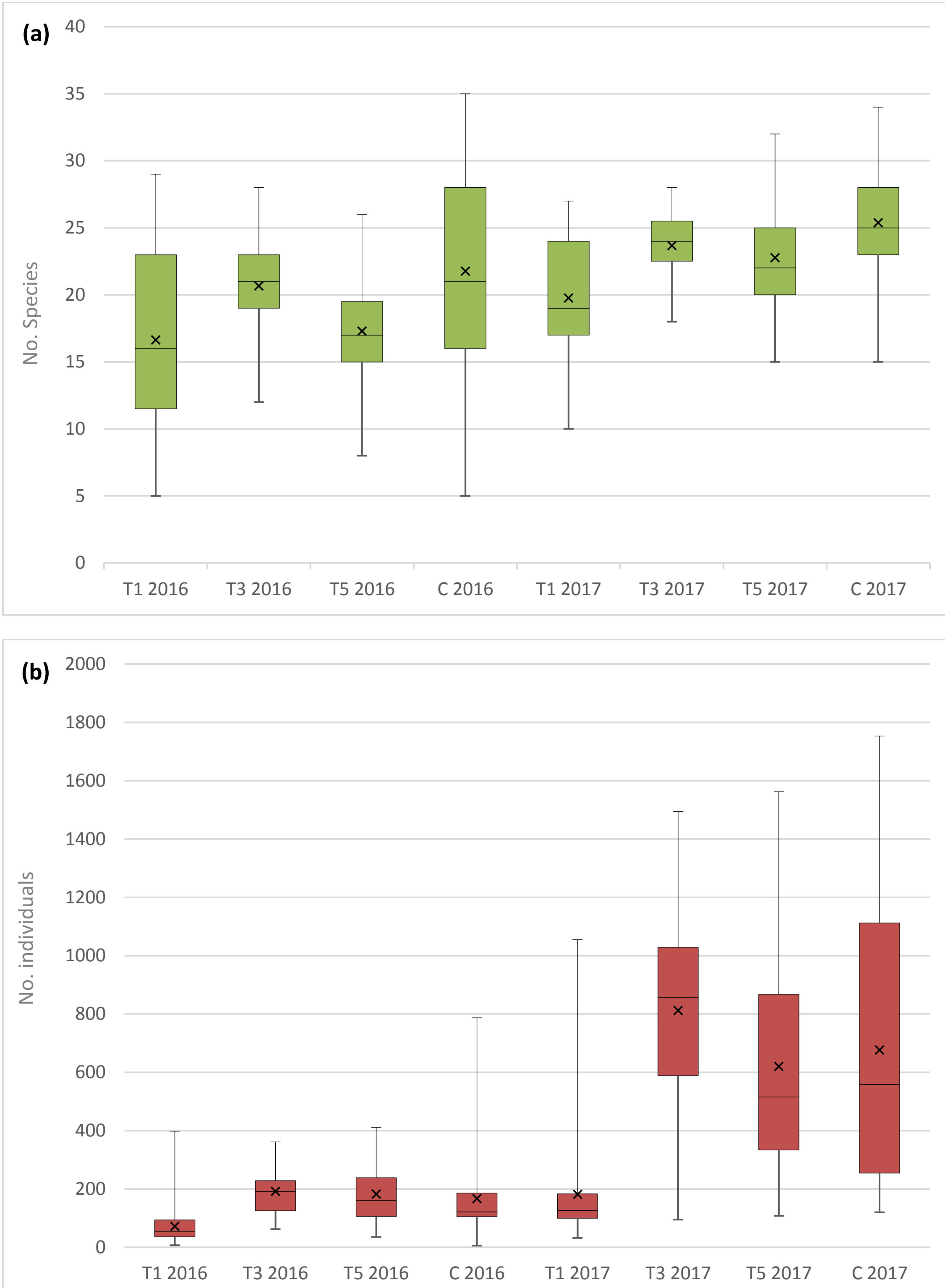
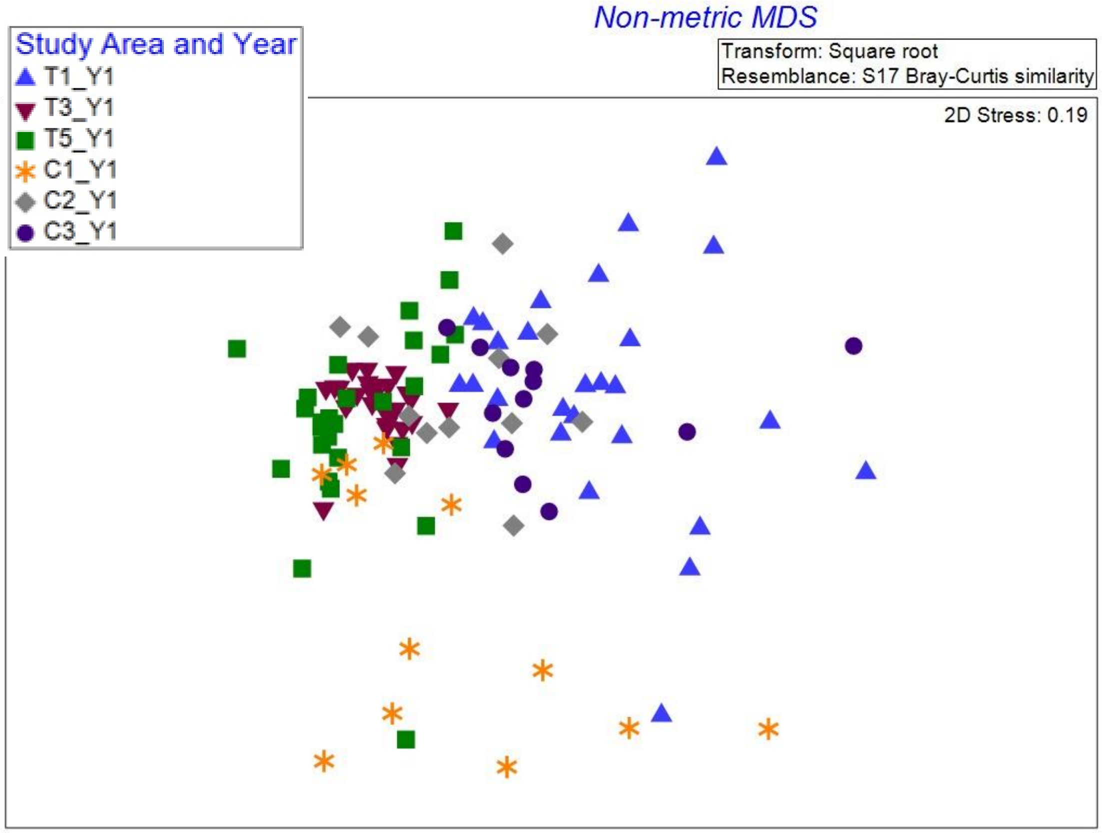


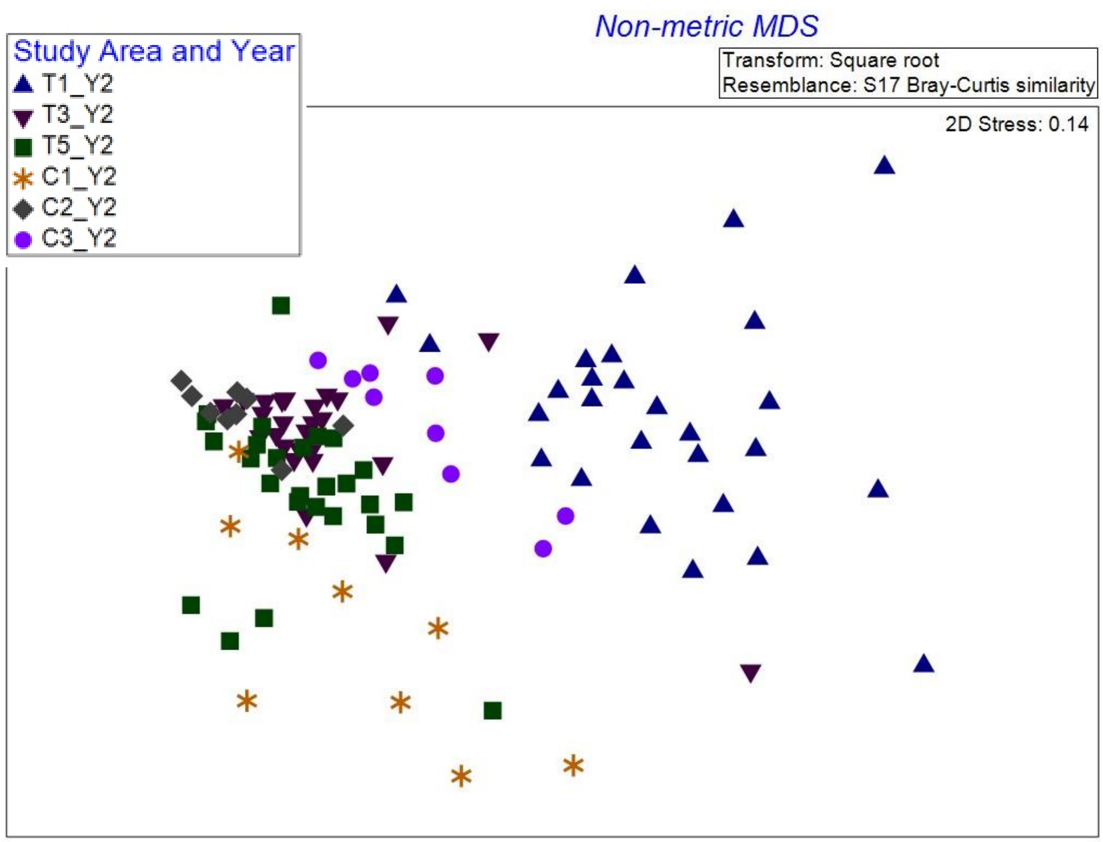
Figure 22. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of the number of species (a) and number of individuals (b). *Note: Data shown for each turbine and across all reference areas for vessel-based grab samples collected in Year 1 and Year 2.*

Table 11. Summary of macrofaunal indices for vessel-based grab samples collected in Year 1 and Year 2. *Note. Mean abundance values exclude nematodes.*

		Turbine 1	**Turbine 3**	**Turbine 5**	**Control Areas**
Year 1	Mean No. Species	16.6	20.7	17.3	22.6
	Mean Species Abundance	71.1	191.9	182.4	160.0
	Mean Diversity (H)	2.18	2.21	1.84	2.26
	Mean Richness (d)	3.82	3.79	3.22	4.42
Year 2	Mean No. Species	19.7	23.7	22.8	25.3
	Mean Species Abundance	76.1	211.5	213.9	240.3
	Mean Diversity (H)	1.8	1.3	1.6	1.7
	Mean Richness (d)	3.8	3.5	3.5	3.9

Assessment of macrofaunal community structure using nMDS plots, SIMPER, and Permdisp routines support the overall conclusions that the individual study areas are broadly comparable. The nMDS plot shows the control samples generally plot among the turbine samples and occupy the sample relative position on the plot from Year 1 to Year 2 (Figure 23). Additionally, SIMPER reports comparable average similarities across the turbine (Year 1: 38.91%-63.49%; Year 2: 55.33%-69.95%) and control areas (Year 1: 36.32%-51.11%; Year 2: 54.68%-75.15%) for a given year (Table 12). One distinction noted in the nMDS plots is that the Year 2 samples are generally more cohesive within each individual study whereas the Year 1 samples show more variability. This pattern is also reflected in the SIMPER output (i.e. Year 2 areas have higher within-study area similarities and lower among-study area dissimilarities) and in the PermDisp output, which reports the Year 2 samples exhibit a lower average multivariate dispersion (average dispersion = 32.194) compared to that calculated between the Year 1 samples (average dispersion = 43.093). The nMDS plots also show Turbine 1 samples are more scattered across the plot for both years, indicating macrofaunal communities are more variable. Again, SIMPER supports this finding, reporting that Turbine 1 consistently has the lowest average similarity (Year 1: 38.91%; Year 2: 55.33%) compared to Turbine 3 (Year 1: 62.49%; Year 2: 69.95%) and Turbine 5 (Year 1: 50.49%; Year 2: 66.8%). These patterns are further corroborated by the Permdisp output, reporting greater average values for multivariate dispersion for Turbine 1 samples for both years compared to the other turbine and control areas.


Non-metric MDS
Transform: Square root
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0.19
Study Area and Year
T1_Y1
T3_Y1
T5_Y1
C1_Y1
C2_Y1
C3_Y1


Non-metric MDS
Transform: Square root
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0.14
Study Area and Year
T1_Y2
T3_Y2
T5_Y2
C1_Y2
C2_Y2
C3_Y2

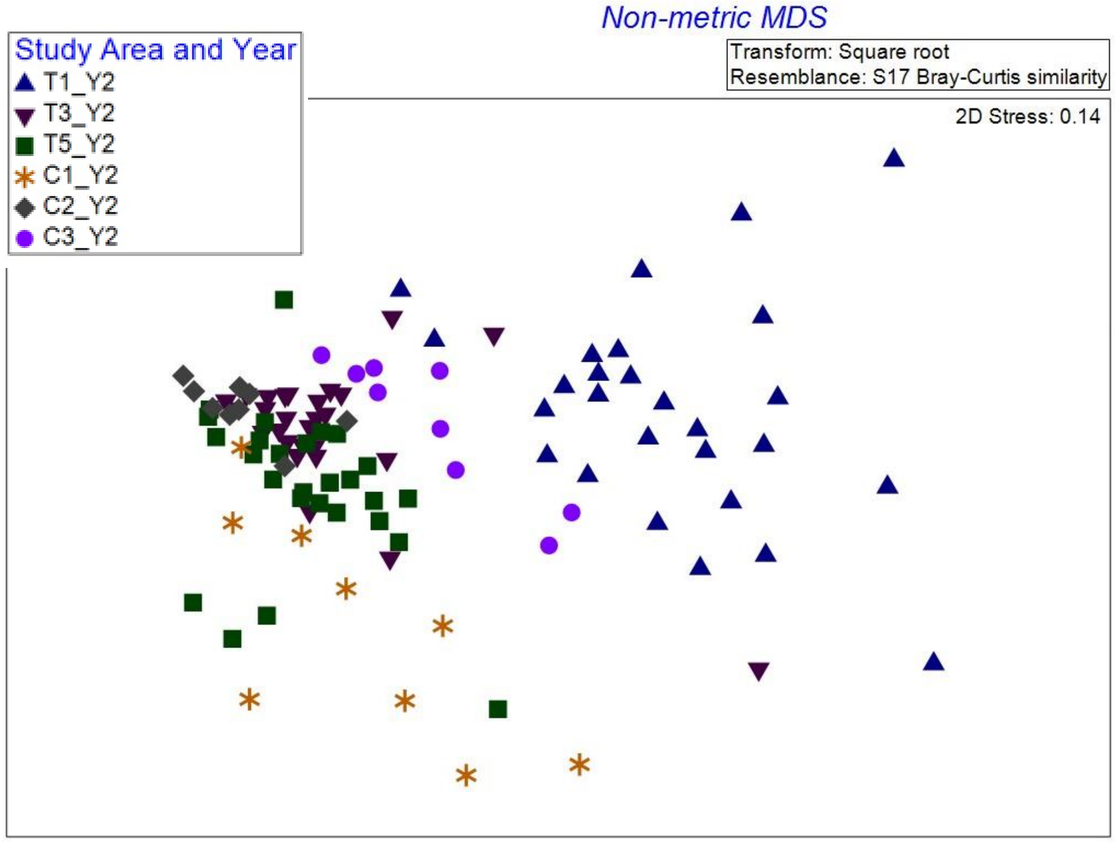


Figure 23. Non-metric MDS plot of vessel-based grab samples collected within each turbine and control area in Year 1, Year 2, and both years combined.

Table 12. SIMPER results of vessel-based grab samples collected within each turbine and control area in Year 1 and Year 2.

Average Similarity (%)				Average Dissimilarity (%)		
Station	**Year 1**	**Year 2**		**Station**	**Year 1**	**Year 2**
T1	38.91	55.33		T1, T3	66.47	57.14
T3	62.49	69.95		T1, T5	70.32	58.91
T5	50.49	66.8		T3, T5	48.56	33.6
C1	36.32	54.68		T1, C1	76.19	60.5
C2	51.11	75.15		T3, C1	67.03	47.28
C3	48.52	68.14		T5, C1	66.18	44.42
T1 and T3	41.96	52.94		T1, C2	63.85	62.98
T1 and T5	37.05	51.23		T3, C2	52.8	30.51
T3 and T5	53.92	67.58		T5, C2	61.9	35.26
				C1, C2	71.53	47.7
				T1, C3	61.67	50.64
				T3, C3	61.8	39.84
				T5, C3	66.21	42.68
				C1, C3	72.91	48.37
				C2, C3	59.11	40.76

The nMDS plots and SIMPER output, along with the ANOSIM output, also provide evidence that macrofaunal communities at Turbines 3 and 5 are more similar to one another and Turbine 1 is more distinct (refer to Figure 23 and Table 12). Specifically, the nMDS plots in show the Turbine 1 samples separate out from those collected at Turbines 3 and 5, especially in Year 2. Conversely, Turbines 3 and 5 samples are clustered together and exhibit a high degree of overlap for both years. The SIMPER results complement the nMDS plots, reporting Turbines 3 and 5 have the lowest average dissimilarity (Year 1: 48.56%; Year 2: 33.6%). Comparatively, the average dissimilarity is greater between Turbines 1 and 3 (Year 1: 66.47%; Year 2: 57.14%), and between Turbines 1 and 5 (Year 1: 70.32%; Year 2: 58.91%). Further, when combining the Turbines 3 and 5 samples, SIMPER reported an average similarity of 53.92% and 67.58% for Year 1 and Year 2, respectively, whereas the averaged similarities are noticeably lower for Turbines 1 and 3 combined and for Turbines 1 and 5 combined. The results of the ANOSIM analyses mimic the patterns identified in the nMDS plots and SIMPER analyses. Turbines 3 and 5 continue to exhibit the lowest degree of distinction, with ANOSIM reporting an R value of 0.251 in Year 1 and 0.133 in Year 2 (both $p = 0.001$), compared to Turbines 1 and 3 (R: Year 1 = 0.582; Year 2 = 0.729; both $p = 0.001$) and Turbines 1 and 5 (R: Year 1 = 0.552; Year 2 = 0.792; both $p = 0.001$). These results are particularly pronounced in Year 2.

Examination of the macrofaunal data shows high agreement in the dominant species and their broad distribution for both years across the different turbine areas (Table 13), which were characterized by nematodes and polychaetes. With respect to sampling years, four of the five dominant species at each of the turbine areas in Year 1 continue to dominate in Year 2. In Year 2, the polychaete, *Parapionosyllis longicirrata* becomes a dominant species at Turbines 3 and 5, replacing the polychaete, *Lumbrinereis acuta*, although both species were also present in high abundances for the year they are not listed in the top five. *Parapionosyllis longicirrata* also replaces the polychaete, *Sabellaria vulgaris*, at Turbine 1 in Year 2. The disappearance of *Sabellaria vulgaris* from the current dataset for Turbine 1 is attributed to the patchy distribution of the species. For the turbine areas within a given year, the same five species dominate within Turbines 3 and 5, three of which are dominant at Turbine 1. The most apparent difference across turbine areas is the variation in the abundances of these dominant species. This pattern is consistent from Year 1 to Year 2. The discrepancy in species abundances, rather than the species composition, between areas likely accounts for the differences in macrofaunal community structure identified in the statistical analyses.

Table 13. Top dominant species for vessel-based grab samples collected within each turbine area for Year 1 and Year 2. *Note: Asterisk (*) denotes species listed for a given turbine area in both years. Carrot (^) denotes species that are listed in all three turbine areas for a given year.*

Sampling Period	Study Area	Dominant Species	Taxonomic Group	Abundance	Occurrence (n=27)
Year 1	**Turbine 1**	*Sabellaria vulgaris*	Polychaete	382	16
		Nematoda^*	Nematode	262	26
		*Goniadella gracilis**	Polychaete	170	22
		Polygordius^*	Polychaete	170	22
		Lumbrinereis acuta^*	Polychaete	105	20
	Turbine 3	*Nematoda*^*	Nematode	1,344	27
		*Polycirrus eximius**	Polychaete	847	27
		*Pisione**	Polychaete	645	27
		Polygordius^*	Polychaete	481	27
		*Lumbrinereis acuta^*	Polychaete	476	26
	Turbine 5	*Nematoda*^*	Nematode	1,501	27
		*Polycirrus eximius**	Polychaete	863	24
		Polygordius^*	Polychaete	860	27
		*Pisione**	Polychaete	434	26
		*Lumbrinereis acuta^*	Polychaete	385	24
Year 2	**Turbine 1**	*Nematoda*^*	Nematode	2,840	27
		Polygordius^*	Polychaete	541	27
		*Goniadella gracilis**	Polychaete	303	27
		*Parapionosyllis longicirrata^*	Polychaete	217	23
		*Lumbrinereis acuta**	Polychaete	175	26
	Turbine 3	*Nematoda*^*	Nematode	16,214	27
		*Polycirrus eximius**	Polychaete	838	25
		*Pisione**	Polychaete	731	25
		*Parapionosyllis longicirrata^*	Polychaete	626	27
		Polygordius^*	Polychaete	619	27
	Turbine 5	*Nematoda*^*	Nematode	10,974	25
		*Polycirrus eximius**	Polychaete	876	27
		*Pisione**	Polychaete	786	27
		Polygordius^*	Polychaete	742	27
		*Parapionosyllis longicirrata^*	Polychaete	741	27

Comparison of Distance from Turbine

Analyses revealed there are no localized differences in macrofaunal communities as a function of distance beyond 30 m and within 90 m of the center point of the turbine structures in Year 1 and Year 2. ANOSIM performed on the sample data between distance bands for each turbine for each year revealed no significant differences ($P>0.05$) between any of the pairwise comparisons. Permanova results for the Year 2 data also did not identify any significant differences with respect to the distance bands and turbine areas. The Tukey HSD test confirmed there were no statistically significant differences in the numbers of individuals between the different distance bands at each turbine location ($p>0.05$). Several other analyses (not shown) further support there are no clear relationships macrofaunal characteristics with distance, including regression plots comparing species abundance and richness within distance bands; nMDS plots of macrofaunal assemblages coded by distance band; comparison of the mean number of species and mean number of individuals within each distance band; and plots of the spatial distribution of number of species, species abundance, the Shannon Weiner index of diversity (H’), and Margalef’s Richness (d).

The only notable results are from the Turbine 1 Year 2 regression plots, which suggest a weak relationship of increasing species richness and abundance with increasing distance from the turbine ($R^2 = 0.1293$ and 0.1754, respectively). Also, two way ANOVA of the data for factors ‘distance band’ and ‘turbine year’ identified a highly significant difference in the number of species between years ($F_{(7,192)} = 9.3941$, $p = 5 \times 10^{27}$). Subsequent follow up Tukey HSD tests found a significantly higher number of species within the far field (70 to 90 m) distance band at Turbine 5 in Year 2 compared to Year 1

($p<0.05$). The mean number of species recorded at far field locations at Turbine 5 was 15.89 in Year 1 compared to 24.22 in Year 2. The macrofauna data reports species present in the far field within Turbine 5 in Year 2, but not Year 1, included *Pseudomystides* sp., *Syllides* sp., *Cirrophorus furcastus*, *Marphysa bellii*, Oligochaetes, and *Leptosynapta* sp. While not specifically recorded within the far distance band at Turbine 5 in Year 1, these species are generally characteristic of the study area and have been recorded in both sampling years at other turbine and control areas. Therefore, it is unlikely that these records represent a significant ecological change at Turbine 5, but rather reflect the patchy distribution of species within the wider area. Species numbers were not significantly different between other pair-wise tests and there was no significant interaction between the two factors.

2.3.2. Turbine Footprint Area

2.3.2.1. Surficial Sediment Composition

The PSD analysis and still photographs confirm sediment characteristics within the footprint of Turbines 3 and 5 are nearly identical to those of the vessel-based grab samples collected in the vicinity of the turbine structures. The PSD reports all samples are dominated by coarse sand and contained no clay or silt particles, and the fractions of medium, coarse, and very coarse sand combined account for greater than 90% of the sediment composition. The mean fractions of each Wentworth-defined sediment class were also comparable for sediment samples collected within the footprint and the surrounding area of Turbines 3 and 5. In contrast, at Turbine 1, the five samples collected under the structure have a substantially higher finer grain size composition relative to those of the surrounding area. The clay and silt content for each sample ranges from 24%

to 34% for four of the samples and is 72% for one sample. Also, the contribution of fine sand is between 3.2% and 7% for each sample. In comparison, none of the samples from the surrounding area contain clay, silt, or fine sand. The mean proportion of medium sand for the footprint samples is 26.1%, nearly half of the 49.6% for the vessel-based samples for both years. Similarly, the mean proportion of coarse sand is 25.9%, versus 41.6% and 43.4% for vessel-based samples collected Year 1 and Year 2, respectively. The sediment characteristics described by the PSD analysis for Turbine 1 are fully captured in the still imagery.

2.3.2.2. Sediment Organic Content

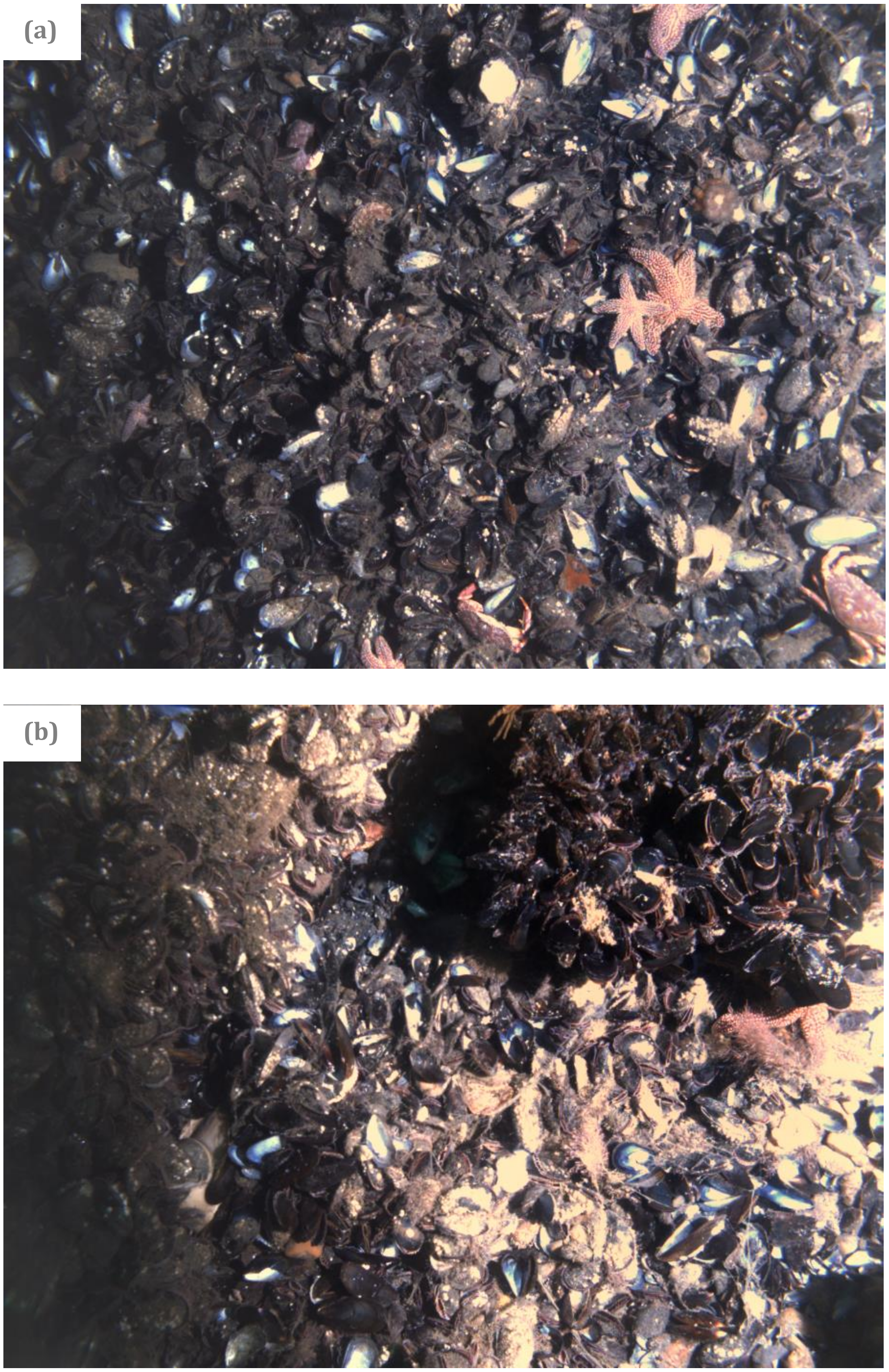
A 1-way ANOVA ($\log_{10}$+1 transformed data) demonstrated that both TOC and TOM levels in the sediment samples collected within the foundation footprint of Turbine 1 were significantly higher than those recorded in samples collected under Turbines 3 and 5 ($p<0.05$) and were also significantly higher than the vessel-based samples collected within the control areas. The mean level of TOC for the Turbine 1 samples was 2.5%, with a maximum level of 5.4%. The mean and maximum TOM levels at were 1.1% and 2.3%, respectively. In contrast, levels of TOM and TOC in the footprint samples from Turbines 3 and 5 were nearly identical to those recorded for the vessel-based samples. These samples contained a mean TOM and TOC of 0.5% and 0.2%, respectively, at Turbine 3, and, similarly, at Turbine 5 mean TOM and TOC was 0.3% and 0.1%, respectively.

2.3.2.3. Imagery Analysis

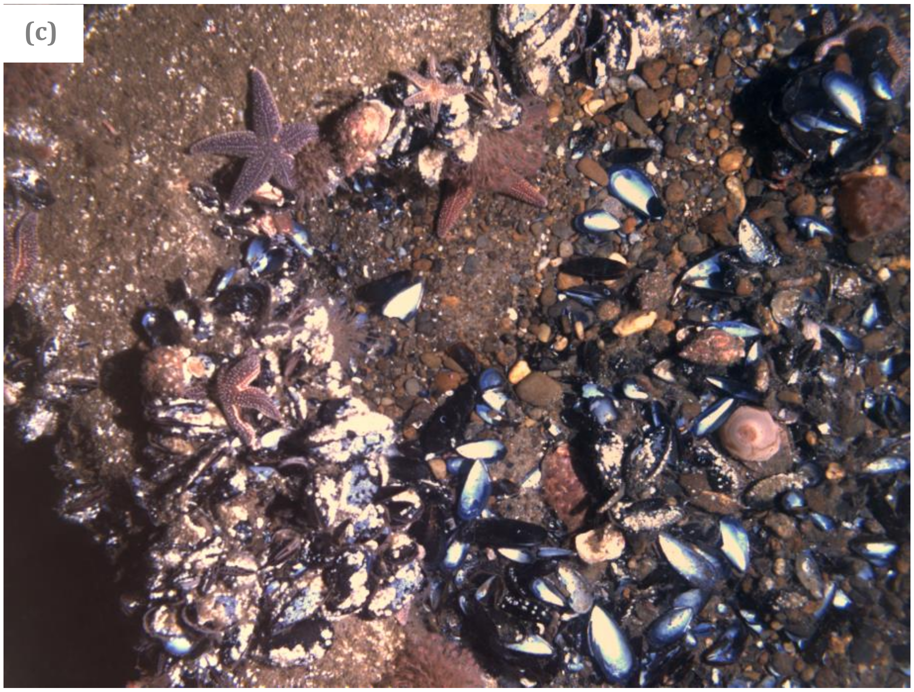
The imagery clearly shows the three turbines vary along a gradient in the density of blue mussels, *M. edulis*, on the seafloor within the foundation footprints (Figure 24).

Specifically, at Turbine 1 living mussels and mussel shells are present in extremely dense concentrations within the entire footprint. The grate structure on the seafloor is entirely colonized by mussels and is not detectable in the images. Conversely, Turbine 5 has very few mussels and shells and the grate structure is not colonized. Turbine 3 is in the middle of this spectrum, although it is more similar to Turbine 5. Interestingly, it appears that the mussels are contained within the footprint of the turbine structures. The imagery, as well as diver observations, suggest mussels are absent just outside the perimeter, including at Turbine 1. The images also capture several scavenger species that have appear to be attracted to the area due to the mussels, including crabs, sea stars, and moon snails. Also noted were several species of fish and elasmobranchs, including black sea bass, flounder, spiny dogfish, and winter skate.

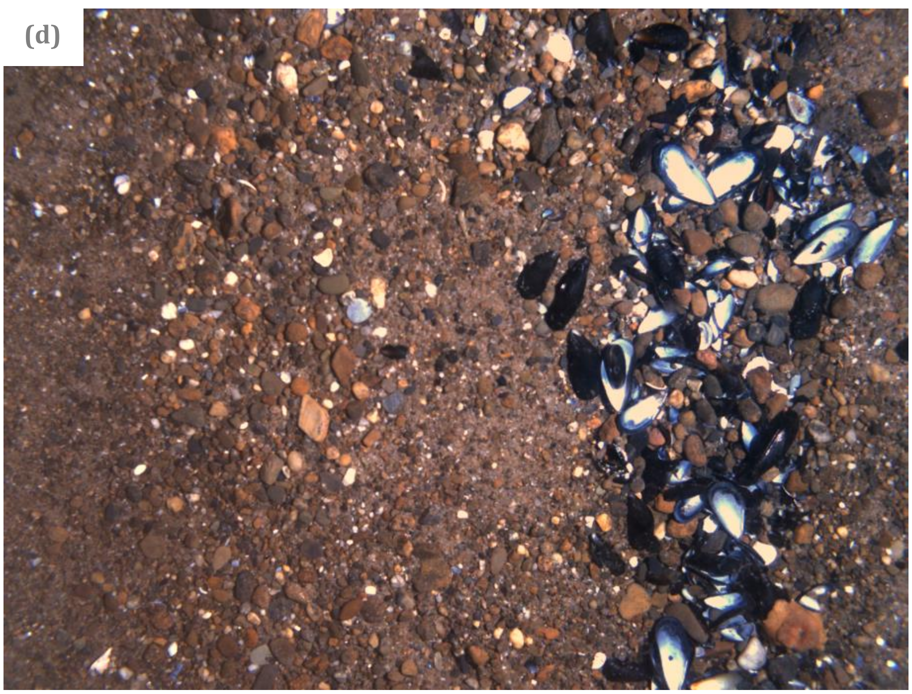
Though unintended, the imagery also provided the opportunity to evaluate fouling of the protective concrete mats overlain on portions of the buried transmission cable. The images revealed that the mats are consistently, bare both under the turbine structure and outside of it. The mats are not colonized by any organisms, with the exception of encrusting sponges covering small areas (refer to Figure 24).

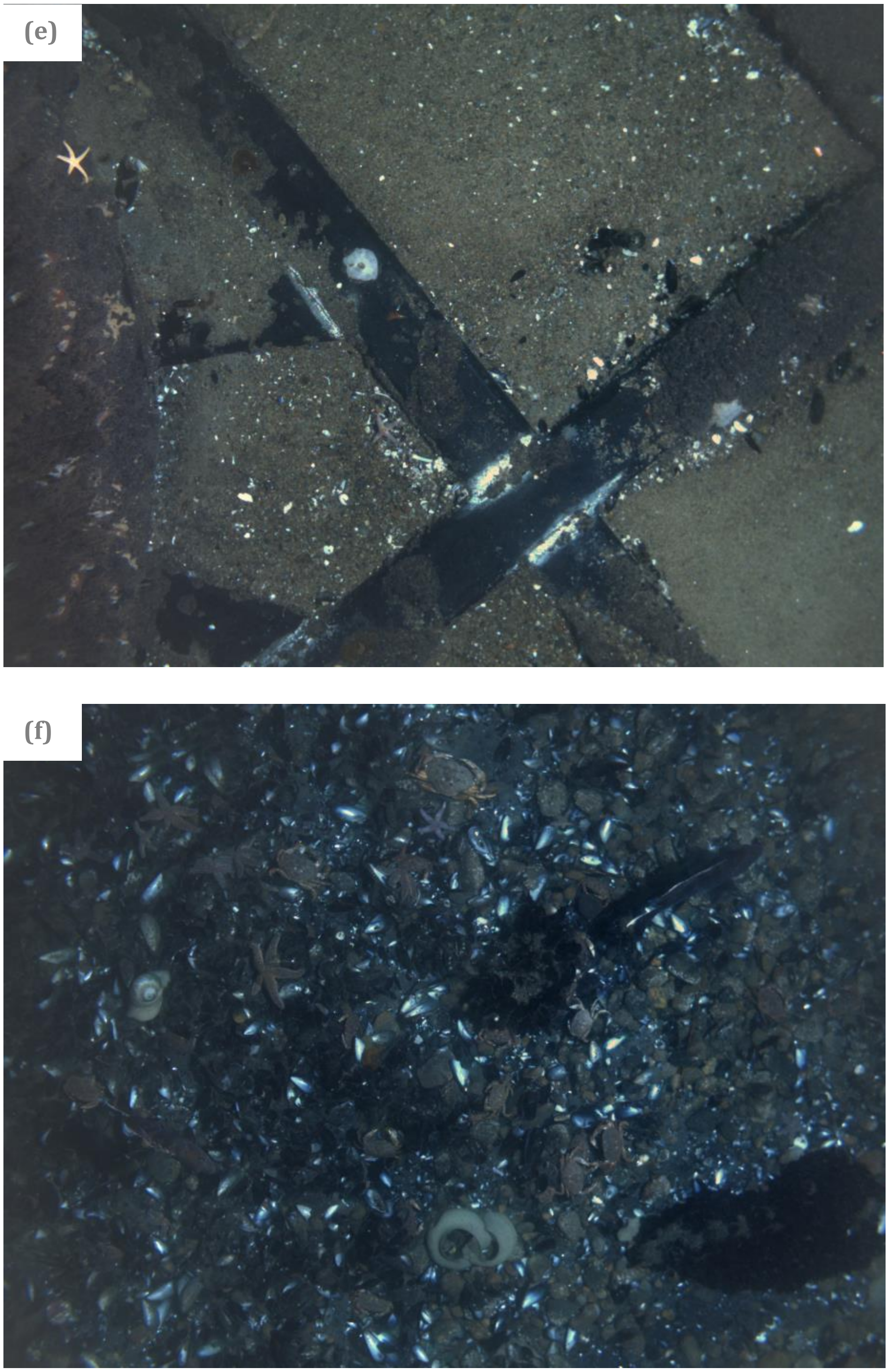

(a)
(b)

(c)



(d)




(e)
(f)

(g)

Figure 24. Example images taken within the footprint of the turbine structures by the diver-towed camera system in Year 2. *Note: The images at Turbine 1 (a) and (b) show the dense cover of living mussels and shells at Turbine 1 and the heavy colonization of the grate structure on the seafloor. Image from Turbine 3 (c) and (d) show the partial colonization of the grate structure by mussels and that mussels are present to a much lesser extent. The image at Turbine 5 (e) show the lack of mussels on the seafloor and that the grate structure is not colonized. Some of the images also show the high density of scavenger species amongst the mussels, including starfish, crabs, moon snails, which is again highlighted in image (f). Neither mussels or other organisms have colonized the protective concrete mats at any of the turbines, as shown in image (g) taken at Turbine 1.*

2.3.2.4. Macrofaunal Analysis

It should be noted that the size of samples collected within a given turbine are comparable, although the sample size among turbines varies considerably due to inconsistencies in diver sampling techniques (Table 14). The smallest samples were collected under Turbine 3 (average volume = 1.2 L), while Turbine 5 had the largest samples (average volume = 7.8 L). Samples from Turbine 1 fell in the middle of the spectrum (average volume = 4.3 L). The samples were not standardized (e.g., by volume) because examination of species abundance and number of species across the samples revealed no consistent relationship with grab volume. This inconsistency prevented the use of a multiplier to standardize the volumes across all the samples. As such, the "raw" data were used in analyses and the results presented should be considered relative, rather than direct, descriptions and comparisons.

A total of 3,521 individuals belonging to 70 species were recovered from the 15 grab samples (Table 14). Nearly 100% of the macrofauna belonged to four phyla, with nematodes comprising 49% of the total species abundance, followed by mollusks (20%), crustaceans (16%) and annelids (i.e., polychaetes; 15%) (Figure 25). With regard to number of species, polychaetes contributed 47%, crustaceans 31%, and mollusks 16%. Nematodes were identified to the phylum level and therefore the number of species cannot be provided.

Table 14. . Summary of species abundance and species richness for all macrofaunal samples collected within the footprint of each turbine structure in Year 2. *Note: Sample weight is heavily influenced by the concentration of larger sediment particles (i.e., pebble, gravel, and cobbles).*

	Turbine 1	Turbine 3	Turbine 5	All Combined
Total Species Richness	26	36	50	70
Mean Species Richness	11.4	15.4	23.2	--
Range of Species Richness per Sample	8-16	11-26	17-32	8-32
Total Species Abundance	429	270	2,822	3,521
Total Species Abundance (Nematoda excluded)	349	249	1,200	1,798
Mean Species Abundance	86	54	564	--
Range of Species Abundance per Sample	45-128	29-94	420-716	29-716
Average Volume of Sample (L)	4.3	1.2	7.8	4.4
Average Weight of Sample (lbs)	24	5.2	37.2	22.1

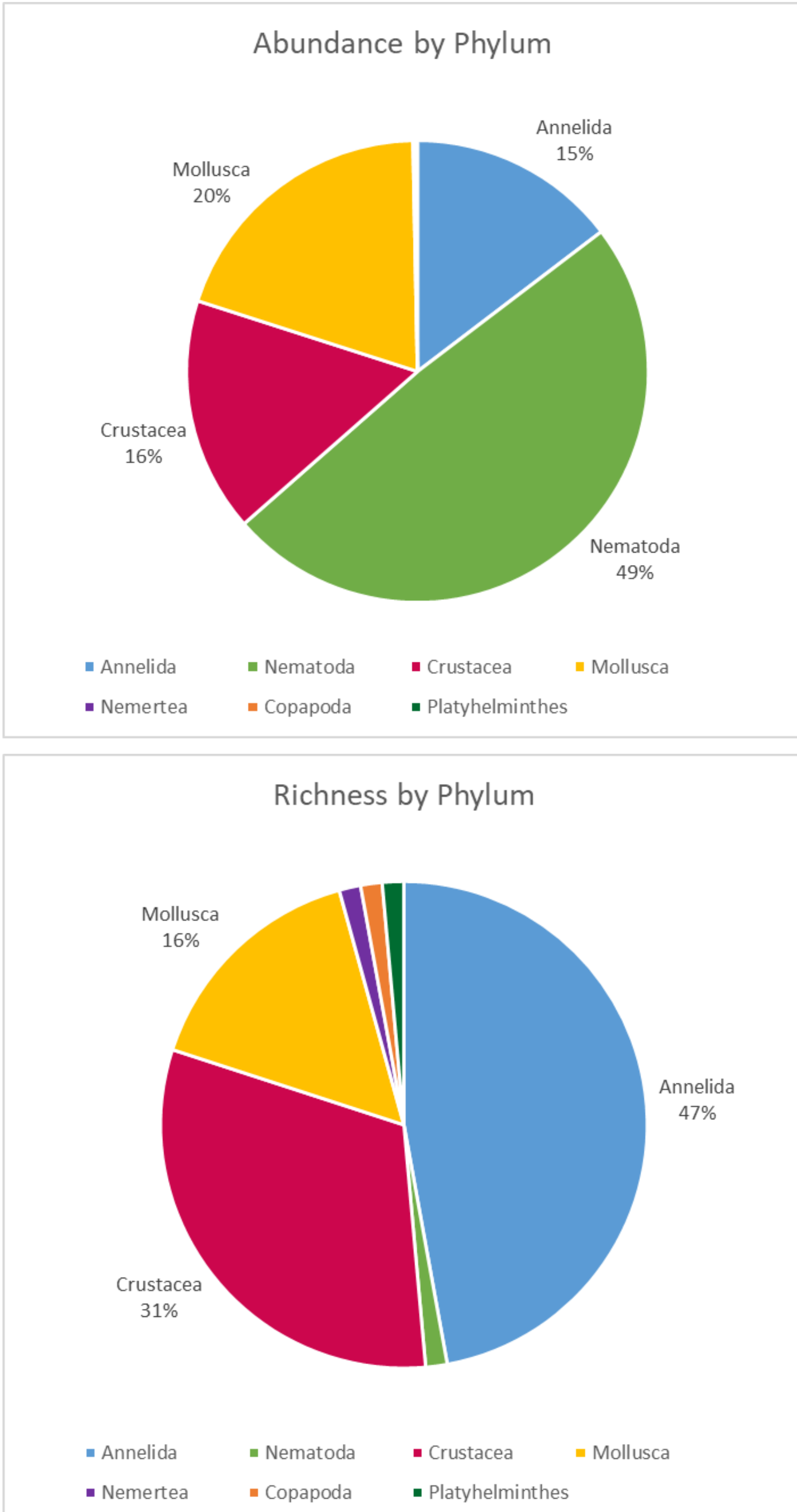


Figure 25. Proportion contribution of macrofauna characterized by phylum to the total abundance and total species richness for all macrofaunal samples collected within the footprint of each turbine structure in Year 2.

The four phyla were broadly distributed, with individuals from each recovered within all samples. The most conspicuous species across all the samples in terms of total abundance were nematodes, followed by the blue mussel, *Mytilus edulis* (Table 15). Also dominant were the barnacle, *Balanus*; the amphipods, *Unciola irrorata* and *Byblis serrata*; and the polychaetes *Polygordius* and *Lumbrinereis fragilis*. In general, these dominant species were also the most frequently occurring. No species were recovered in all 15 samples and only four species were recovered in 14 of the samples, with the remaining macrofauna present in 11 samples or fewer.

Table 15. Most abundant and frequently occurring species for all diver-based samples collected under the structure of each turbine in Year 2. *Note: Asterisk denotes species listed as both abundant and frequent. Bold font denotes species that were also listed in the vessel-based grab samples collected in Year 1 and/or Year 2.*

Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=15)**
Most abundant (< 100 individuals)			
Nematode*	Nematoda	1721	15
Mytilus edulis*	Mollusk	668	15
Balanus spp*	Mollusk	243	14
Unciola irrorata*	Amphipod	159	11
Polygordius spp*	Polychaete	137	10
Byblis serrata	Amphipod	109	7
Lumbrinereis fragilis*	Polychaete	99	14
Most Frequent (< 10 samples)			
Nematode*	Nematoda	1721	15
Mytilus edulis*	Molluska	668	15
Balanus spp*	Molluska	243	14
Lumbrinereis fragilis*	Polychaete	99	14
Unciola irrorata*	Amphipod	159	11
Polygordius spp*	Polychaete	137	10
Goniadella gracilis	Polychaete	25	10

Comparison of Individual Turbines

The result of the data analyses strongly indicate that macrofaunal community characteristics vary considerably within the footprint of the three turbine structures along a gradient, with Turbine 3 reflecting the transition area between Turbines 1 and 5. One way ANOVA of the macrofauna data confirmed significant differences in the number of species between the turbine locations ($F_{(2,14)} = 3.8853$, $p = 0.009$) and *post-hoc* Tukey HSD tests highlighted that the number of species at Turbine 5 were significantly higher than those at Turbine 1 ($p <0.05$). Similarly, there were significant differences in total species abundance (one-way ANOVA) ($F_{(2,14)} = 3.8853$), $p = 1.72$ x $x10^6$), with Turbine 5 containing significantly higher abundances than Turbines 1 and 3 (Tukey HSD $p < 0.05$).

ANOSIM reports there are statistically significant differences in macrofaunal community composition among the three turbines ($R = 0.791$; $p = 0.001$). The SIMPER and nMDS outputs also support this finding (Table 16 and Figure 26). Furthermore, these outputs show macrofaunal composition is more variable at Turbine 3 and is intermediate to Turbines 1 and 5. Specifically, the nMDS plot shows the Turbine 3 samples plot between those of Turbines 1 and 5 and are more loosely scattered, whereas the samples for Turbines 1 and 5 are more cohesive clusters. SIMPER reports that the six species contributing most to the average similarity of the samples within Turbine 3 also contribute to the similarity within Turbine 1 and/or Turbine 5. In comparison, only two contributing species are shared between Turbines 1 and 5, nematodes and *M. edulis*, which overwhelmingly dominated all three turbine areas. Additionally, SIMPER reports Turbine 3 has the lowest average similarity across its fives samples (44.53%), i.e. the greatest variability in macrofaunal composition. In comparison, the average similarity for Turbines 1 and 5 was 54.13% and 66.46%, respectively.

Table 16. SIMPER results showing average similarity and top contributing species (70% cut-off) of diver-based samples collected under the structure of each turbine in Year 2.

Study Area	**Average Similarity (%)**	**Contributing Species (70% cut-off)**
Turbine 1	54.13	*Mytilus edulis* (24.89%)
		Amphibalanus amphitrite (23.99%)
		Nematoda (15.46%)
		Lumbrinereis fragilis (14.27%)
Turbine 3	44.53	*Amphibalanus amphitrite* (20.48%)
		Mytilus edulis (15.04%)
		Polygordius spp. (14.26%)
		Nematoda (12.76%)
		Lumbrinereis fragilis (6.94%)
		Pisione sp. (5.96%)
Turbine 5	66.46	*Nematoda* (37.50%)
		Mytilus edulis (13.58%)
		Unciola irrorata (8.21%)
		Polygordius spp. (6.82%)
		Pisione sp. (6.27%)
All combined	40.32%	*Mytilus edulis* (20.06%)
		Nematoda (19.71%)
		Amphibalanus amphitrite (17.17%)
		Lumbrinereis fragilis (10.83%)
		Unciola irrorata (6.83%)

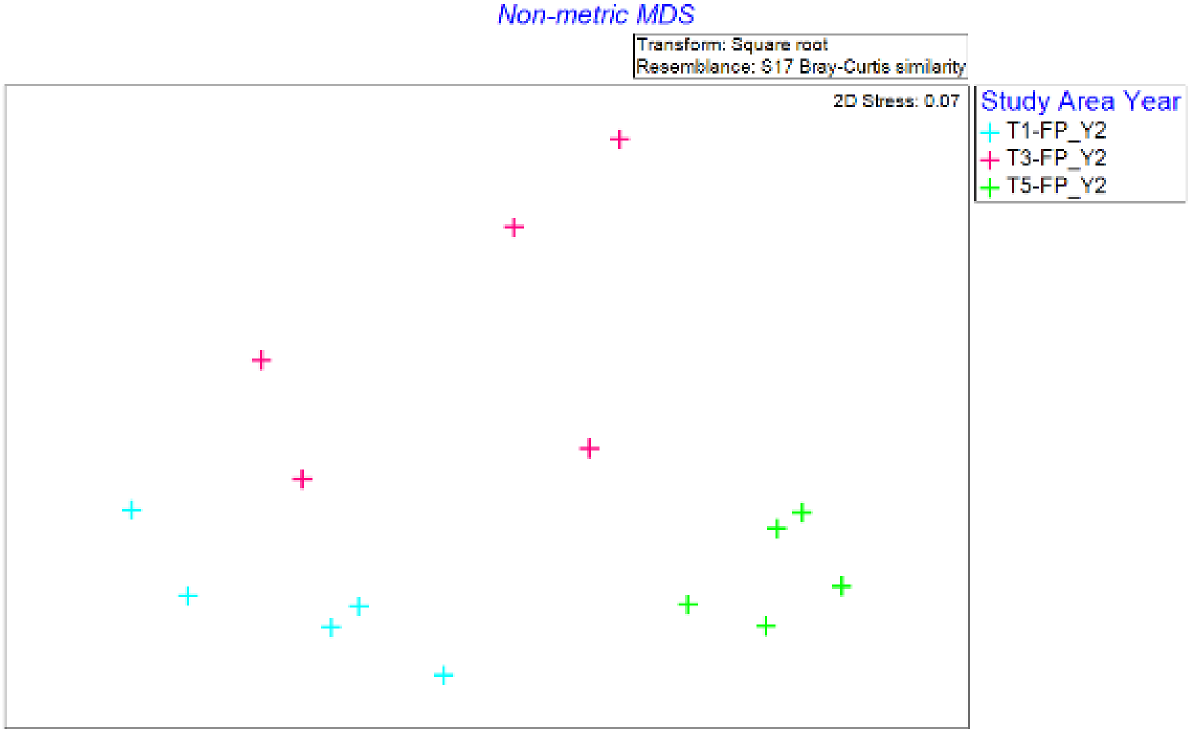


Figure 26. Non-metric MDS plot of diver-based samples collected with the footprint of each turbine in Year 2.

Further examination of the macrofauna data continue to indicate Turbine 3 is intermediate to Turbines 1 and 5. The Turbine 3 samples are similar to the Turbine 5 samples with regards to macrofaunal community composition, although species are found in overall lower abundances. In particular, Turbine 5 has substantially higher densities of the blue mussel *Mytilus edulis,* the polychaete *Polygordius,* and the amphipods *Unciola irrorata* and *Byblis serrata*, in addition to nematodes. However, Turbine 3 is more similar to Turbine 1 with respect to species abundance, both recording relatively low densities for all species, with a few exceptions. Turbine 1 is conspicuously less similar to Turbine 5 in terms of species composition. For example, two of the species with high abundances at Turbine 5 are not present at all at Turbine 1, namely *Byblis serrata* and *Polygordius*. Further, no amphipods were recovered within any of the Turbine 1 samples, with the exception of minor abundances of *Unciola irrorata*. Polychaetes were noticeably absent only at Turbine 1 in addition to *Polygordius* include *Lumbrinereis acuta*, *Parapionosyllis longicirrata*, and *Pisione* sp. Unique to Turbine 1 is the polychaete *Harmothoe* sp, although in relatively minor abundances, and the relatively high abundance of barnacles.

Comparison of Turbine Samples within Footprint of Structure and Surrounding Area

Turbines 3 and 5 show a greater degree of overall similarity in macrofaunal community structure relative to Turbine 1 for both the samples collected under the turbine structure and within the surrounding area. However, Turbine 3 shows the greatest within-group variability for the footprint samples, while this attribute goes to Turbine 1 for the turbine area samples. Within Turbines 3 and 5, overall, macrofauna characteristics under the turbine structure and within the surrounding area were similar such that they may be considered part of a continuum of species distributions at these locations. The main distinction is that dense mussels were present in the samples collected under the turbine, but showed a minimal presence in the vicinity, and thus appear to be a feature solely associated with the foundation. The still imagery also provides evidence of this pattern.

Five macrofauna listed as most abundant or most frequently occurring across all of the Year 1 and Year 2 samples collected in the vicinity of the turbines were also listed as such across all of the samples collected within the turbine foundation footprints (refer to Table 15 and Table 9). These macrofauna are nematodes, the barnacle *Balanus*, the amphipod *Unciola irrorata*, and the polychaetes, *Polygordius* and *Goniadella gracilis*. Further cross examination of the macrofauna data reveals that the majority of the 12 remaining top ten most dominant and broadly distributed macrofauna identified across all of the samples in the areas surrounding the turbines are also present within the footprint samples, although to a much lesser extent. The dominant species in both the Year 1 and Year 2 surrounding area samples, aside from nematodes, was the polychaete *Polycirrus eximius*, of which 12 individuals were recorded in seven samples from below the turbine structures. The polychaete *Pisione*, has a greater presence, with 62 individuals recovered in nine samples. For three of the other eight species, abundances ranged from 28 to 32 individuals and frequency of occurrence ranged between 6 and 7 samples. The other five species showed a minimal presence, having 1 to 10 individuals across 1 to 5 samples. Similarly, the three remaining species listed as most dominant or frequently occurring in the footprint samples were also found within the samples from the surrounding area. These species were the polychaete *L. fragilis*, with 363 individuals found within 131 samples; the blue mussel *M. edulis*, with 120 individuals found within 46 samples; and the amphipod *B. serrata*, with 45 individuals found within 19 samples.

2.4. Discussion

This study has provided opportunity to study near-field interactions between the BIWF with respect to benthic macrofaunal communities and sediment characteristics over a two year period. The data presented here establishes a comprehensive body of information against which subsequent studies can be compared to (i) detect the presence of any gradient effects (ii) measure the spatial extent of effects from the foundations and (iii) characterize the effect in terms of the biotic and abiotic change compared to control data. Results are intended to help improve understanding of the degree and spatial scale of benthic changes, add to existing observations on the potential short-range ecological influences of offshore wind facilities, and provide valuable information to underpin future offshore development management objectives. This discussion focuses on relating the findings from this study to previous studies.

2.4.1 Surficial Sediment Composition

The grab sample and imagery data reporting a seabed dominated by mixed medium and coarse grain sand, along with various concentrations of gravel and cobble concur with previous accounts of reworked glacial moraine deposits within the region (Normandeau Associates 2012; LaFrance et al., 2010; Savard, 1966). The continuum of increasing levels of medium sand, and decreasing levels of coarse and very coarse sand from west (Turbine 5) to east (Turbine 1), also align with current understanding of the region, as do observations of dense cobble and boulder concentrations within Control 1 in Year 1.

The samples collected within the turbine and control areas contained little to no silt or clay particles, which may be indicative of natural seabed disturbances and the winnowing and erosion of silt and clay particles from seabed deposits resulting from tidal and current movement and associated shear stresses at the seabed. From the imagery data, the degree of local seabed mobility and disturbance can be assessed by the presence of bedforms (e.g., sand waves, ripples). Seabed mobility further indicated by recent multibeam data collected by Fugro USA Marine, Inc. (Fugro, 2017), which show the presence of extensive and well-defined sand ripple fields at Turbines 3 and 5 (Figure 27). The data also show no or limited seabed impacts from initial cable and foundation installation activities at these locations, suggesting that successful in-filling and covering of cable trenches and seabed scars from construction vessels by locally available transient sediments is occurring. In contrast, the seabed at Turbine 1 appears to be immobile and no sediment ripples are present within the recent multibeam data, suggesting the area is characterized by weaker hydrodynamic forces. The data provide evidence of this condition, as construction related impacts remain more conspicuous on the seabed indicating that seabed recovery is occurring over a much longer time period.

The results from previous studies assessing alterations to surficial sediments induced by the construction and/or presence of offshore wind farms have been variable and influenced by the type of foundation installed, local sedimentary and hydrodynamic conditions, and the spatial scale at which the study was conducted. Tidal water flows around a turbine foundation will be accelerated around its edges and reduced within its wake creating depositional and erosional conditions within the local foundation, the degree to which depends on tidal orientation and current speeds (Coates 2014). This altering of local hydrodynamic conditions can cause scour and the erosion of finer sediment particles around the base of the turbines (Coates et al., 2014; Brabant et al., 2012; Schröder et al. 2006; Leonhard, 2006), thus creating a higher energy environment than previously existed in close proximity to the structures. For example, at Thorntonbank offshore wind farm, which utilizes gravity base foundations, significantly finer sediments were reported close to a foundation (within 15 to 50 m) compared to sediments farther away (>100 m), as well as along transects aligned with the principal tidal water flows, three to four years after construction (Coates et al. 2014). Coates et al. (2014) also found that perpendicular to the principal tidal flow direction, sediments were significantly coarser within 15 m of the foundation when compared to those at greater distances and demonstrated considerable inter-annual variability. These observations were attributed, in part, to the effects of the construction of the wind farm and to modification to the local hydrodynamic conditions as a result of the presence of the foundation.

In comparison, the design of jacketed foundations may allow water to flow through the structure with less influence on bottom current speeds. At study at the FINO1 renewables research platform in Germany, which uses a jacket foundation, recorded changes in the local hydrodynamic regime and associated modifications to the sediment composition nearby (Schröder et al., 2006). Sediment in the direct vicinity of the piles (up to 5 m away) was found to be much more heterogeneous compared to pre-construction conditions and contained more dead shells, assumed to have been washed from the seabed by sediment erosion. Finer sediment material had been eroded creating local pits around the piles up to 1 m to 1.5 m deep within which heavier shell material had been retained. Another study documented no significant sediment changes 50 m away from turbines at a wind farm dominated by jacket type foundations (Reubens et al. 2016). This finding suggested alternations to grain size distributions remain localized to within a few tens of meters of turbine foundations (Colson et al. 2017).

This study at the BIWF is unique in that it demonstrates changes in surficial sediment composition can manifest over very small and localized spatial scales leading to distinct conditions within a single wind farm. In general, the findings reported here support the those reported by Reubens et al. (2016), and agree with Colson et al. (2017), Coates et al., (2014) Schröder et al. (2006) that sediment monitoring should focus on the near vicinity of turbine foundations. Specifically, this study found no evidence of alterations to the surficial sedimentary conditions at the BIWF for distances of 30 m to 90 m from the center point of the three turbine foundations (i.e., 15 m from the perimeter of the foundation structure) after two years of monitoring. Minor temporal fluctuations in sediment composition between sampling years were largely reflected within the control areas, indicating the change was reflecting natural variations throughout the area. However, within the footprint of the turbine foundations, significantly higher quantities of silt and clay sized particles were recovered at Turbine 1, though these changes were not observed at Turbines 3 and 5. The precise mechanism for fine sediment accumulation at Turbine 1 is unclear at present, but likely relates to the apparent limited seabed mobility here as evidenced by the recent multibeam data. Intuitively, fine sediment accumulation would occur in areas of reduced water flow where current speeds are generally insufficient to erode and winnow fine sediment particles from the seabed. It is similarly unknown whether high levels of fine sediment at Turbine 1 are seasonal or whether this is a permanent feature, or whether the spatial extent of the alteration will expand in the future or develop at the other turbines.

Continued monitoring is needed to understand sediment-foundation interactions, temporal and spatial scales of associated sediment alterations, and the influence such alterations may have on benthic communities.

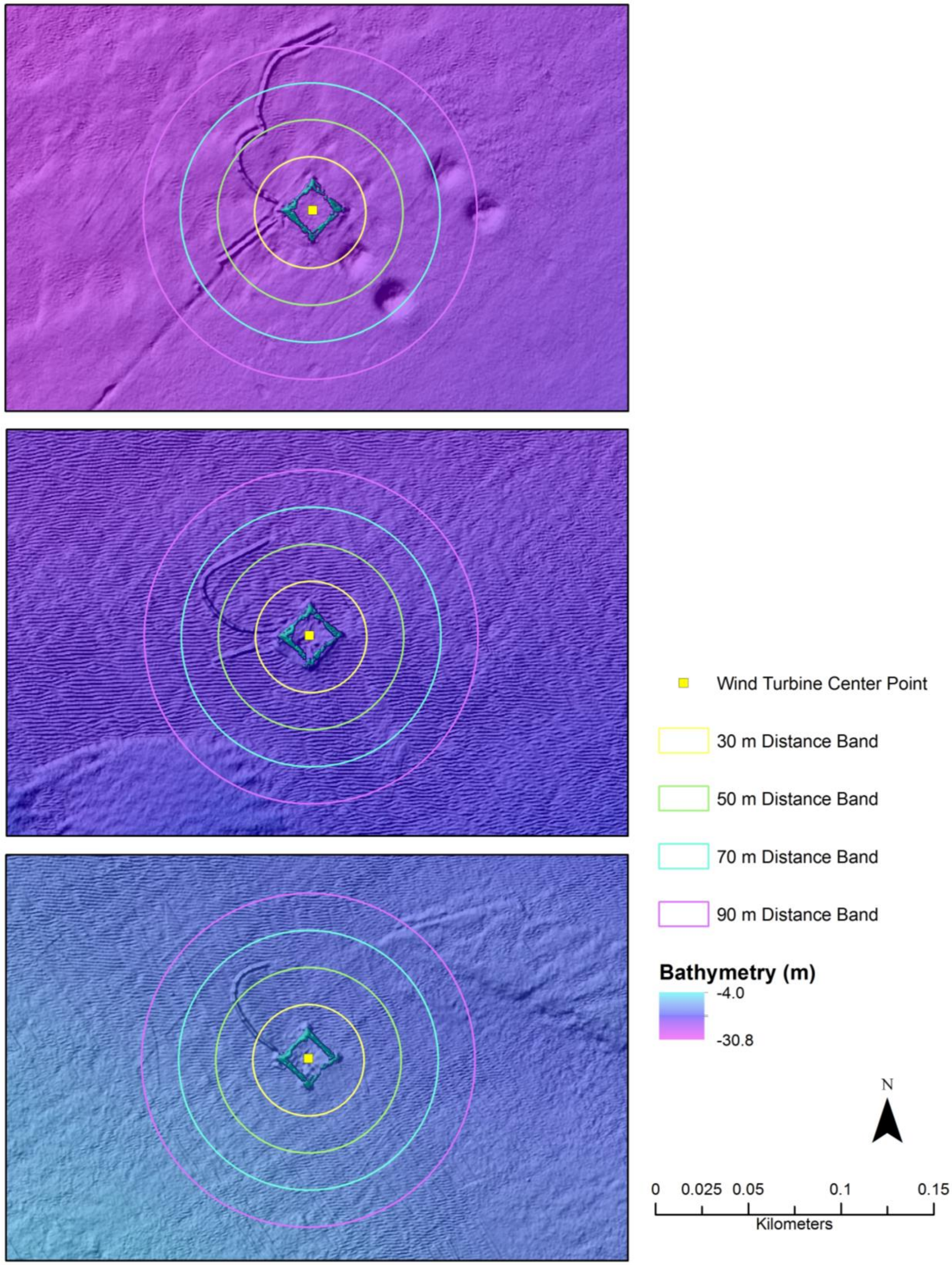


Figure 27. Multibeam imagery showing variability in seabed features near Turbines 1, 3, and 5. *Note: Data provided by Fugro USA Marine, Inc. (Fugro, 2017).*

2.4.2 Sediment Organic Carbon

Accumulation of organic carbon within marine sediments may occur where the input exceeds the natural utilization rate of the consumers. Effects of excess organic carbon in sediments can result in changes in sediment chemistry and benthic community composition (Hyland et al., 2005; Valente et al., 1992) according to classic models (e.g., Pearson and Rosenberg, 1978). Such changes can include reduced oxygen levels and increased toxin levels (e.g., ammonia and sulfide), which can lead to depletions in species richness, abundance, and biomass. Hyland et al. (2005) advises that benthic communities are at high risk from organic loading and other stressors where TOC levels in sediments exceed 3.5%, at low risk at levels that are less than 1.0% and intermediate risk at levels in between. Further, technical guidance offered by the New York State Department of Environmental Conservation for screening contaminated sediments (2006) suggests that total organic carbon levels for contaminated and severely impacted sediments are 1% and 10%, respectively. Using these values as guidance, organic conditions in the sediment samples collected within the areas surrounding the BIWF turbines or within the structure of Turbines 3 and 5 are not indicative of impaired conditions. However, TOC levels detected within the footprint of Turbine 1 ranged between 1.7% and 5.4%, resulting in a moderate to high likelihood of detecting a decline in benthos (Hyland et al. 2005). With reference to New York State Department of Environmental Conservation guidance, the values of TOC found under Turbine 1 were indicative of contaminated sediments.

With the exception of the samples collected within the footprint of Turbine 1, this study found there have been no effects on TOC levels within the sediments with distance from the foundations due to the BIWF, and that levels were comparable across the study areas and sampling years. The lack of effects beyond 30 m from the center point of the foundations is not unexpected given that sampling was first conducted two years after the installation of the foundations (July – October 2015). This short time period may not have been sufficient for fouling communities to develop, mature, and subsequently slough off of the structures, and thus contribute significantly to the organic carbon content of local sediments beyond the footprint of the foundations. This hypothesis that more time is needed for changes to occur is supported in the video and still imagery collected over the two sampling years. In Year 1, there is negligible evidence for the presence of fouling organisms (e.g., mussel clusters, shell hash) or increased predators or scavengers (e.g., sea stars, moon snails, crabs) visible in the video footage, whereas, in Year 2, mussels were much more prevalent within the turbine areas. That this increase did not also occur within the control areas indicates the change is caused by colonization of the turbine structures, rather than natural variation. This study is potentially monitoring the beginning of alterations that will magnify with time. At Thorntonbank, 3 to 4 years after installation of a gravity base foundation, a trend of increasing organic matter content was observed within 25 m of the foundation along the axis of the principal tidal movements and within 15 m perpendicular to the main tidal flow (Coates et al. 2014). Factors other than the prevailing hydrodynamic regime were attributed to this observation (Coates et al. 2014).

There has, however, clearly been significant alteration to the seabed below the foundation at Turbine 1 within the three years since installation of the BIWF commenced. This finding indicates time is not the limited factor in the immediate vicinity of the structures. Rather, the degree to which changes have occurred appear to be related to local hydrodynamic conditions. The input of organic material at Turbine 1 is primarily attributed to the extremely high densities of the blue mussel, *M edulis*, occupying the seafloor within the entire footprint of the foundation. Within Turbine 1 and also the larger area of the BIWF, organic material also likely derives from epifouling organisms, predominately *M. edulis,* which colonize the entire turbine foundation structure from the sea surface to the seafloor. These communities can lead to organic enrichment of the seafloor sediment due to the excretion of organisms (Dewsbury and Fourqurean, 2010) and from biomass sloughing off in large clusters (Schröder et al. 2006). The input and accumulation rate of organic material within the sediments from fouling organisms is currently unknown and may vary seasonally and over time (years) in response to successional change and intra-annual variations in recruitment, growth rates and inter and intra -specific interactions.

Continued research is warranted to help further understand spatial and temporal sediment organic content characteristics below each turbine and with distance from the foundations, to record any expansion of the effect, and to determine any associated biological consequences.

2.4.3 Macrofaunal Analysis

Relatively few studies have focused on impacts to soft sediment benthic communities due to the presence of offshore wind farms and changes remain not well understood. Further, it appears that the temporal and spatial scales at which data is acquired and assessed influences the changes that are detected. At larger spatial scales, study results have been more conclusive, but the question of sufficient time elapsing still remains. Studies from the first offshore wind farm, Thornton Bank, in the Belgian part of the North Sea and comprised of gravity-based foundations reported no large scale changes were detected the first years following installation (Coates et al. 2012; Coates and Vincx, 2010; Reubens et al., 2009). Other studies that collected samples between one and six years after foundations were installed at distances ranging from 100 m to 300 m from the foundations also reported no clear impacts on benthic community characteristics (e.g. community composition, species abundance, biomass, production) due to the presence of offshore wind turbines (e.g. Bergman et al., 2015; Vandendriessche et al., 2015; Vandendriessche et al., 2013; Lock et al., 2014; Degraer et al., 2009).

At smaller spatial scales, the studies have reported more variable findings. Benthic changes were noted almost immediately within the vicinity (1 m) of the FINO 1 piles after installation (Schröder et al., 2006). The initial change was attributed to construction effects although local scouring was also thought to be a contributing factor. Over time, changes in sediment structure and increased numbers of predators resulted in a displacement of typical soft sediment fauna and nearly two years after installation, the effects of the platform on benthos was noticeable up to 15 m distance. At Thornton Bank, a study five years post-installation used a Van Veen grab sampler to collect samples at varying distances from one turbine (15m, 25m, 50m, 100, and 200m) (Coates et al. 2012). The study reported statistically significant changes in benthic macrofaunal characteristics of both epifauna and infauna, including community composition, species richness, density and biomass up to distances of 50m from the foundation scour protection systems Coates et al. (2012). Other studies also reported increases in species richness, abundance, and organic content of the sediment near the turbines, with decreasing impacts with distance from the turbines (as summarized in Jak and Glorius, 2017). Yet, other studies detected no differences in benthic communities within and outside of a wind farm after years of monitoring. Leonhard & Pedersen (2006) took core samples at distances of 5m to 100m from turbines over six years, and Vettenfall (2009) collected samples with a grab sampler over three years within both the near and far field areas of turbine foundations. These studies reported changes in benthic communities were associated with natural variation, rather than due to the presence of turbine structures.

This study at the BIWF is unique in that it demonstrates changes can manifest over very small and localized spatial scales leading to distinct conditions within a single wind farm. Data collected in the immediate vicinity of the turbine structures, i.e., within the jacket foundation, revealed that macrofaunal community characteristics are notably different at Turbine 1. Further, changes are occurring along a gradient, with Turbine 3 being the most variable and intermediate to Turbines 1 and 5. The variable spatial and temporal pattern over which these changes are occurring poses challenges for predicting future conditions and highlights the complexity of trying to do so. While there is evidence to suggest that that these changes will continue across the wind farm over time, the rate at and extent to which they will occur is unknown. The situation is further complicated since the reasons for the inconsistencies among the turbines, located 800 m apart, are unknown, though are likely linked to the apparent difference in hydrodynamic conditions (i.e., calmer) that may allow for organisms (i.e., mussels) to settle and establish more readily. It is also possible that the design and layout of the wind farm has created localized accumulation centers within low energy areas within the wake of other foundations structures. If these truly are influential factors, then alterations may occur to a lesser degree within the footprint of the other turbine structures, perhaps following a gradient that reflects hydrodynamic conditions.

Over the larger study area, no substantial differences in macrofaunal community composition characteristics were detected within the BIWF between the turbine areas (collected 30 m – 90 m from center of foundations) and control areas three years after installation of the foundations commenced. All sample groups are predominantly characterized by polychaetes and nematodes, which is consistent with previous studies for Rhode Island Sound and Block Island Sound (LaFrance et al., 2014; LaFrance et al., 2010; Steimle, 1982; Deevey, 1952; Smith, 1950). However, considering the findings by Coates et al. (2012), it appears that changes could be anticipated over the next few years extending out to 50 m from the turbine foundations. Evidence that changes are beginning to occur and may lead to significant shifts in benthic communities is provided in the Year 2 video footage, where there is an increased presence of *M. edulis* throughout all of the turbine areas, though the species is largely absent within the control areas. This finding indicates the change is caused by colonization of the turbine structures, rather than natural variation. Continued research is critical to further understand the temporal and spatial scales of alterations to benthic communities, both at individual turbine foundations and within the larger area encompassing the wind farm.

With regard to data analysis, the high degree of variability within the grab data may have implications for the interpretation of results from this and subsequent surveys. Though some of the statistical analyses (e.g. ANOSIM, Permanova+) reported discrepancies in macrofaunal community structure among sample groups, other analyses (e.g. nMDS, SIMPER) and further investigation of the raw data strongly indicated these distinctions are related to changes in species abundances, rather than species composition. This finding demonstrates it is important to carefully consider the statistical routines used to assess complex, multivariate datasets, such as macrofaunal abundances over several study areas spanning two sampling years. ANOSIM and Permanova+ searches for differences within entire groups of samples and showed to be more sensitive to variations in abundances among samples. The use of these multivariate routines alone may lead to misleading conclusions. In comparison, nMDS and SIMPER were more attentive to community composition and were able to consider the samples in a broader context. SIMPER, in addition, was able to identify why the reported differences were likely occurring at the species level. Expert examination of the imagery and raw macrofauna data also provide context and guide interpretation of the statistical outputs. Taken together, the suite of analyses employed in this study were effective in examining the data in a comprehensive manner to detect any changes.

2.4.4 Future Monitoring

The current monitoring effort at the BIWF should continue on an annual basis to further develop a detailed dataset documenting alterations resulting from offshore wind energy development over short and long term temporal scales, and to understand the complex abiotic-biotic interactions that cause such alterations. Extended monitoring is especially important for the BIWF area because the available time series data is likely insufficient to have fully capture and understand the potential changes that will occur, both with respect to severity and spatial extent. This study documents that alterations are beginning to transpire within the footprint of the turbine structures, with Turbine 1 exhibiting the fastest rate of change. Expanding the scope of the diver sampling surveys should be a priority, also. Specifically, grab and imagery data should be acquired within the footprint of all five turbine foundations. And, there is a gap in data coverage that should be addressed by collecting samples along the perimeter of the turbine structures (i.e., 15 m from the center point) out to 30m from the center point. These additional samples will allow for better understanding of the gradient along which the extent and rate of changes are occurring across the BIWF. For longer-term studies, it would be beneficial to sample across seasons to investigate any seasonality that may be present. A long term dataset would be required to discern any seasonal patterns from variability caused by other factors (e.g., year-to-year, BIWF, food-web dynamics).

Diver sampling studies are currently underway to collect quantitative information on fouling communities on the turbine foundations at BIWF. The data may be used to describe the characterizing species colonizing the turbines, the zonation of the colonizing communities, and the presence of non-native species and important species contributing to the overall fouling biomass and the ecosystem services provided (i.e., increased feeding and refugia). Repeat studies would allow assessment of temporal fluctuations in these colonizing communities including any important losses of species and biomass following storm events, which might represent episodic inputs of biomass to the benthos and lead to enrichment of the sediment and associated changes.

Additionally, periodic acoustic surveys (e.g., multibeam, sidescan) would allow for broader-scale assessment of changes in seafloor characteristics over time, such as general sediment composition, bedform distribution and development, and recovery rates for disturbed areas. Such information could be valuable for interpreting patterns and changes detected in the macrofauna and surficial sediment data.

2.5. Conclusions

The BIWF is the first offshore windfarm in the United States and this study represents the first benthic monitoring of offshore platforms within the Atlantic Ocean along the northeast coast of the United States. This study establishes a multi-year comprehensive baseline dataset that can serve as a point of comparison for measuring future change in macrofaunal and sediment characteristics at the BIWF, whether a result of human activity or natural processes. The data acquired from the current two-year study support the following conclusions:

- No appreciable change in macrofaunal characteristics, surficial sediment composition, or sediment organic content with respect to distance was detected in Year 1 or Year 2 in the data collected 30 to 90 m from the center point of each turbine. This finding suggests that there are no strong localized benthic effects in the surrounding area due to the presence of the wind farm at this time. However, at the scale these samples were collected, it is anticipated that it will take a longer period of time for changes to manifest than has already elapsed.
- For Turbines 3 and 5, no appreciable change macrofaunal characteristics, surficial sediment composition, or sediment organic content was detected in the data collected under the footprint of the turbines compared to the data collected 30 to 90 m from the center of each turbine. This finding suggests that macrofaunal and sediment characteristics are similar within and outside of the turbine structure, and further indicates that there are no strong localized benthic effects at Turbines 3 and 5 at this time.

- For Turbine 1, in contrast, substantial changes were evident in both biotic and abiotic characteristics for the grab samples and video footage collected within the footprint of the turbine structure relative to the same data collected in the surrounding area (30 to 90 m from center point of turbine structure) and at Turbines 3 and 5. The most notable differences for the area under Turbine 1 were the presence of extremely dense mussels that covered the entire surface of the seafloor, elevated levels of organic content, and the transition to much finer-grained sediment. The reasons why these alterations only occurred at Turbine 1 are unclear at present, but it likely attributed to local hydrodynamic conditions.
- This study is valuable in improving the understanding of changes to macrofaunal and sediment characteristics resulting from wind facility construction and initial operations in the New England region over short time scales (e.g., < 1 to 2 years). For the area surrounding the turbine foundations, this study has recognized that changes are not likely to take place within two years. Within the footprint of turbine foundations, however, the degree of change can vary. At the BIWF, change is occurring along a geospatial gradient, ranging from minimal changes (i.e., comparatively the same as outside the turbine footprint) to transitioning to a habitat with entirely different characteristics than previously existed. The variable spatial and temporal pattern over which these changes are occurring poses challenges for predicting future conditions and highlights the complexity of attempting to do so. It is anticipated this transition will occur within the footprint of all the turbine structures over time, and potentially expand to the nearby surrounding area, though the rate at which this will occur remains unknown. The

potential for highly localized and site-specific benthic alterations to occur within wind farm sites, as shown in this study, should be considered in the planning of monitoring programs for future offshore wind facilities.

- Additional offshore wind facilities are planned for the U.S. east coast and a sound knowledge of associated influences on benthic communities will be vital for accurate assessment. As such, monitoring efforts at the BIWF should continue to documenting any alterations resulting from offshore wind energy development over short and long term temporal scales, and to further understand the complex abiotic-biotic interactions that cause such alterations. While it is recognized that spatial and temporal patterns that are identified will be most relevant on a regional scale, the results from this and future studies at BIWF will be broadly relevant to Europe and elsewhere by adding to existing studies and contributing information on the range of alterations that could be anticipated within similar environments. Furthermore, this study provides the opportunity to inform current knowledge gaps regarding the specific construction and operational effects of jacket foundation structures on the benthos.

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MANUSCRIPT 3: Benthic habitat mapping and its application to coastal resource management

3.1. Conclusions

Marine submerged lands and their associated resources exhibit a diverse range of environments and species, which have the potential to be altered due to natural processes, climate change, and human activity, including development and resource extraction. A multidisciplinary understanding of ecosystem structure and function across various spatial (e.g. local, regional, continental) and temporal (e.g. seasonal, yearly, decadal) scales is necessary for management and regulatory agencies to implement effective strategies that maintain a balance between the protection and human use of submerged lands, and improve their capacity to anticipate, interpret, and address future change. The two benthic habitat mapping studies presented in this dissertation begin to address this data need for two coastal areas within the northeast region of the United States. These studies also advance our ecological understanding of benthic habitats and contribute to benthic habitat mapping as a scientific discipline.

Chapter 1 focuses on Fire Island National Seashore (FIIS), which is located off of the southern shore of Long Island, NY and is one of 10 national seashores within the National Park System in the United States. The primary objective of the study was to develop biotope classification maps to define relationships between macrofaunal communities and attributes of their associated environments utilizing the Coastal and Marine Ecological Classification (CMECS) framework for the Otis Pike and Sunken Forest study areas. Secondary goals were to examine overall macrofauna assemblage patterns and to assess variations in seagrass distribution and density over time throughout

Otis Pike and Sunken Forest; provide a description of the biotic and abiotic benthic characteristics within the area to the east of the new tidal inlet created as a result of Hurricane Sandy; and investigate the potential influence of Hurricane Sandy on FIIS. For Chapter 2, the Block Island Wind Farm (BIWF) is the first offshore windfarm in the United States and this study represents the first benthic monitoring of offshore platforms in the Atlantic Ocean along the northeast coast of the United States. The primary objectives of the study were to document current conditions and detect any alterations in benthic macrofaunal communities, surficial sediment composition, or sediment organic enrichment resulting from the construction and operation of the BIWF facility. Data were analyzed between turbine and control areas, among and within individual turbine areas, and as a function of distance from the turbine foundations. Both the FIIS and BIWF studies produced a comprehensive dataset that can serve as a point of comparison for measuring future change, whether caused by human activity or natural processes.

Furthermore, both studies document changing biotic and abiotic conditions and demonstrate the critical need for an established monitoring program. Discrete datasets and associated outputs (e.g. biotope maps) provide a depiction of an area at a given moment in time. Therefore, these data are a static temporal representation of an ever-changing marine realm. While valuable, such data would be most effective as part of a time-series, which can allow for the identification of changes and their associated temporal and spatial extent and magnitude. For FIIS, monitoring should be conducted to continue to assess the effects of Hurricane Sandy. While the findings from this study cannot be directly compared to pre-Sandy conditions, evidence suggests the new inlet is having a positive ecological influence. For example, seagrass has increased in close proximity to the inlet, while it has declined further away. Additionally, dense concentrations of blue mussels were recovered near the inlet, although they were largely absent elsewhere. Monitoring of FIIS is also important to understand the dynamism, resiliency, and vulnerability of the Seashore, particularly in the face of global climate change, which is certain to have an impact on the environments and species within this extremely shallow, nearshore area. While the BIWF study is part of a three-year monitoring program, findings from the first two years suggest this timeframe is insufficient to fully capture and understand the potential alterations that may occur, and, therefore, continued monitoring will be necessary. Currently, changes are manifesting along a geospatial gradient within the footprint of the turbine structures, ranging from minimal change at Turbine 5 in the southwestern area of the wind farm and transitioning to a habitat with entirely different characteristics than previously existed at Turbine 1 in the northeastern area. The variable spatial and temporal pattern over which these changes are taking place poses challenges for predicting future conditions and highlights the complexity of attempting to do so. It is anticipated this transition will take place across the wind farm, and potentially expand to the nearby surrounding area, though the rate at which this will occur remains unknown. Longer term monitoring should be conducted to continue to document alterations to the benthos, and to further understand the complex abiotic-biotic interactions that cause such alterations.

With respect to methodology, both studies demonstrate the utility of multivariate statistical analyses (e.g. ANOSIM, nMDS, SIMPER) to investigate patterns in macrofaunal communities. Interestingly, though, these analyses were used to satisfy different objectives. In the FIIS study, ANOSIM was used to identify statistically significant biotopes, accomplished by assessing the level of distinction among user-defined groups representing macrofaunal communities that were generated according to various geological and sediment features. In this approach, the user constructs sample groups in efforts to determine which variable/s (e.g. feature/s of the environment) exhibit the strongest relationship with (i.e., can best explain) macrofaunal community composition, as reflected by the highest R value. In comparison, ANOSIM was used in the BIWF study to identify any changes resulting from the wind farm. While sample groups are still defined by the user, they are designed in detect change across multiple spatial scales (e.g. within and across turbine and control areas) and temporal scales (e.g. within year, between years). As such, the purpose is not to achieve the highest R value possible, but, rather, to allow the R value to report the degree of distinction among each grouping to inform if any change has occurred. In both studies, SIMPER and nMDS plots were then used to support and guide interpretation of the ANOSIM output. For example, SIMPER reported the average percent biological similarity within each group and dissimilarity between each group, as well as the degree to which each individual species contributes to the reported similarity and dissimilarity.

CMECS played a key role in both studies and demonstrated the value of the framework in providing ecologically meaningful information that is applicable to scientist and environmental agencies. For the FIIS study, the classification approach using CMECS produced biotopes that describe biotic-abiotic relationships by establishing well-recognized and statistically distinct macrofaunal communities among the defined map units within both Otis Pike and Sunken Forest. That the CMECS-defined map units were able to characterize the study areas at such a high level indicates the utility of

CMECS beyond as a framework for classifying data in the final stages of a study. This same approach was previously employed to define biotopes in the region of the BIWF during the siting phase of the windfarm as part of the Rhode Island Ocean SAMP. The biotopes developed for the Ocean SAMP were then examined to determine the sampling strategy for the BIWF study, further demonstrating the value of CMECS. Knowledge of the existing biotopes allowed for changes from the BIWF to be investigated across the largest possible range of environmental and macrofaunal community characteristics, rather than unknowingly focusing on a subset of these. Accordingly, Turbines 1, 3 and 5 were selected because they offered the broadest representation of the biotopes present in the study area. Additionally, the biotope maps allowed for appropriate control areas to be identified.

Both studies were conducted at the request of Federal agencies (FIIS for the National Park Service and BIWF for the Bureau of Ocean Energy Management), which highlights the importance and applicability of benthic mapping studies from a management and regulatory perspective, in addition to being ecologically valuable. The findings from these studies have direct applications for developing and implementing scientifically sound decisions. The data collected within FIIS can be used to promote resource stewardship, identify habitats and species of interest, and guide conservation and restoration efforts. The BIWF study is relevant since additional offshore wind facilities are planned for the east coast of the United States in the future and knowledge of the associated influence on the benthos will be vital for accurate assessment and can guide the proactive mitigation or avoidance of impacts in areas where necessary.