OCS Study
BOEM 2018-047

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US Department of the Interior
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ABOUT THE COVER

Cover photo: Block Island Wind Farm Facility Wind Turbine 3 Foundation Construction. Courtesy of the HDR RODEO Team. Used with permission. All rights reserved.

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List of Abbreviations and Acronyms

AWAC	acoustic wave and currents
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
CMECS	Coastal and Marine Ecological Classification Standard
FGDC	Federal Geographic Data Committee
MDE	minimum detectable effect
OSAMP	Ocean Special Area Management Plan
OWF	offshore wind farm
PCA	Principle Components Analysis
QC	quality control
RODEO	Real-Time Opportunity for Development Environmental Observations
TOC	total organic carbon
TOM	total organic matter
UTM	Universal Transverse Mercator projection

Editorial Notes

- All coordinates used in this report are referenced to WGS84 UTM Zone 19 North unless stated otherwise.
- Current direction is the direction towards which the current is flowing.
- All times are in Coordinated Universal Time unless stated otherwise.

Executive Summary

Key observations, data, findings, and results from benthic monitoring conducted in and around the Block Island Wind Farm (BIWF) Project Area are presented in this report. The monitoring was conducted to gather real-time data during the installation and initial operations of the wind turbine generators. The data collected during this monitoring will provide additional information necessary for the Bureau of Ocean Energy Management's (BOEM) evaluation of environmental effects of future facilities and generate data to improve the accuracy of models and analysis criteria employed to establish monitoring references and mitigations.

The BIWF is a 5-turbine, 30-megawatt facility located 4.5 kilometers from Block Island, Rhode Island, in the Atlantic Ocean. It is the nation's first commercial offshore wind farm and it will supply power to Block Island, with excess power being transmitted to mainland Rhode Island. One hundred and twenty-one benthic grab samples were collected within the project footprint and analyzed for macrofaunal diversity and abundance, sediment grain size, and total organic carbon. In addition, underwater video and imagery was collected throughout the study area to provide broader contextual information.

The overall goal of the study was to better understand the nature and potential spatial and temporal scales of anticipated alterations in benthic macrofaunal community characteristics because of the long-term placement of the turbine foundations on the seafloor. Key community characteristics evaluated included species abundance, richness, and assemblage structure, along with relationship dynamics between macrofaunal communities and their associated environments.

Three turbine locations were selected for sampling based on their representativeness of the biotopes present in the study area. Grab samples were collected from nine randomly located stations at each turbine foundation. A cluster sampling strategy was employed so that three grab samples were collected at each of the nine stations. This resulted in the collection of a total of 27 samples at each turbine. Further, the sampling stations were divided into three distance bands (30-50 meters [m], 50-70 m, and 70-90 m), yielding three stations within each band at each turbine.

Three control areas located in the vicinity of the BIWF Project Area were also sampled in a cluster of three at four stations to provide a benchmark for comparison. Four additional samples were collected for independent quality control. Each sample was processed and analyzed for sediment grain size, organic content and macrofaunal community composition.

At each sampling location, an underwater video camera attached to the grab sediment sampler was used to capture information over a broader scale for context information and to assess the degree of spatial heterogeneity of the environment and associated benthic biological communities. The video footage was also used to identify bedforms, coarse surficial material concentrations (i.e., boulders, cobble, gravel), and species that are more mobile or are present at low densities (i.e., crabs, starfish, algae) and so tend to not be captured by the grab sampler.

At each turbine and control area sampling location, the adjacent seabed was also photographed using a Lagrangian floating remote digital stills camera. This camera arrangement captures still images at a rapid rate, allowing for a continuous series of overlapping seabed images of the seabed that can then be mosaicked. This comprehensive set of images and mosaics provide contextual information of the geological environments, as well as conspicuous species present throughout the camera deployment.

The sampling strategy and detailed statistical analyses were designed to test the following hypothesis:

- H0 1 – There will be no difference in benthic communities among turbine areas.
- H0 2 – There will be no difference in benthic communities between control areas and turbine areas.

- H0 3 – There is no impact on distance from the wind farm foundation regarding organic enrichment or benthic communities.

The results indicate that all three hypotheses can be accepted. There are no substantial differences in benthic communities among turbine areas (H01) or between turbine areas and control areas (H02), The analyses (e.g., SIMPER, ANOSIM, nMDS plots) show that there is a high degree of species overlap among the groups and the primary differences are related to species abundance, rather than species composition. The groups are predominantly characterized by polychaetes and nematodes in coarse sediments.

With respect to distance from turbine foundations (H03), the analyses (e.g., ANOVA, nMDS) indicate there are no significant differences in benthic communities or total organic carbon levels close to turbine foundations compared to those further away. This result was not unexpected as the fouling communities on foundations may not have developed sufficiently within the time between the start of foundation installation and the commencement of the current field sampling survey. This short time frame may not have been enough to substantially contribute to the organic composition of adjacent sediments or have led to alterations in macrofaunal community composition in the area sampled. It is also possible that samples were collected at distances too far away from the turbine structures to allow for changes to be detected. Levels of TOC in the samples that were collected were low. This suggests that macrofauna in the current study area are not exposed to an over-abundance of TOC within the sediments which could otherwise lead to community modification.

Biotopes classified for the study area were comparable with those previously mapped across the region and reported within the literature prior to construction of the BIWF. Specifically, biotopes exhibited complex topography containing mixed coarse sediments and supported a typical coarse sand macrofauna including a diverse assemblage of polychaetes, nematodes, amphipods, and bivalves. That the pre- and post- BIWF biotopes have remained unchanged over time provided further evidence supporting the acceptance of the three hypotheses.

Overall, no appreciable change in biotic or abiotic variables with distance from each of the turbine foundations was detected. This observation suggested that there were no strong localized benthic effects because of the presence of the turbine foundations at this time. Localized effects due to the presence of the turbine foundations are expected to take a longer period of time than has already elapsed to manifest or may occur closer to the foundations than the current sampling design allows.

Future monitoring should continue to employ the same sampling methods to ensure data consistency for temporal comparison and will be required to identify and describe benthic changes attributable to the presence of the foundations. Subsequent studies may also need to consider methods for data collection at closer distances to the foundations (e.g., within 25 m) to capture benthic change at close ranges.

The results and findings from this study could serve as the basis for extrapolation to larger wind facilities and will provide useful information on the effects of jacket type foundations which are generally unrepresented in European studies. 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. Observations of effects at the local level can be used to inform future predictions of potential wider scale and cumulative effects associated with larger, and multiple, offshore wind facilities.

The field observations presented in this report were conducted for BOEM by the HDR RODEO Team under Contract M15PC00002, Task Order M16PD00025, Task 2.4.3 (Benthic Monitoring).

1 Introduction

This report presents key observations, data, findings, and results from a benthic monitoring study conducted in and around the Block Island Wind Farm (BIWF) Project Area (**Figure 1**) soon after completion of that facility's construction and initiation of operations. The BIWF is a commercial offshore wind farm in the United States, and it is located 4.5 kilometers from Block Island, Rhode Island, in the Atlantic Ocean. The five-turbine, 30-megawatt facility is owned and operated by Deepwater Wind Block Island, LLC. Power from the turbines is transmitted to the electric grid via a 34-kilometer transmission submarine power cable buried under the ocean floor, making landfall north of Scarborough Beach in Narragansett. The facility primarily supplies power to Block Island, with excess power being transmitted to mainland Rhode Island.

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. Benthic grab samples, video, and still imagery data for this study were collected between December 2016 and August 2017.

Each of the five turbines at the Block Island Wind Farm consists of a 6 MW GE Haliade 150 three-bladed turbine with a rotor diameter of 150 m and mounted to a piled steel jacket foundation. The hub height is 100 m and the overall turbine height is 150 m. The total weight for each turbine, including jackets, decks and piles, is 1,500 tons. It is noted that only 5 percent of offshore wind foundations installed in Europe are jacket structures. Consequently, there is a lack of monitoring data for these foundation types and impacts on benthic ecology are generally lacking. This study therefore provides opportunity to significantly contribute to the effects of offshore renewables, and in particular, to fill current knowledge gaps regarding the specific construction and operational effects of jacket structures on seabed sediment communities.

The monitoring reported in this document 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 this Program is 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. The purpose also includes recording direct observations during the testing of different types of equipment that may be used during future offshore development to measure or monitor activities and their impact producing factors.

Data collected under the RODEO Program may be used as input to analyses or models that are used to evaluate effects or impacts from future offshore activities. This Program is not intended to duplicate or substitute for any monitoring that may otherwise be required to be conducted by the developers of the proposed projects. Also, RODEO Program monitoring is coordinated with the industry and is not intended to interfere with or result in delay of industry activities.

The BIWF is the first facility to be monitored under the RODEO Program. **Table 1** identifies the types of field data collected under the RODEO Program during construction and/or initial operations of this facility.

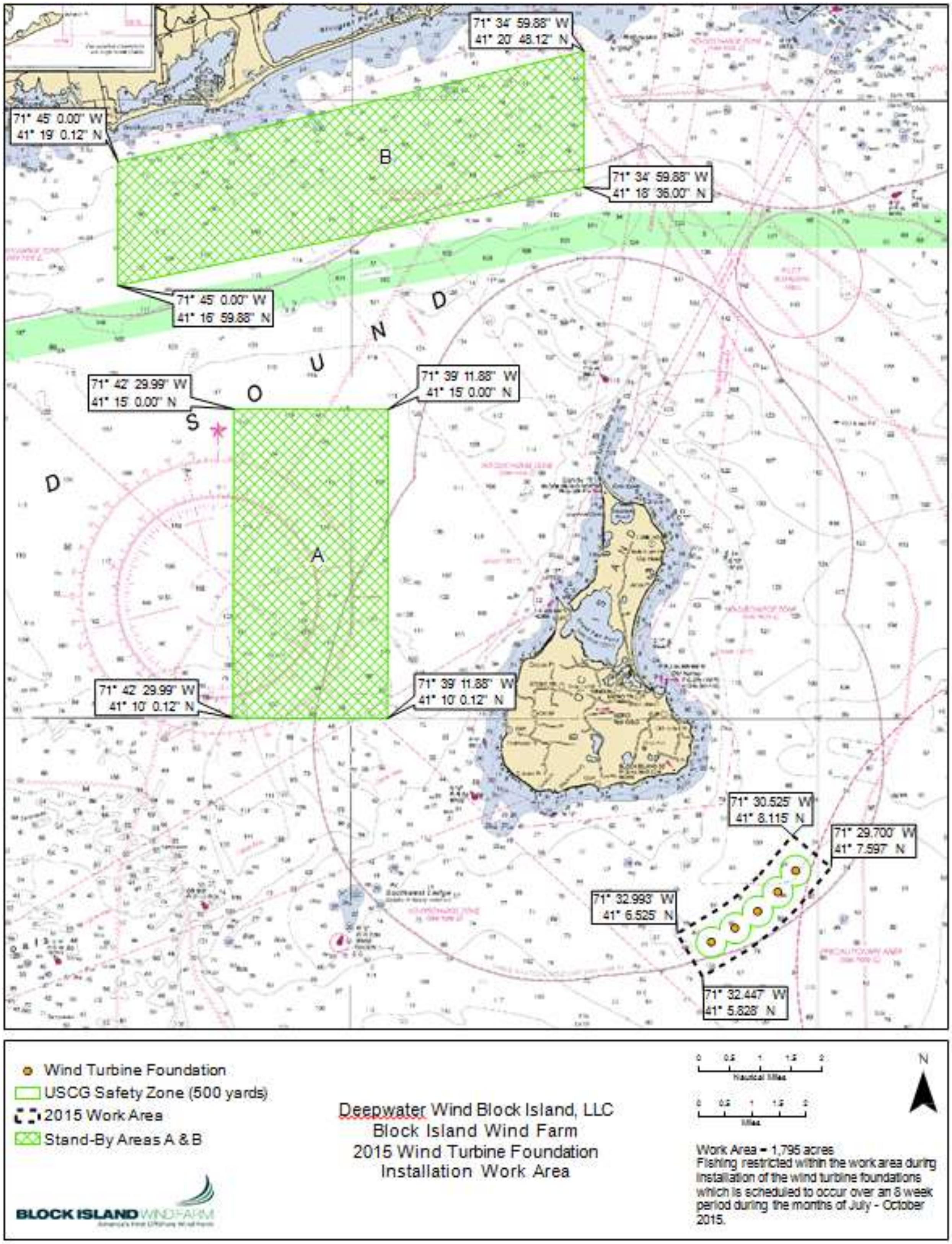

Figure 1. BIWF Work Area.

Table 1. RODEO Program Monitoring conducted at the BIWF

Phase	Construction Activity	Dates	Monitoring Surveys	Comment
Construction Phase 1	• Steel jacket foundations were installed on the seabed using two different types of hammers. Piles were installed with a 13.27° rake from the vertical.	July 26, 2015 – October 26, 2015	• Visual observations and documentation of the construction activities. • Airborne noise monitoring associated with the pile driving. • Underwater sound monitoring associated with the pile driving. • Seafloor sediment disturbance and recovery monitoring through bathymetry surveys conducted immediately after construction was completed and in approximately 3-month intervals for a year. • Turbine platform scour monitoring through installation of 2 scour monitoring devices on selected WTG foundations. • An Acoustic Wave and Current Profiler was also deployed within the project area.	See report entitled: "*Field Observations During Wind Turbine Foundation Installation*" for additional information.
Construction Phase 2	• Wind turbine generators installed on the steel foundations.	January 2016 – August 18, 2016	• Visual observations and documentation of the cable laying activities and of turbine installation from both on shore and off shore locations. • Airborne noise monitoring.	Included still photography and filming of portions of trenching operations for cable laying.
	• Submarine transmission power cables connecting Block Island and mainland were laid using a jet plowing in the offshore portions and horizontal directional drilling in the near shore area.	June 3, 2016 – June 26, 2016	• Seafloor sediment disturbance monitoring. • Post-construction seafloor recovery through bathymetry surveys.	See report entitled: "*Observing Cable Laying and Particle Settlement During the Construction of the Block Island Wind Farm*" for additional information

Phase	Construction Activity	Dates	Monitoring Surveys	Comment
Initial Operations	• Testing of the newly installed turbines. • Testing of the submarine transmission power cables.	August 29, 2016 – November 2016 Wind Farm operation began on December12, 2016	• Visual observations of the operational wind farm from varied distances on shore and off shore locations. • Airborne noise monitoring. • Underwater sound monitoring. • Seafloor sediment disturbance and recovery monitoring. • Benthic monitoring[2].	See report entitled "*Field Observations During Wind Turbine Installation and Operation*[1]" for additional information.

[1] This report is currently a work in progress and it will be completed after the results from the various monitoring surveys are compiled and analysed.

[2] A separate standalone report (this document) was prepared to present the findings and results from the benthic monitoring. Key information from the benthic monitoring report will be excerpted and summarized in the main report.

1.1 Study Goals and Objectives

The overall goal of this study is to better understand the nature, as well as the potential spatial and temporal scales, of anticipated alterations in benthic macrofaunal community characteristics caused by the BIWF facility. These characteristics include species abundance, richness, diversity and assemblage structure, along with relationship dynamics between macrofaunal communities and their associated environments. 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 and are poorly understood for the BIWF at this time. Results and findings from this monitoring could serve as the basis for extrapolation to larger wind facilities in southern New England.

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. 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. Based on preliminary studies in Europe, changes in benthic composition due to the operation of the turbines could be anticipated within 50 m of the foundation scour protection systems (Coates et al. 2012) with the possibility of a long-term shift in community composition, which may become spatially extended.

In design of the measurements, the following three hypotheses were tested:

- H0 1 – There will be no difference in benthic communities among turbine areas.
- H0 2 – There will be no difference in benthic communities between control areas and turbine areas
- H0 3 – There is no impact on distance from the wind farm foundation regarding organic enrichment or benthic communities.

1.2 Study Challenges

The data presented in this report represents a snapshot of benthic ecological conditions in and around the BIWF Project Area. It does not characterize natural variations in local communities that may occur, for instance, between seasons or over years, or as a result of storm events. Data from control areas can be used to characterize natural regional fluctuations in benthic communities over time and used to correct for operational effects during future assessments.

For this study, macrofaunal samples were collected over three days throughout the winter season (one day each in December 2016, January 2017, and March 2017). The delay between sample days was because of inclement weather. However, that the samples were collected over a four-month period is not considered to be problematic in the BIWF study area. This timeframe is considered adequate because the sampling was completed well within the winter season (i.e., conditions were consistent). Moreover, the benthic macrofaunal communities within Rhode Island Sound and Block Island Sound have been found to experience minimal natural variation, both with regards to seasonally and over longer periods of time (LaFrance et al. 2014, Steimle 1982, Savard 1966, Pratt Pers. Comm). Steimle (1982) specifically examined seasonal variability of benthic macrofauna within Block Island Sound and concluded that “there were not many apparent, clearly defined seasonal changes, comparing the February and September results” and that “natural benthic community fluctuations in the Sound are probably minimal compared to other areas.” Steimle (1982) also notes that most species recovered in his samples (collected in 1976) were also recovered in samples collected in the mid-to-late 1940s in studies by Smith (1950) and Deevey (1952). Savard (1966) also suggested the benthic environments within Block Island Sound are stable and may be predictable. More recently, LaFrance et al. (2014) saw minimal evidence of seasonality in benthic samples collected offshore of Block Island between October 2008 and August 2009 as part of the Ocean

Special Area Management Plan (OSAMP. Furthermore, the dominant species recovered by LaFrance et al. (2014) were also identified by Steimle (1982), though the abundances at which they were recovered is unknown. This comparability indicates the composition of macrofaunal communities has persisted in this area for over four decades.

In addition, previous data collected in and around the BIWF study areas over the past decade has shown only minor changes in geological environments. For example, the geologic features within the side-scan sonar data collected as part of the OSAMP in September 2008 can easily be identified in the side-scan sonar data collected in December of 2016 for this study (**Figure 2**). This environmental stability further suggests the associated benthic macrofaunal communities are likely stable.

From the literature, it was expected that coarse seabed deposits, including boulders, cobble, and gravel, would be present within the study area. Experience shows that such coarse seabed deposits can be difficult to sample with repeatable quality using grab samplers and may often result in failed samples or samples of various volumes being recovered.

To account for these sampling challenges, a Smith-McIntyre grab sampler was employed, as it is regarded as reliable for use in open sea conditions from small boats (Eleftheriou 2013). The use of this sampler at all sampling locations meant that the bite area of the device was consistent across all of the samples collected and that the macrofauna, most of which live within the uppermost seabed sediment layers, were adequately represented and comparable across the study area. The grab sampler was re-deployed after any failed attempts until a sample having a volume of 1/8th or greater of the sampler was collected. It was evident that 1/8th was the largest volume that was recoverable in areas with dense boulder, cobble, and/or gravel concentrations. It was also believed this volume was enough to capture the surficial material of the seafloor within which the benthic biological community resides.

Furthermore, a cluster sampling strategy was used, which consisted of collecting three grab samples at each sample station. These cluster samples are not considered true replicates due to the difficulties of collecting three co-located samples when working in offshore conditions in waters depths averaging 30 m. This sampling strategy also allows for more robust statistical analyses of the biological communities, as well as the assessment of small-scale spatial variability. Examination of the species richness and abundance across the three cluster samples at each sample station revealed no consistent relationship with grab volume. More specifically, at some stations, a sample with a lower volume exhibited higher species richness and/or abundance than a sample with a larger volume; whereas at other stations, species richness and abundance increased with larger volumes; and yet, at other stations, cluster samples of the same volume exhibited substantial variations in species richness and abundance.

This inconsistency prevented the use of a multiplier to standardize the volumes across all the samples in the BIWF study area. As such, samples were analyzed according to the “raw” species richness and abundance counts. It is recognized that the inconsistency in sample volume may create some bias in interpretation of the data, but this approach was favored over attempting to standardize the samples, which would have certainly introduced error.

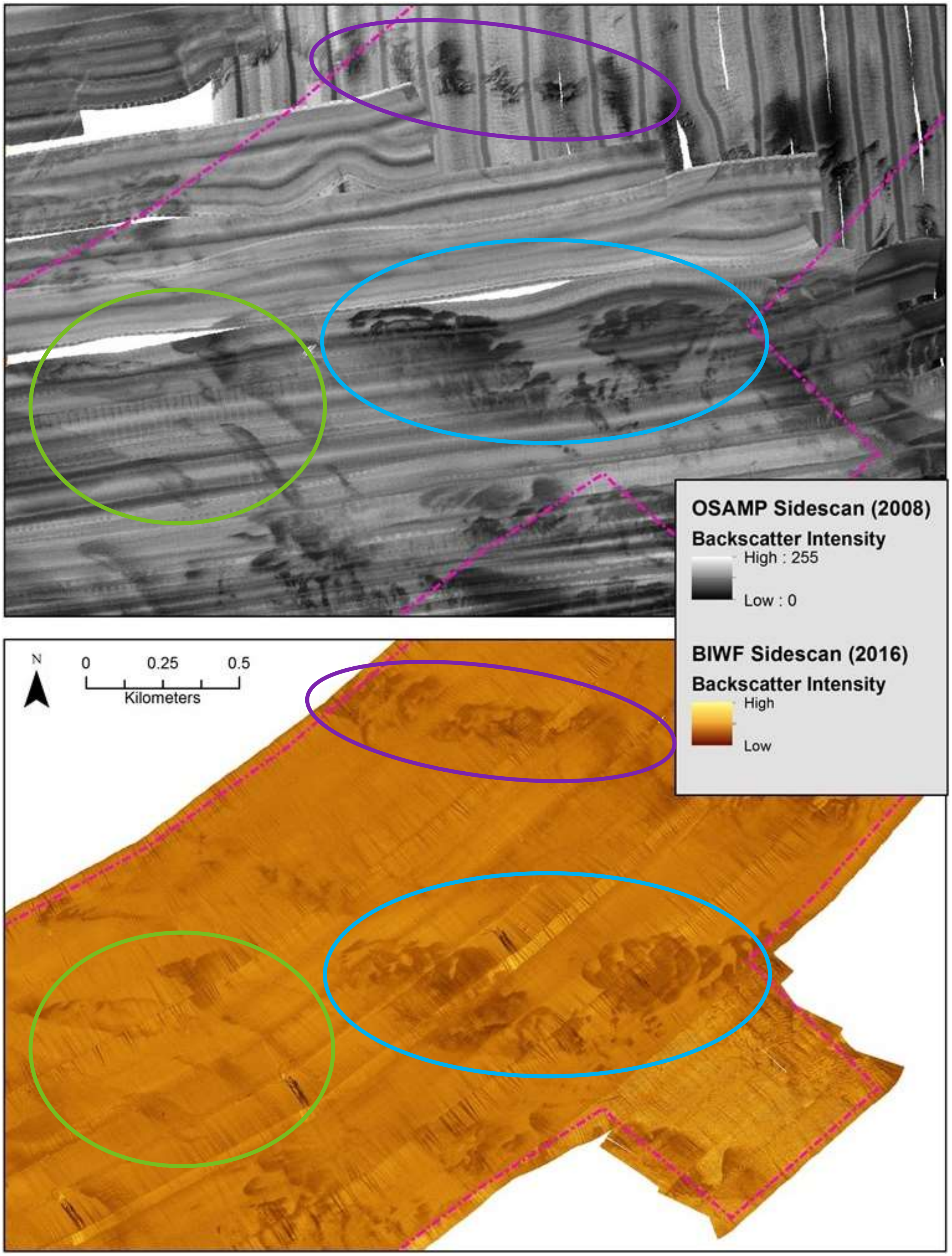

Figure 2. Comparison of 2008 and 2016 side-scan mosaics showing minor changes to geological environment. Specific examples are highlighted in colored circles, though such similarities are visible throughout the two mosaics.

1.3 Study Context

1.3.1 Overview of Physico-chemical and Ecological Conditions within BIWF Region

Marine physico-chemical and ecological conditions for Rhode Island and Block Island Sounds, the wider region surrounding the BIWF development, are described in the Rhode Island OSAMP (CRMC 2010) within which the BIWF is located. Site-specific information is presented in the Block Island Wind Farm and Transmission System Environmental Report (Deepwater Wind 2012) with descriptions of the benthic ecological resources, described through seabed video surveillance, presented in supporting appendices (Normandeau Associates 2012). RPS ASA (2012) described water circulation patterns for the region and Fugro (in prep.) have deployed an AWAC sensor on the seabed at the BIWF site for the measurement of local hydrodynamic conditions. Two scour monitors were also deployed at BIWF turbine 3 to monitor physical changes to the sea floor in the immediate area of the foundation. A brief overview of the findings from these studies is presented below.

Regionally, water depths offshore range between 10 and 55 m. Tides in the region are semidiurnal with a mean range of approximately 1 meter. RPS ASA (2012) describes the water circulation in the Block Island Sound and Rhode Island Sound area as predominantly tidally driven and rather complex. Within the wider region, currents on the eastern side of Rhode Island Sound flood to the east, into Buzzards Bay and Vineyard Sound and ebb to the west. Conversely, on the western side of Rhode Island Sound and in Block Island Sound, currents flood to the west, into Long Island Sound and ebb to the east. Here they split around Block Island and flow almost north-south on either side of Block Island (**Figure 3**).

The description of tidal movements and modelled tidal data from RPS ASA are generally consistent with observations from site specific tidal monitoring conducted using bottom mounted AWAC sensors at the wind farm site by the HDR Team. This monitoring showed a dominant north – south tidal axis with maximum depth average current speeds up to approximately 0.24 m per second (Fugro in prep.).

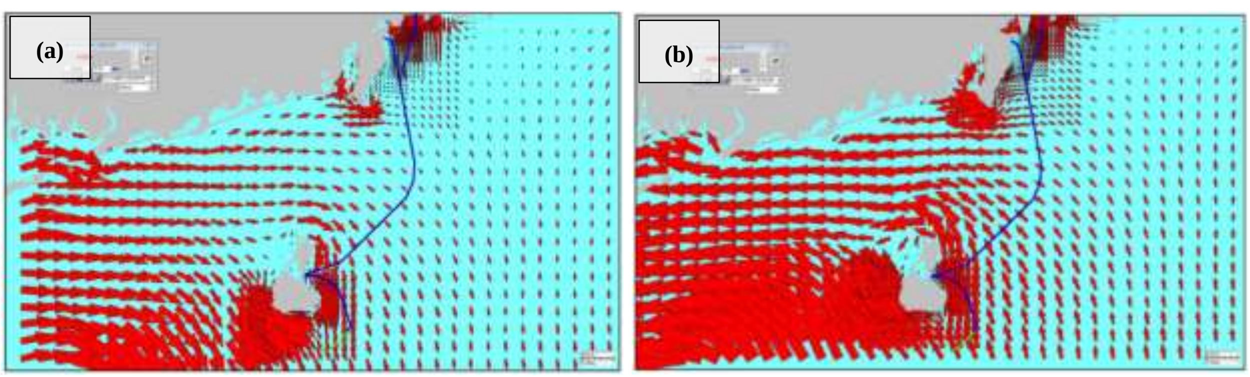

Figure 3. Modelled ebb (a) and flood (b) tidal flow directions within the vicinity of Block Island (taken from RPS ASA (2012).

Review of acoustic data for the wider region reveals a complex seafloor with variable topography comprising a mix of geologic environment types, including sheet sand, sand waves, small dunes, boulder fields, areas of cobble, pebble, and/or gravel, as well as areas of muddy sediment. The geologic environments within the vicinity of the BIWF are primarily comprised of medium, coarse and very coarse sands.

A review of acoustic survey data coupled with video ground truthing (Normandeau Associates 2012) identified hard substrate habitats, towards the southwest of the Block Island wind turbines and within an area to the northeast. Video transects across representative seabed areas identified a seabed comprising boulders and cobbles in varying proportions together with medium and coarse sand deposits. Elevation of hard substrate areas did not exceed 0.6 m above the seabed. Sand waves with gravel and shell debris within the wave troughs were also observed from the video footage. Fauna and flora associated with the harder substrate areas included encrusting coralline and erect red algae, together with the encrusting polychaete Spirobidae, Porifera such as P*olymastia* sp., hydroids, and the cnidarian *Urtica felina*. The echinoderms *Henericia sanguinolenta* and *Asterias* sp. were observed on cobbles and boulders. A variety of fish were observed during the site-specific video deployments including cunner (*Tautogolabrus adspersus*), black sea bass (*Centropristis striata*), winter flounder (*Pseudopleuronectes americanus*), windowpane flounder (*Scophthalmus aquosus*), goosefish (*Lophius americanus*), and skate (*Leucoraja* sp.).

Historic benthic sampling has found coarser sand sediments to be characterized by amphipods, *Byblis serrata* and *Haustorius* spp., polychaetes, *Aricidea* Maldanids, *Nepthys* spp. and Spionids dominated by the bivalve, *Nucula* sp. (Steimle 1982). Elsewhere in Block Island Sound, finer grained silty sand sediments persist and support abundant tube dwelling amphipods *Ampelisca agassizi* and *A. vadorum* together with the co-dominant bivalve, *Nucula proxima* (Steimle 1982). Correlation analyses support a distribution of macrobenthos based on sediment type, water depth and bottom current strength (CRMC 2010).

1.3.2 Overview of Previous Benthic Habitat Mapping Study within BIWF Region

An extensive benthic habitat mapping study was undertaken as part of the OSAMP (LaFrance et al. 2014 and 2010). As part of this study, full coverage, high resolution side-scan and bathymetry data were collected using interferometric sonar for the area surrounding Block Island to the south and west, which also encompasses the BIWF study area (**Figure 4**). These acoustic datasets were integrated with sediment samples, underwater video, and sub-bottom profiles to interpret geologic depositional environments (**Figure 5**).

Geologic depositional environments are defined by a combination of the Quaternary depositional environment, surficial sediment composition, and bedform configuration present within an area. Quaternary depositional environments identified are glacial alluvial fans and moraines. Surficial sediment composition and bedforms represent modern (Late Holocene) processes, and include sheet sand, sand waves, small dunes, boulder fields, as well as areas of cobble, pebble, and/or gravel concentrations. A small portion of the area is composed of fine sediment (i.e., silty sand).

The depositional environments within the vicinity of the BIWF are comparatively coarse, characterized by areas of coarse sheet sand, coarse sand with small dunes, coarse sand with pebble and gravel, as well as areas of cobble and gravel concentrations and boulder and gravel concentrations. The maps reveal the types and overall complexity of the seafloor environments present within the OSAMP study area.

Regarding biological data, a total of 48 benthic grab samples were collected throughout the study area using a Smith McIntyre sampler. Recovered macrofauna were enumerated and identified to the species level. The data were examined to gain an understanding of the benthic macrofaunal community structure, particularly species richness and abundance. A series of statistical analyses were then conducted to determine the relationship between the macrofaunal communities and environmental variables. It was found that geological characteristics were primarily responsible for biological-environmental associations and this relationship wa s used to develop a habitat classification (i.e., biotope) map of the OSAMP study area (**Figure 6**).

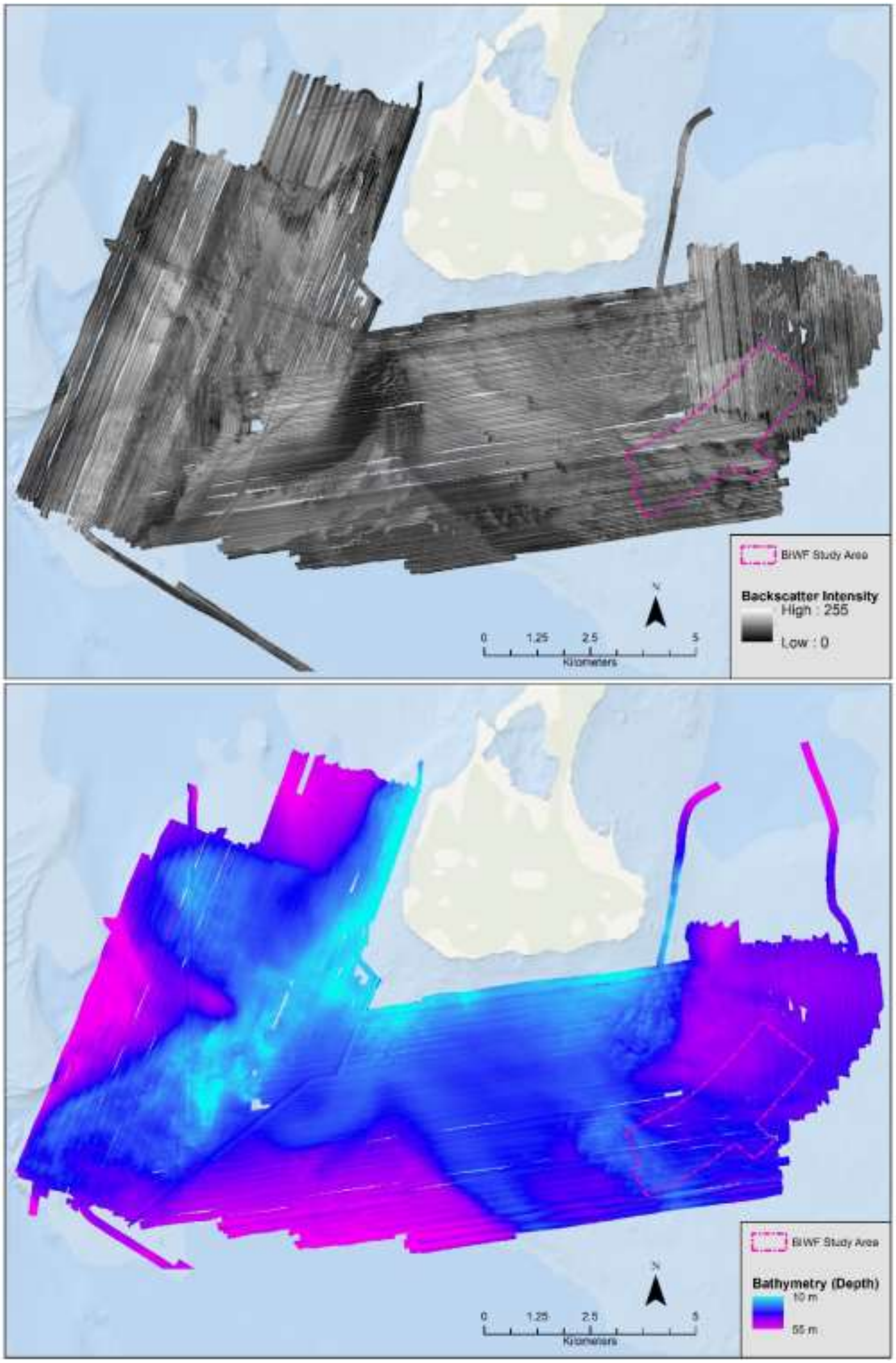

Figure 4. Acoustic datasets collected within the OSAMP study area illustrating the complexity of the area.

Note: The side-scan mosaic is shown at 2-meter pixel resolution on an inverse grey scale with pixel values ranging from 0 (black) to 255 (white). The lighter pixels indicate strong acoustic returns and represent hard bottoms, such as coarse sand, cobbles, and boulders that tend to reflect sound, whereas darker pixels represent softer sediments, which tend to be acoustically absorbent. The bathymetry data are shown at 10-meter pixel resolution and shows water depths ranging from 10 to 50 m.

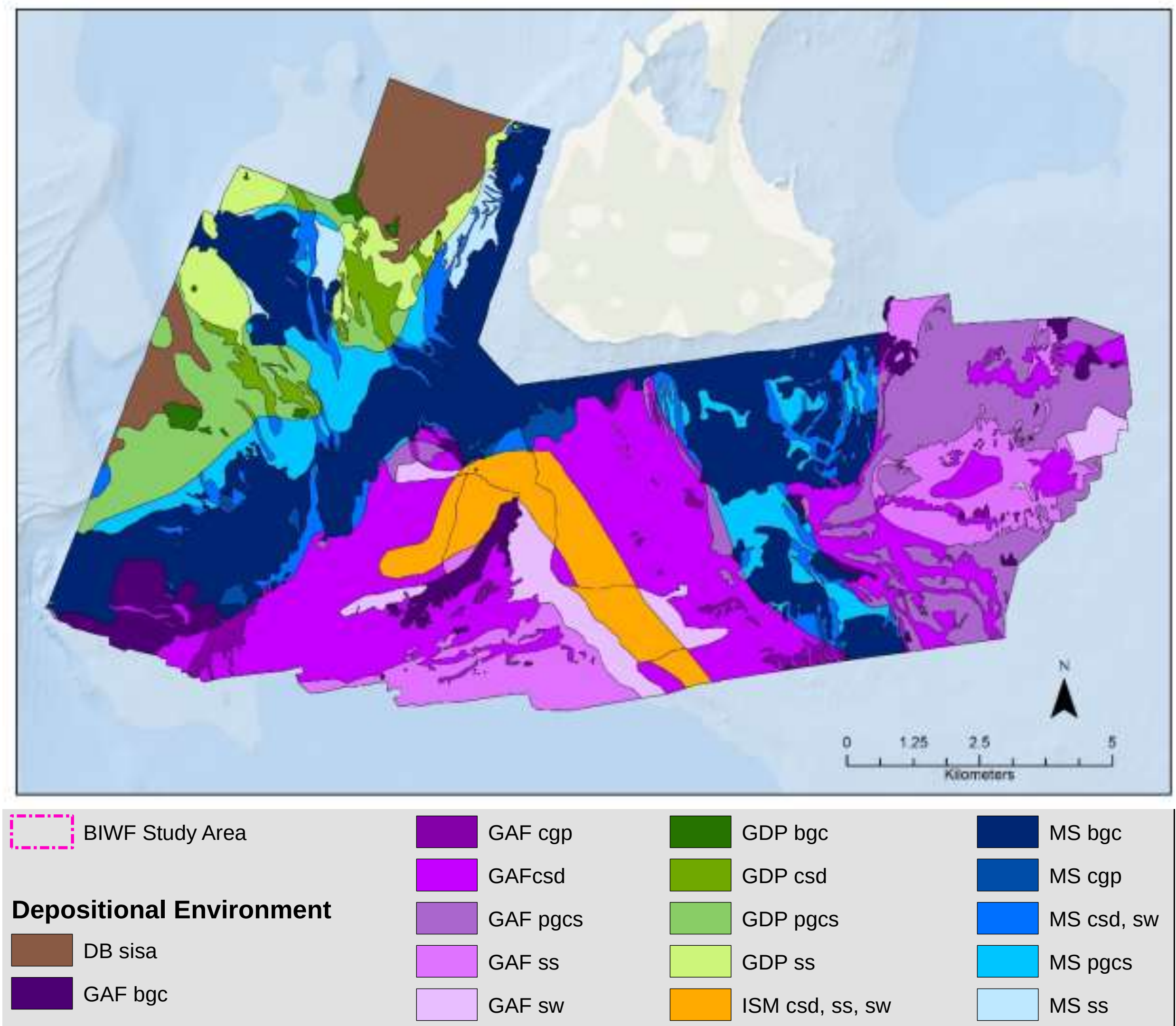

Figure 5. Benthic geologic depositional environments of the OSAMP study area.
Note: The polygons are labeled according to the CMECS Geoform Component Level 1 (capital letters), followed by Level 2 (lowercase letters). For visual emphasis, each general color represents a Geoform Level 1 unit, and shades of the same color represent the Level 2 designation within that Level 1 unit. Abbreviations are as follows: Level 1: DB = Depositional Basin; GAF = Glacial Alluvial Fan; GDP = Glacial Delta Plain; ISM = Inner Shelf Moraine; MS = Moraine Shelf. Level 2: bgc = boulder gravel concentrations; cgp = cobble gravel pavement; csd = coarse sand with small dunes; pgcs = pebble gravel coarse sand; sisa = silty sand; ss = sheet sand; sw = sand waves.

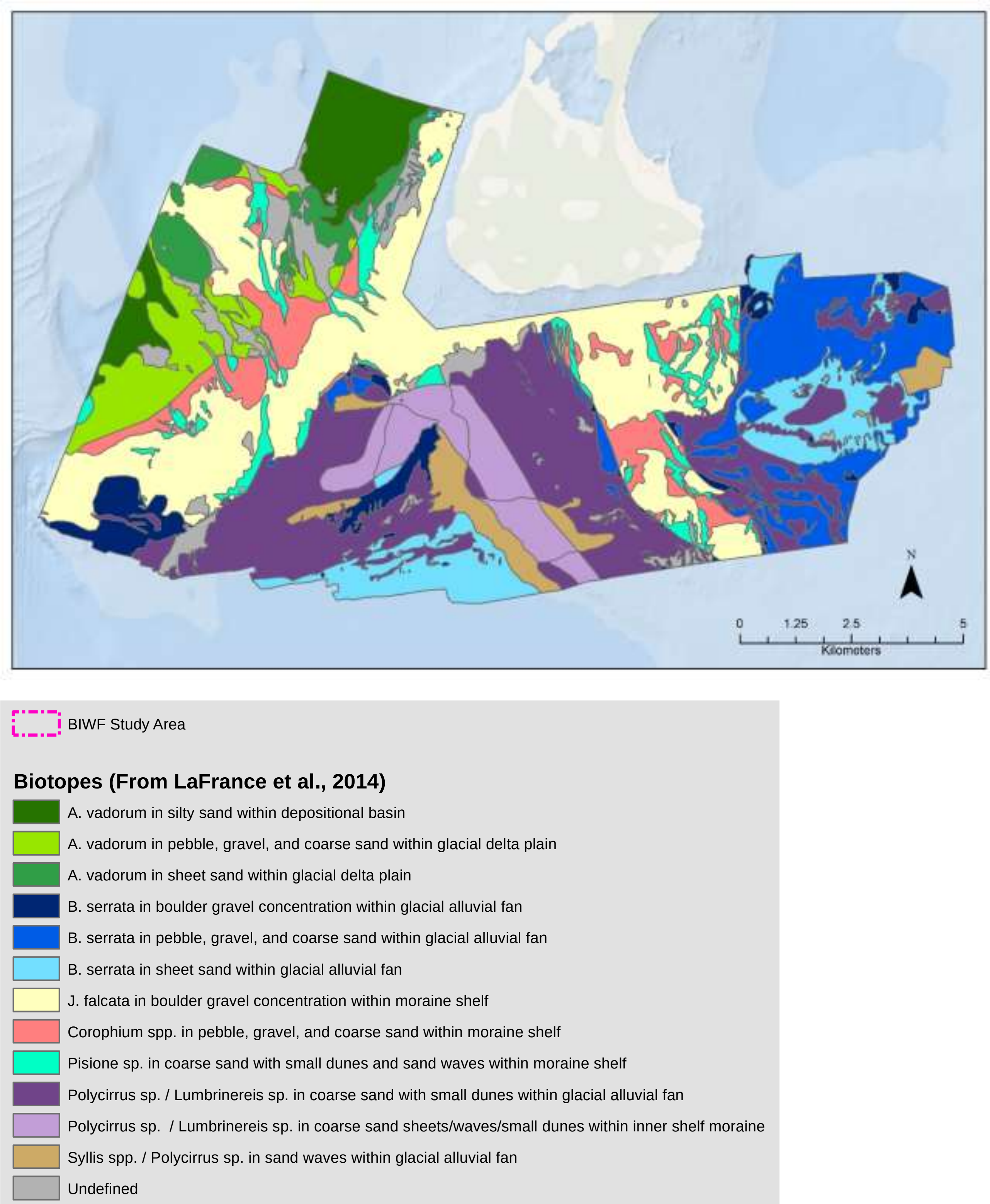

Figure 6. Biotope map of BIWF study area and surrounding area.
Note: Biotope map units are classified according to the Coastal and Marine Ecological Classification Standard (CMECS) and are defined according to the Geoform and Biotic Components, represented by depositional environment type and dominant species, respectively. The color scheme of the biotope map shown here is slightly modified from its original version developed by LaFrance et al. 2014.

The biotopes are defined by the dominant species within the given biotope unit and the associated geologic depositional environment. The map indicates there are twelve distinct biotopes within the OSAMP study area. These biotopes are represented by eight dominant species, of which four are tube-building amphipods and four are polychaete worms (two burrowing, one tube-building, and one mobile) (**Table 2**).

Table 2. List of biotope-defining species within the OSAMP study area.

Species	Phylum	Common Group	Functional Designation
Ampelisca vadorum	Arthropoda	Amphipod	Tube-building
Byblis serrata	Arthropoda	Amphipod	Tube-building
Corophium spp.	Arthropoda	Amphipod	Tube-building
Jassa falcata	Arthropoda	Amphipod	Tube-building
Lumbrineries hebes	Annelida	Polychaete worm	Burrowing; primarily carnivorous
Pisione remota	Annelida	Polychaete worm	Small burrowing; selective deposit feeder
Polycirrus medusa	Annelida	Polychaete worm	Soft tube; selective deposit feeder
Syllis spp.	Annelida	Polychaete worm	Mobile; carnivorous

Note: The functional designation is also provided to describe the ecological role of each species. Species are listed in alphabetical order. (Table adapted from LaFrance et al. 2014).

2 Methods

2.1 Monitoring Survey Design

2.1.1 Turbine Selection

Samples were collected at three of the five turbines to allow for a denser number of samples to be collected. This increased sampling resolution created adequate sample replication and optimized the spatial distribution of samples to detect change across the different distance bands. The turbines were selected relative to the location of biotopes previously defined by LaFrance et al. (2014) to ensure representation within the sampling array. As such, BIWF 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 (**Figure 7**).

This sampling strategy allowed for pre- and post-construction comparisons to be made and is valuable for understanding the responses of macrofaunal communities to potential changes relative to the BIWF and to natural variation. Furthermore, the data and conclusions drawn from this monitoring study will have maximum utility at future wind farm developments elsewhere within the region and wider U.S. continental shelf where comparable ranges of biotopes exist. In addition, selection of Turbine 3, which hosts the scour monitoring equipment[1], may allow opportunity for correlations between measured physical seabed changes with observed habitat and biological community effects.

2.1.2 Sampling Strategy

A total of 121 grab samples at 43 stations were planned within the BIWF study area. Grab sample stations were planned at three of the five turbines (T1, T3, and T5) and within three control areas (C1, C2, C3) (**Figure 7**). Three grab samples were collected at each station but were 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 samples allows for more robust statistical analyses of the biological communities and allows for the degree of small-scale spatial variability present throughout the study areas to be assessed.

Nine sample stations were randomly positioned within each turbine area, resulting in 27 samples per turbine (81 samples total). 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 so that samples were collected at increasing distances from the turbine foundation. This strategy was intended to provide adequate coverage of the anticipated effects based on prior observations (Schröder 2006, Coates et al. 2012 and 2014) because one of the principal interests of the study was to investigate potential benthic modification with distance from the turbine foundations. From the center point under the foundation structure, these distance bands were equal to 30–49 m, 50–69 m, and 70–90 m.

[1] Installed under a concurrent task.

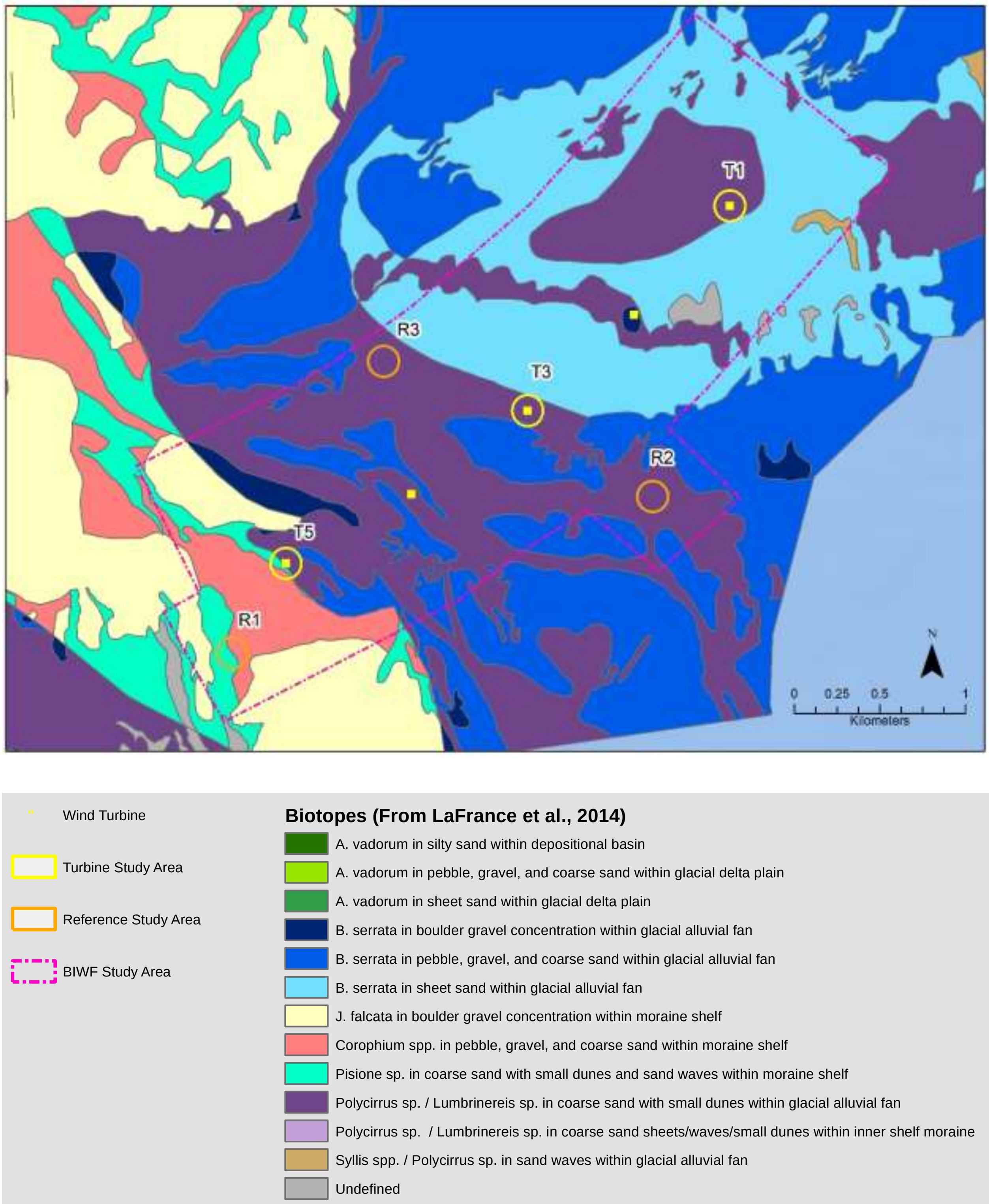

Figure 7. Distribution and extents of classified seabed biotopes in relation to BIWF.

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, the closest distance band (30 m) is located 15m from the corner points and 20 m from the sides of the foundation structure itself **(Figure 8).**

Within each control area, four sampling stations were randomly positioned (without the use of distance bands), resulting in 12 samples per area (36 samples total). The control areas were selected at locations outside of the predicted influences of the construction and operation of the BIWF. The areas were also comparable in substrate and depth conditions to that of the turbine areas. Data from the control areas allowed assessment of benthic change attributable to the BIWF against baseline conditions.

In addition to the 117 turbine and control samples, four samples were collected for independent quality control (QC). These samples were intended to be subjected to taxonomic analyses by an independent benthic macrofaunal expert not associated with the analysis of the samples collected within the turbine and control areas. One QC sample was randomly selected within each turbine area and within one of the control areas.

Data acquired at each sample station consisted of grab samples for analysis of sediment grain size and macrofaunal community composition, paired with underwater video to provide broader contextual information of the surrounding area. **Table 3** presents a summary of the benthic sampling effort.

Table 3. Summary of Benthic Survey Sampling Effort.

Distance Bands	No. Stations					
	Turbine 1	Turbine 3	Turbine 5	Ref. 1	Ref. 2	Ref. 3
30–49 meters	3	3	3	--	--	--
50–69 meters	3	3	3	--	--	--
70–90 meters	3	3	3	--	--	--
Control Areas	--	--	--	4	4	4
Total no. samples (cluster samples = ×3 per station)	27	27	27	12	12	12
Independent QC samples	1	1	1	--	--	1
Total Number of Samples	**121**					

2.2 Data Collection and Processing

2.2.1 Grab Sample

A total of 121 grab samples were collected using a Smith McIntyre grab sampler (approximately 620-square centimeter sample area). An overview of the locations of the grab deployments is presented in **Figure 9** with detailed sampling locations at each turbine location shown in **Figures 10a, b and c** and at each control area in **Figures 11a, b and c**.

Upon recovery of the sample, the sediment within the grab bucket was inspected to assess whether the sample was acceptable (i.e., has not been subject to partial washout during retrieval, and is of sufficient volume relating to depth of bite). An assessment of sample volume was made and a visual description recorded. Any conspicuous sediment features and obvious fauna were also recorded.

A sub-sample was collected for sediment grain size analysis and organic content. The remaining material was transferred to a bucket for macrofaunal analysis. All samples were stored in pre-labeled containers with locking lids to ensure no loss of material and brought back to the lab for analyses. Upon arrival to the lab, all samples were stored at 4 degrees Celsius until processed to reduce deterioration. Field survey records, including on-site descriptions of the grab samples are presented in **Appendix 1**.

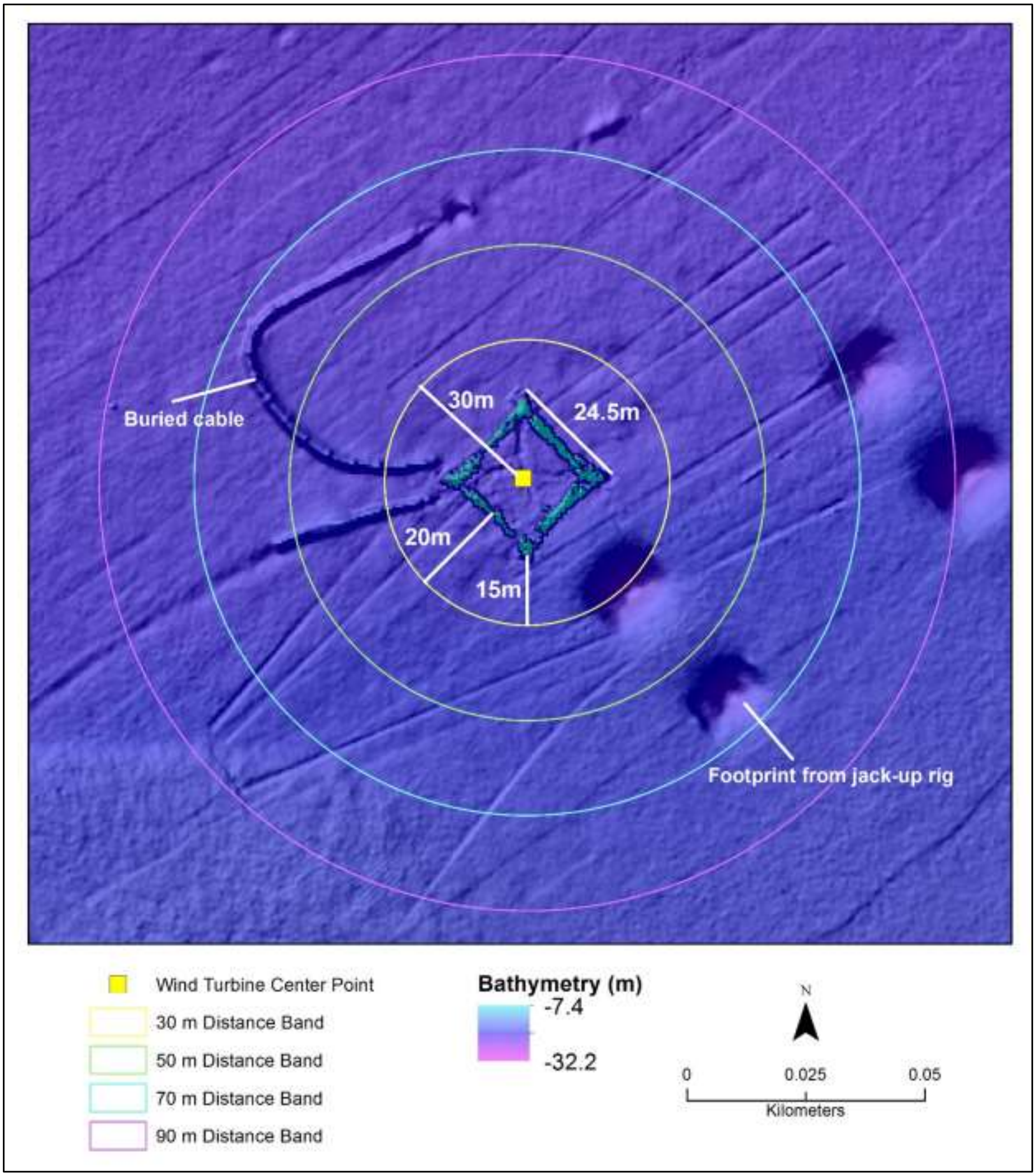

Figure 8. Example of the relationship between distance bands and footprint of the foundation structure

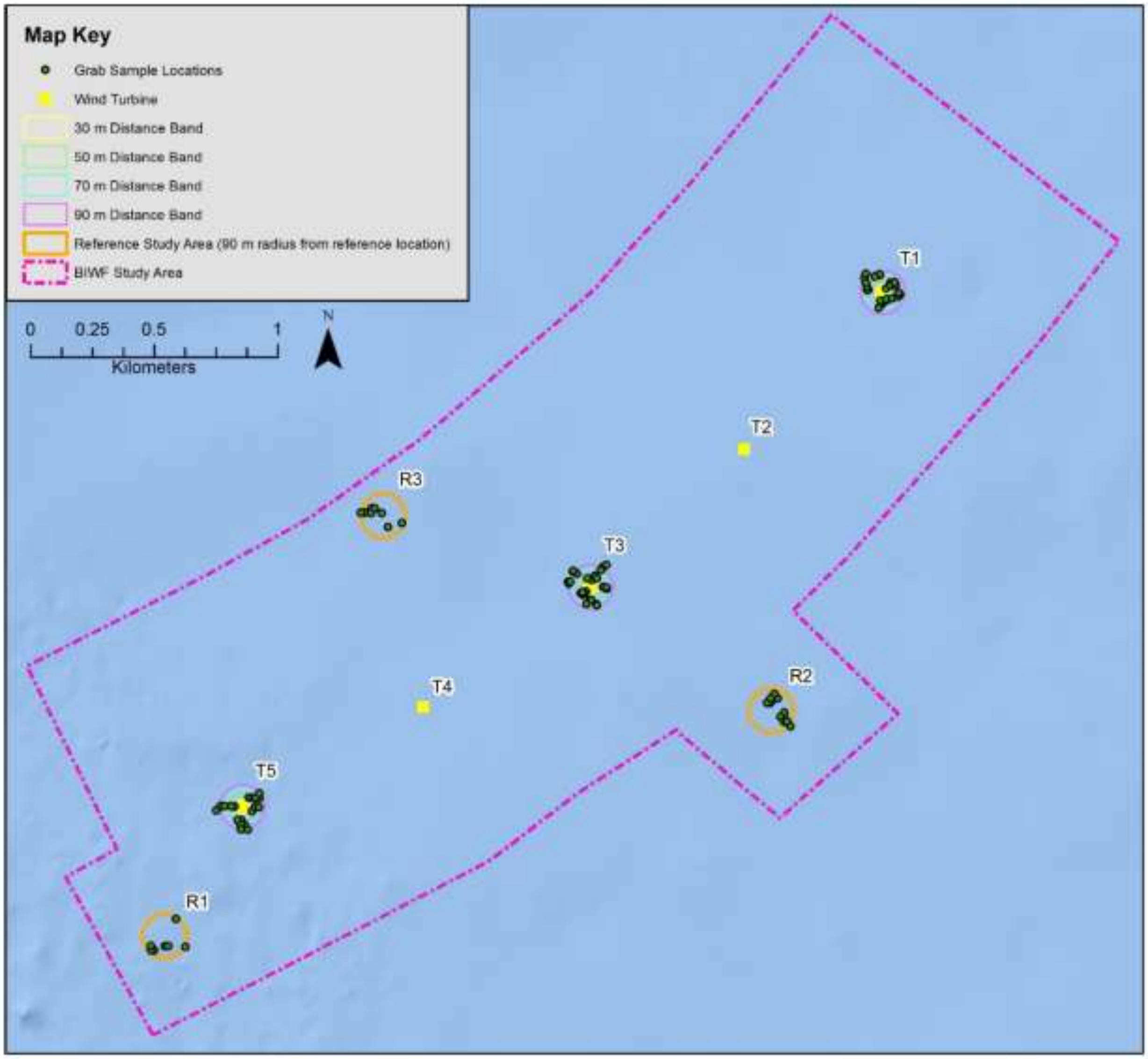

Figure 9. Location of the collected grab samples and seabed video within the BIWF study area.

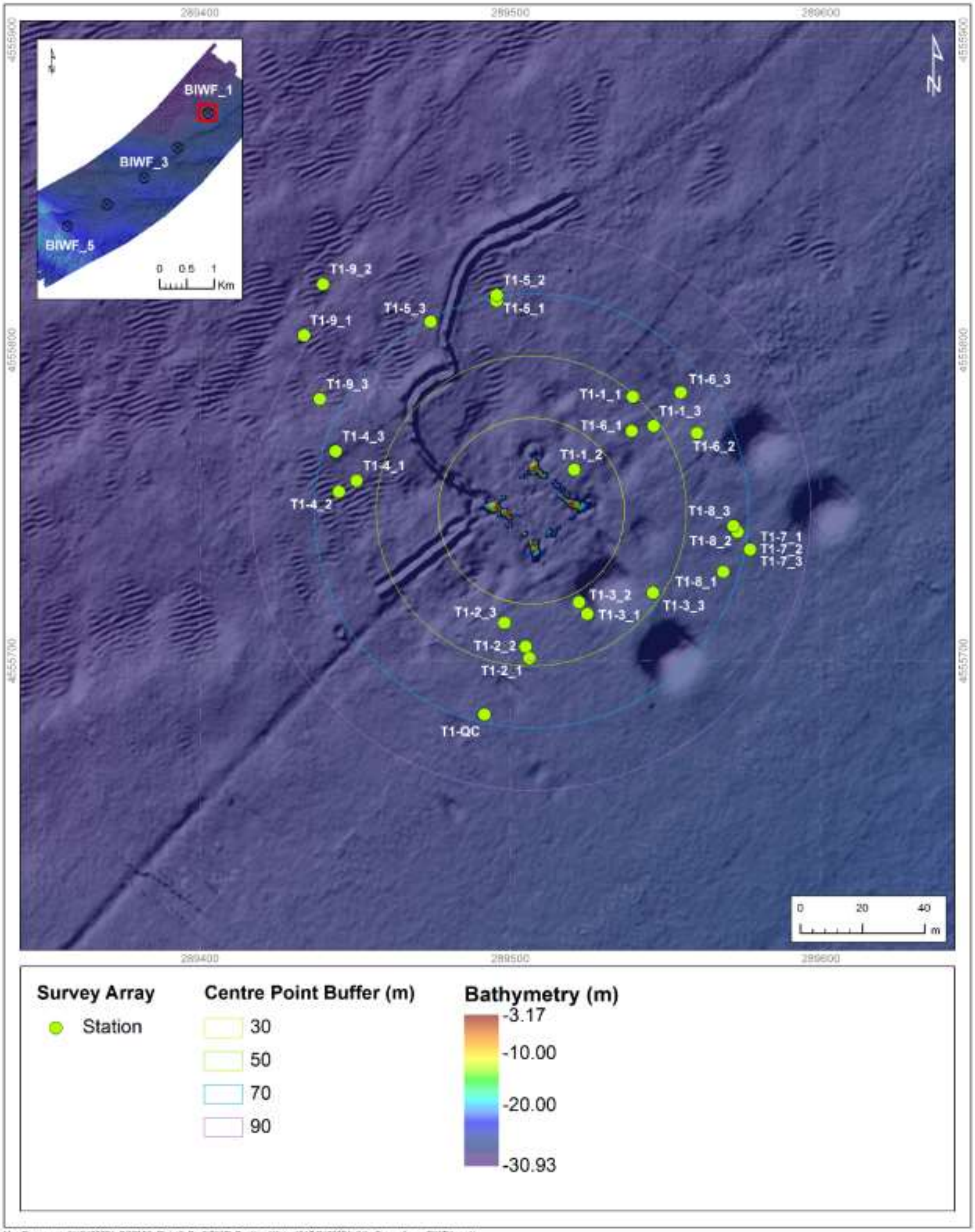

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Figure 10a. Locations of collected grab samples and seabed video relative to Turbine foundation 1

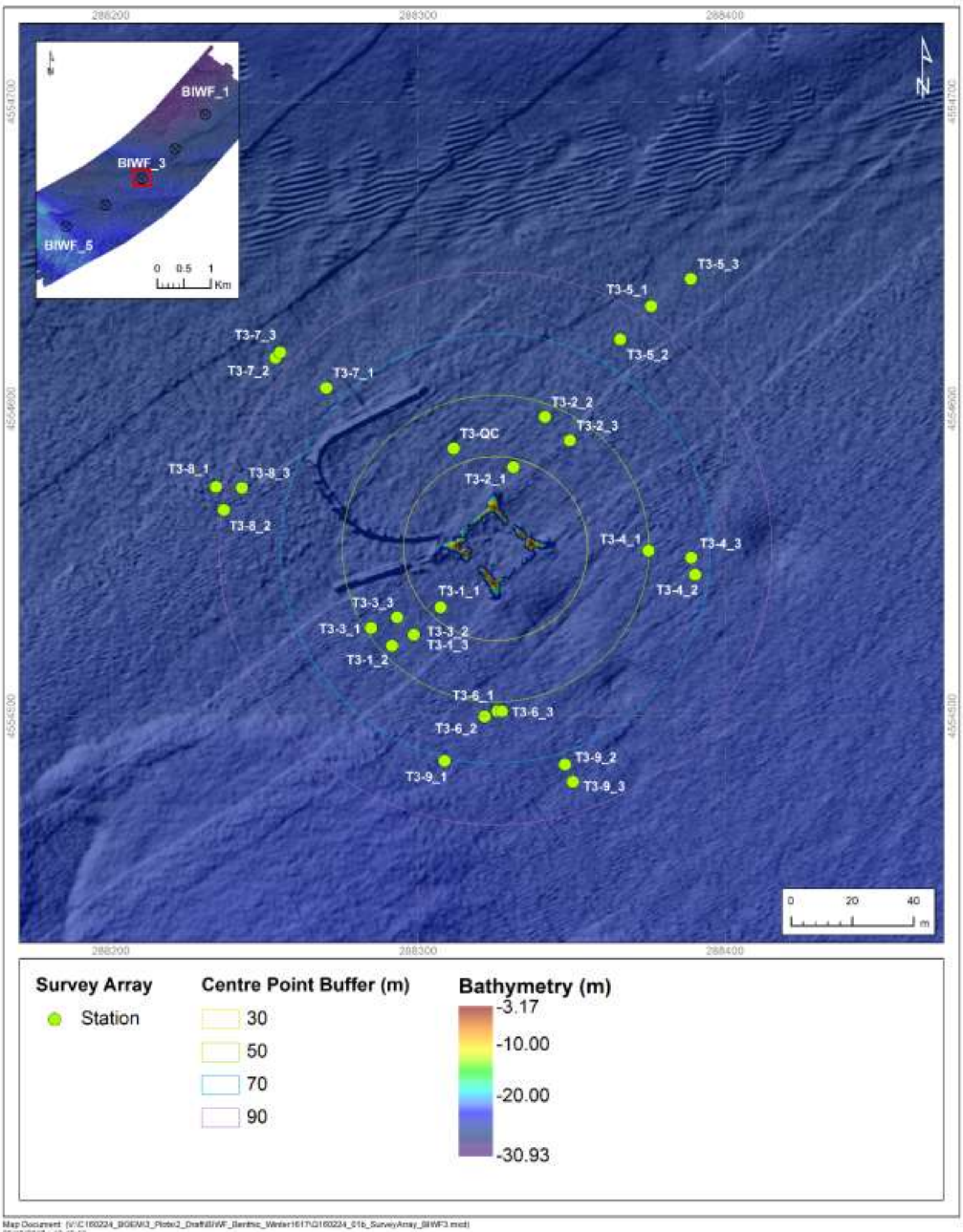

Figure 10b. Locations of collected grab samples and seabed video relative to Turbine foundation 3

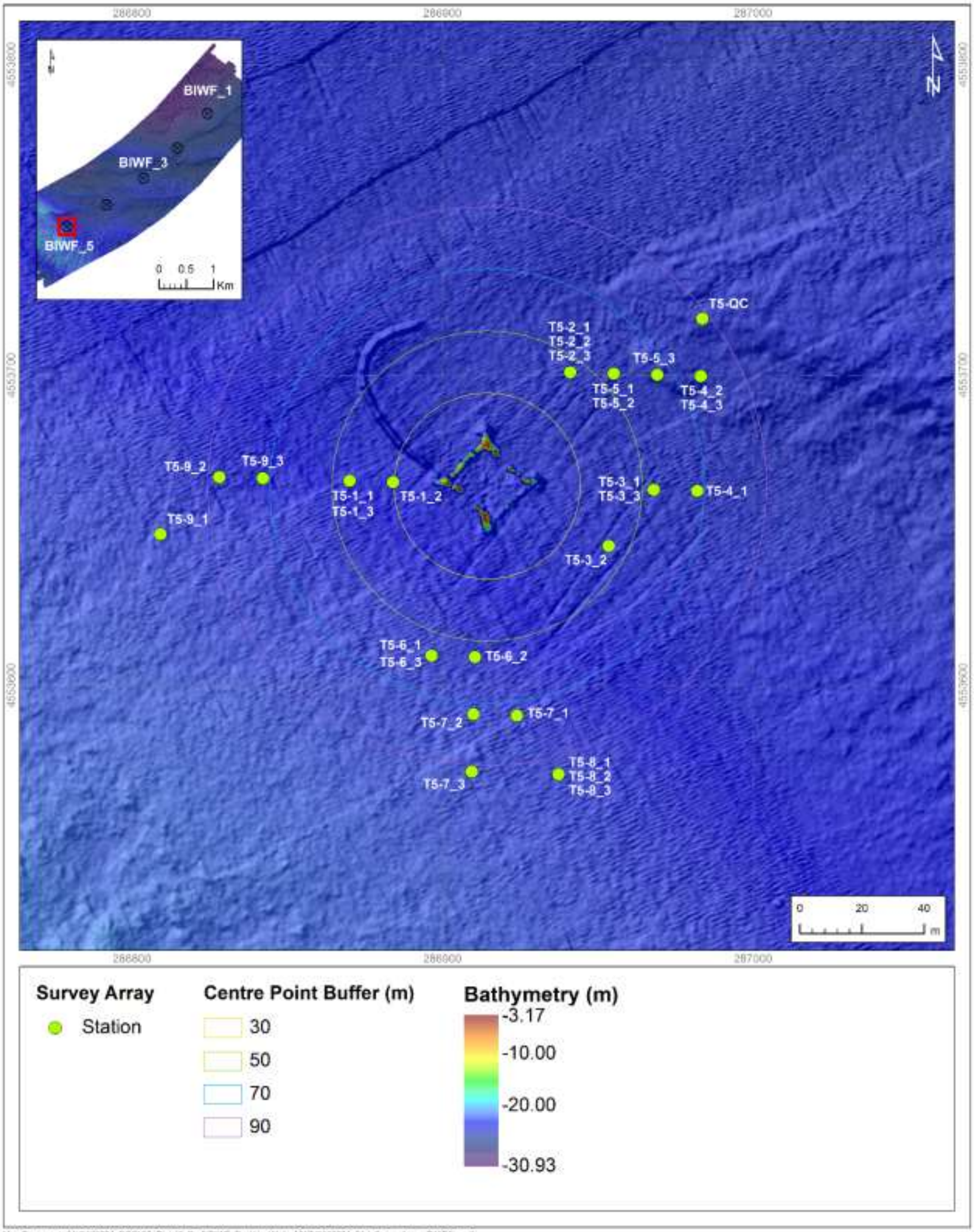

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Figure 10c. Locations of collected grab samples and seabed video relative to Turbine foundation 5

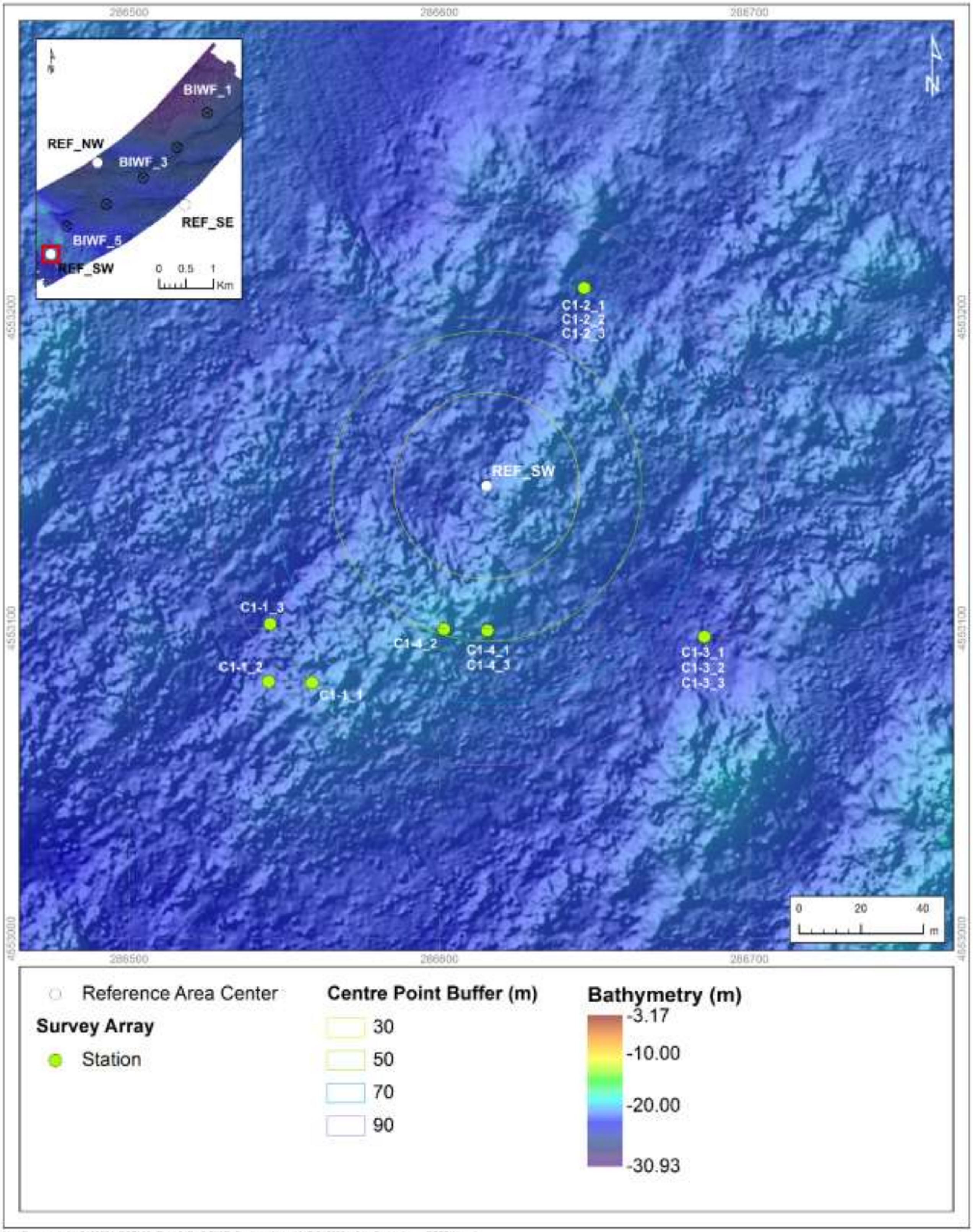

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Figure 11a. Locations of collected grab samples and seabed video within Control Area 1

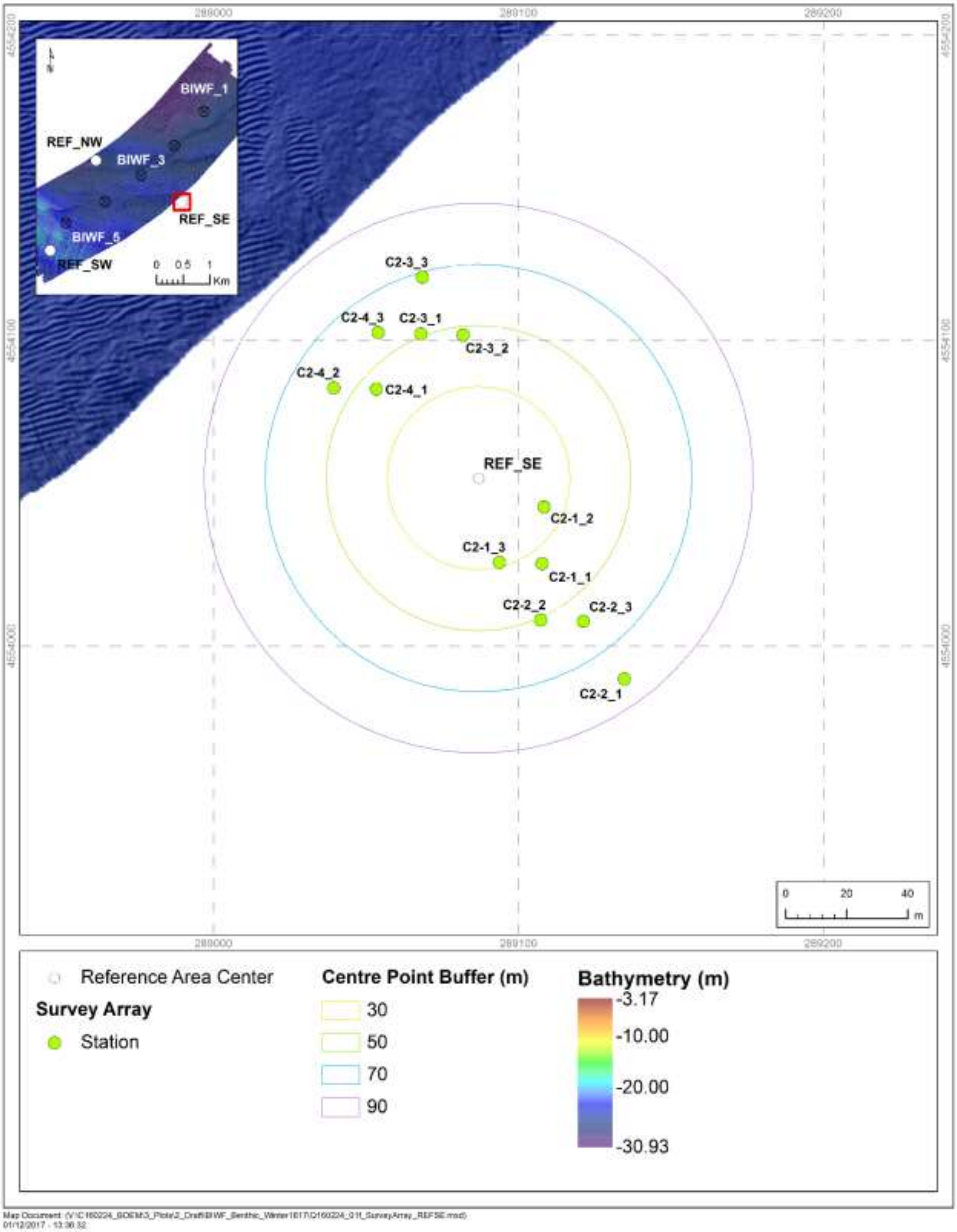

Figure 11b. Locations of collected grab samples and seabed video within Control Area 2

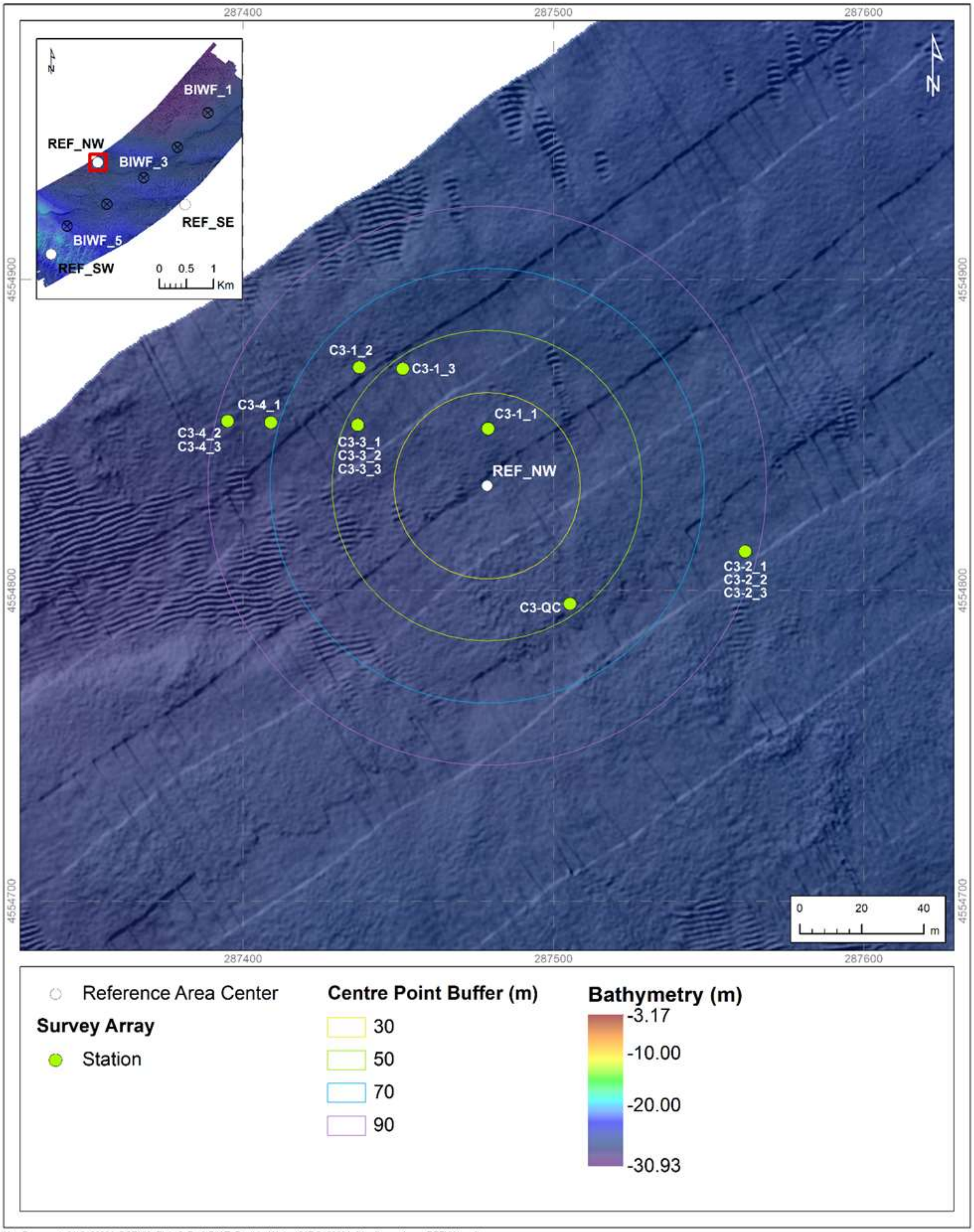

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Figure 11c. Locations of collected grab samples and seabed video within Control Area 3

Sediment properties of the sub-samples 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 1927). Therefore, sediment analyses were performed on grain sizes ranging from 0 to 2,000 micrometers (µm). While sediment larger than 2,000 µm (e.g., gravel, cobble, and boulder) were not quantitatively assessed, qualitative data of such material was collected. Specifically, the recovery of these sediment types within the grab sample was noted, as well as the presence and concentrations of gravel, cobble, and boulder from the underwater video (**Section 2.3.2**).

A portion of the sub-sample was also analyzed for total organic matter (TOM) and total organic carbon (TOC) content. A muffle furnace was used for the organic matter content determination following the Loss-On-Ignition method of Dean (1974).

For biological analysis, each grab sample was sieved through a 1-millimeter aperture mesh sieve. The contents of the sieve were transferred into a pre-labeled bucket and fixed on-site using 4 percent buffered saline formalin solution with Rose-Bengal stain added. The samples were transported to the designated lab where all individuals recovered were counted and identified to the species level or lowest possible taxonomic group. The primary macrofaunal analysis of the 117 samples and four QC samples were conducted by taxonomic specialists at the Ecological Consulting Organization. The identification spreadsheet was reviewed by Sheldon Pratt, a local expert on the staff at URI, to ensure consistency with regards to nomenclature and to confirm species identified were could be reasonable expected within the study area based on historical accounts.

The performance of the grab sampler differed depending on substrate type as indicated in the field survey records (**Appendix 1**). In general, the grab returned smaller samples from coarser sediments compared to finer grained deposits. **Figures 12 (a)** and **(b)** summarize the effect of seabed substrate type on the size of sample returned and compares sample sizes from each of the turbine locations, respectively. The substrate types selected in this instance derive from the field visual descriptions of the samples.

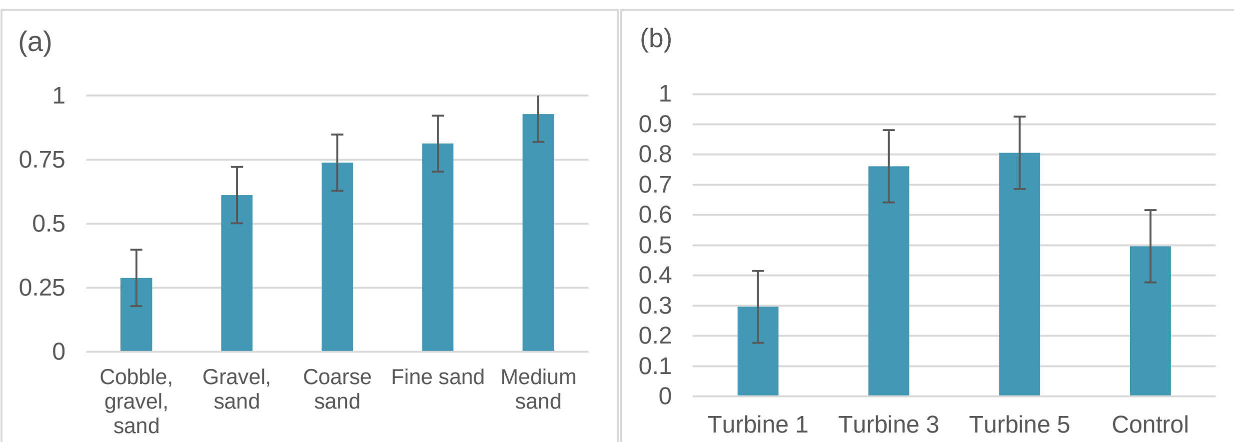


Figure 12. Summary of size of grab samples collected from (a) different substrates at BIWF and (b) different turbine locations.

In general, samples collected from mixed coarse deposits (e.g., cobble, gravel, and sand) were small and the grabs recovered from this substrate type were on average just above ¼ full. Grab samples collected from 'gravel, sand' deposits were on average between ½ and ¾ full those collected in 'coarse,' 'medium' and 'fine' sands were approximately ¾ full or greater. Field records also noted that samples collected at Turbine 1 were comparatively small (on average only 1/3 full) compared with those collected at the other two turbine locations (on average ¾ full).

2.2.2 Underwater Video

To complement the grab sample data, underwater video was collected to capture information over a broader scale for context information and to assess the degree of spatial heterogeneity of the environment and associated benthic biological communities. Additional information provided by the video included the identification of bedforms, coarse surficial material concentrations (e.g., boulders, cobble, gravel), and species that are more mobile or are present at low densities (e.g., crabs, starfish, algae) and so tend to not be captured by the grab sampler. The video camera was attached to the grab sampler, allowing for datasets with identical spatial and temporal attributes. Such co-located datasets reduce uncertainties associated with returning to an area for sampling.

2.2.3 Seabed Photography

Within each turbine and control area, seabed photography was undertaken using a Lagrangian floating remote digital stills camera. The duration of the seabed video surveillance at each station was approximately 15 to 30 minutes. The camera was redeployed where necessary to ensure that all features observed can be confidently described in terms of their spatial extent, composition and characterizing biology. In total, 15 camera deployments were completed **(Figure 13**). The camera was deployed with a tether to a surface buoy to make recovering it easier. The coordinates of the deployment and recovery locations were noted; though the drift pattern of the camera was not documented. The camera was programmed to follow the seabed at a constant altitude of approximately 2.2 m to ensure high resolution images of the seabed, while maintaining a safe distance from boulders and any raised objects that may be present.

The images are collected at a rapid rate, allowing for a continuous series of overlapping seabed images of the seabed that can then be mosaicked. Having the deployment and recovery locations allow for the images to be spaced out over the drift track and provide an estimate location of each image. The raw images are color corrected to account for lighting artifacts and small variations in altitude. This comprehensive set of images and mosaics provide contextual information of the geological environments and local heterogeneity, as well as conspicuous species present throughout the camera deployment.

2.3 Data Analyses

2.3.1 Univariate Analyses

The following univariate measures were calculated using PRIMER (Plymouth Routines in Multivariate Ecological Research) v6.0 package of statistical routines: number of species (S), number of individuals (A), and a range of diversity indices, including Shannon Weiner diversity (H'), Margalef's Richness (d), Pielou's Eveness index (J') and Simpson's Dominance (λ). **Table 4** summarizes univariate measures calculated.

2.3.2 Multivariate Analyses

Multivariate analyses were carried out using the statistical software package, PRIMER v6.0 (Plymouth Routines in Multivariate Ecological Research) with the Permanova+ add-on software (Clarke and Gorley 2006, Anderson et al 2008). Macrofaunal data were imported into PRIMER and 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.

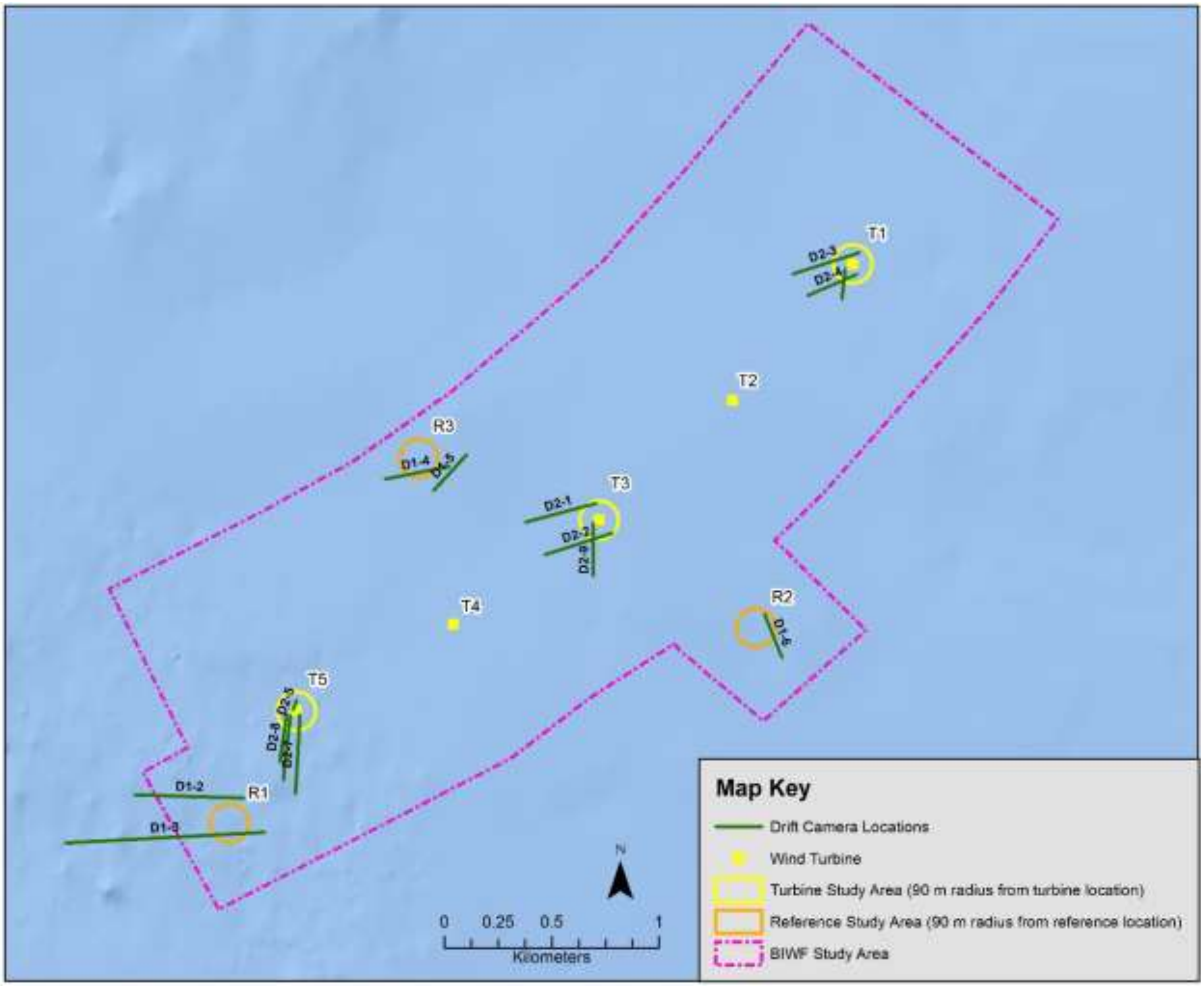


Figure 13. Locations where seabed photography images were collected using a drifting camera system.

Table 4. Primary and Univariate Indices.

Variable	Dominant Influence/s	Formula	Description
Number of Species (*S*)	Richness	S Where: S = the total number of species.	The simplest measure of species richness.
Number of Individuals / Abundance (A)	-	A Where: A = the total number of individuals.	The simplest measure of abundance.
Shannon Weiner (*H′*)	Richness + Evenness	$H' = -\sum_I p_i (\log p_i)$ Where: p_i is the proportion of the total count arising from the *i*th species.	A measure of how the number of individuals are distributed across the number of species found in a sample (Shannon and Weaver 1949).
Margalef's Richness (d)	Richness	$d_{Mg} = \frac{(S-1)}{\log N}$ Where: S = total number of species; N = total number of individuals.	A simple index derived from a combination of the number of species (S) and total number of individuals (Clifford and Stevenson 1975).
Pielou's Evenness or Equitability (*J′*)	Evenness	$J' = \frac{H'}{\log S}$ Where: H' = Shannon-Wiener Index; S = total number of species.	A measure of how evenly individuals are distributed between species (Pielou 1969).
Simpson's Dominance (*λ*)	Evenness	$\lambda = \sum \left(\frac{n_i\ (n_i - 1)}{N\ (N - 1)} \right)$ Where: n_i = number of individuals in the *i*th species; N = total individuals.	A measure of the probability that two individuals randomly selected from a sample will belong to the same species (Simpson 1949).

Abiotic variables extracted from the grab samples and underwater video data were also imported into PRIMER and used to investigate potential relationships with observed macrofaunal patterns. Quantitative data included sediment particle size, organic content, and water depth. All environmental data were normalized prior to analysis to standardize the differing measuring scales of each variable. Sediment particle size data were also subjected to hierarchical clustering using Euclidean distance as the similarity measure to establish sediment spatial distribution patterns. Categorical data included study area (i.e., Turbine 1, 3, 5, Control 1, 2, 3), distance from turbine (i.e., near, mid, far), dominant sediment type (e.g., coarse sand, medium sand), general sediment composition and concentration of gravel, cobble and boulders from the video footage, and the presence of biological features in the video footage (i.e., shell hash, mussels, starfish). The geologic depositional environment types, as defined by LaFrance et al. (2010), were also considered in analyses.

Relationships between sample groupings were presented within nMDS (non-metric Multi-dimensional Scaling) plots. 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 further 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. The plots were used to investigate biotic and abiotic relationships, including benthic community composition to sediment type, geologic depositional environment type, and distance from turbine. The plots were also used to assess the cohesiveness of the cluster samples at each sample station.

PCA (Principal Components Analysis) was used to help assess the relative relationships between environmental samples. Similar to the nMDS approach of ordinating macrofaunal data (described above), PCA is an ordination technique which has been used to map environmental samples according to their relative similarity / dissimilarity of their respective abiotic measurements as indicated by the distance separations between sample points. In this study, PCA has been used to complement the nMDS outputs with the added advantage that it identifies those variables contributing most to the variability between environmental samples. Data input into the PCA analysis included sediment grain size classes, water depth, % total organic carbon and % total organic matter.

SIMPER (Similarity Percentages) is a quantitative complement to nMDS plots and examines data based on user-defined sample groups. SIMPER analysis was applied to the data to rank 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 (as a percentage) 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 turbine and the level of dissimilarity between each turbine. As such, SIMPER can assist the assessment of the distinctiveness of each group identified 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 groups (e.g., turbine, cluster samples, geologic depositional environment). 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.

Clustering of the species abundance data was done using the SIMPROF (Similarity Profile) routine to identify statistically significant groupings of macrofaunal samples ($p<0.05$). SIMPROF is a permutation test which looks for significant evidence of genuine clusters of samples which are a priori unstructured. The result is a dendrogram of groups of samples which are created where there is significant internal structure (Clarke & Gorley, 2006). The test was performed here in an attempt to minimize traditional clustering methods which can employ sometimes arbitrary cut-off values and to assist a more objective identification of sample groups and assessment of the community structure with rationalization of some groups based on the presence of common characterizing species and as guided by a subsequent SIMPER analysis.

2.3.3 Significance Testing

SigmaPlot 12.5 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 simply 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 output of ANOVA is a 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 latter increases relative to the former, the F ratio becomes larger. The p value is obtained with reference to freely available "look up" tables of the F distribution and the degrees of freedom within and between sample groups, and indicates the probability of obtaining that, or a larger, F ratio. The two-way feature of the ANOVA test employed in this study refers to the two different factors tested including tests for differences between each of the turbine and control study areas and tests between each sample station at each turbine.

The ANOVA test requires normally distributed data and comparable variances between groups and this was tested using a Shapiro-Wilks test within the SigmaPlot software prior to performing the analyses. Data passing initial variance and normality assumptions, as indicated by the results of the Shapiro-Wilks test, were transformed as necessary (sqrt or ln), and subjected to ANOVA.

ANOVA tests for differences within the entire group of samples but does not identify where those differences occur. Thus, on detection of statistical differences in ANOVA, post-hoc comparison between pairs of groups was undertaken using a Holm Sidak test. The Holm Sidak test is a multiple comparison procedure as post hoc tests.

Data which did not fulfil the variance and normality assumptions were analyzed using the non-parametric Kruskall Wallis method followed by Tukey Kramer pair-wise tests for significant interactions. The Kruskall Wallis is analogous to the ANOVA approach but where normality/equal variance tests have failed. It then compares on medians only, not means and only for one data set. The Tukey Kramer pair-wise test is analogous to the Holm Sidak test.

Note that the use of four sample stations at each of the three control areas led to an unbalanced design for the ANOVA (i.e., there were 36 total control samples, but only 27 samples for each turbine foundation). Thus, whilst analysis is feasible using General Linear Models, for ease of interpretation and power of analysis, one sample station (containing three cluster samples) was randomly removed from each control location (reducing data from four stations to three per control area). Note, stations were removed using an on-line number generator with control locations numbered 1 through 4 and a random number generated between these values, thus ensuring no bias in data removal.

It was further acknowledged that the method of station selection at the turbines differed from that for the controls. Turbine stations were positioned within three distance bands moving outward from the turbines (concentric circles), thus allowing "between distance bands comparisons" within turbine areas. However, control stations were not selected in this fashion, but were randomly distributed without the use of concentric zones. It is acknowledged that ideally, such design between control and treatment (i.e., turbine) locations should be replicated to ensure continuity; however, in this instance, the design means the random removal of one of the sample stations to three samples stations per control area does not compromise analysis as no "distance away" bands are present in control area data.

In light of the differences in grab sample positioning, significance was considered to be accepted at $P<0.001$. Whilst $P<0.05$ is not considered significant for this study, this value has been mentioned when it occurs. The approach of adopting a stringent P value is also useful as the concentric circle design for the treatment sites were not spatially independent from each other (i.e., a buffer no take zone should ideally have been present between survey bands), and that the control area samples were not collected in the same fashion as treatment locations. Accordingly, accepting a more stringent significance level imbues due caution on results interpretation.

Differences between faunal groupings were tested using ANOSIM and Permanova+ within PRIMER. These tests are analogous to the ANOVA test but are used to distinguish differences in multivariate datasets such as faunal data. Whilst ANOSIM and Permanova+ were essentially used to perform similar functions in this study, the use of the latter routine allowed development of baseline Permanova+ datasets for subsequent use during future monitoring campaigns at BIWF. Future use of Permanova + is envisaged, as the routine 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 the Permanova+. The results from this analysis express observed homogeneity/heterogeneity of the faunal data dispersions for selected groups and were used to assess the variability of faunal communities between turbines and control areas.

2.3.4 Retro-active Power Analysis – Confirming the Sufficiency of the Test Design

Statistical power estimates were calculated in Excel for total number of species, Shannon Weiner diversity (H'), and Margalef's Richness (d) across combinations of turbine and control sample groups. Estimates were derived from computed values of Ø (Zar 1999) using the formula

$$\text{Ø} = \sqrt{\frac{(k-1)(groups\ MS - S^2)}{ks^2}} \qquad \textbf{Equation 1}$$

where k is the number of sample groups and s^2 and MS is the error mean square (MS_{error}) and mean of the squares of the deviations between the groups respectively as calculated by ANOVA. The purpose of the power test was to determine the probability that the statistical test returned a statistically significant result given the number of samples collected, the level of significance (α) and the size of effect to be detected. Power estimates of the ANOVAs performed were also generated from the SigmaPlot software used.

The s^2 values calculated from the ANOVAs were also used to estimate the minimum detectable effect (MDE) between the population means at pre-determined significance and Power levels using the following formula

$$\text{MDE} = \sqrt{\frac{2ks^2\text{Ø}^2}{n}} \qquad \textbf{Equation 2.}$$

where Ø_2 is square of the phi value for the specified Power level and for the degrees of freedom for the 'within' and 'between' sample groups.

In all cases, α was taken as 0.05 and the desired Power (1-ß) for the current sample design was taken to be 0.8. These values for α and 1-ß were considered appropriate for this study and reflect a 5% chance of making a Type I error (i.e., rejecting the Null hypothesis when in fact there is no difference) and a 20% chance of making a Type II error (i.e., failing to reject the Null hypothesis when in fact there is an effect). Cohen (1988) discusses this 5 to 20 percent ratio as a potentially pragmatic solution to achieving a reasonable balance between the risks of committing either a Type I error or Type II error.

In addition to the Power tests, the standard error of the running mean against the number of observations for species numbers for each turbine and the combined control areas were plotted. This was performed as a qualitative portrayal of the sample variance in each area and as an aid to indicate whether the sample numbers collected successfully captured the variance present and reduced this to acceptable levels.

2.4 CMECS Biotope Classification

2.4.1 Description of CMECS

The CMECS habitat classification system (FDGC 2012) is the U.S. national standard adopted by the Federal Geographic Data Committee (FGDC). CMECS provides a common language for organizing and describing scientific information about ecological features in marine and lacustrine environments, including estuaries, coasts, oceans, and the Great Lakes. CMECS provides a catalog of standardized terms for distinct ecological units at respective levels within a classification hierarchy (**Figure 14**). This framework allows the user to incorporate geological, chemical, physical, and biological information into a single structure. The components can also be integrated to define habitats (referred to as biotopes), resulting in detailed and comprehensive classification outputs. In addition, the CMECS framework is sensor and scale independent. These features offer several advantages to its users, including the ability to classify any dataset (e.g., regardless of collection and processing methods, geographic and temporal scales, resolution, density, etc.); facilitate the integration of information from legacy, current, and future datasets; share and compare information across studies more readily; and be applicable to wide and multidisciplinary user base.

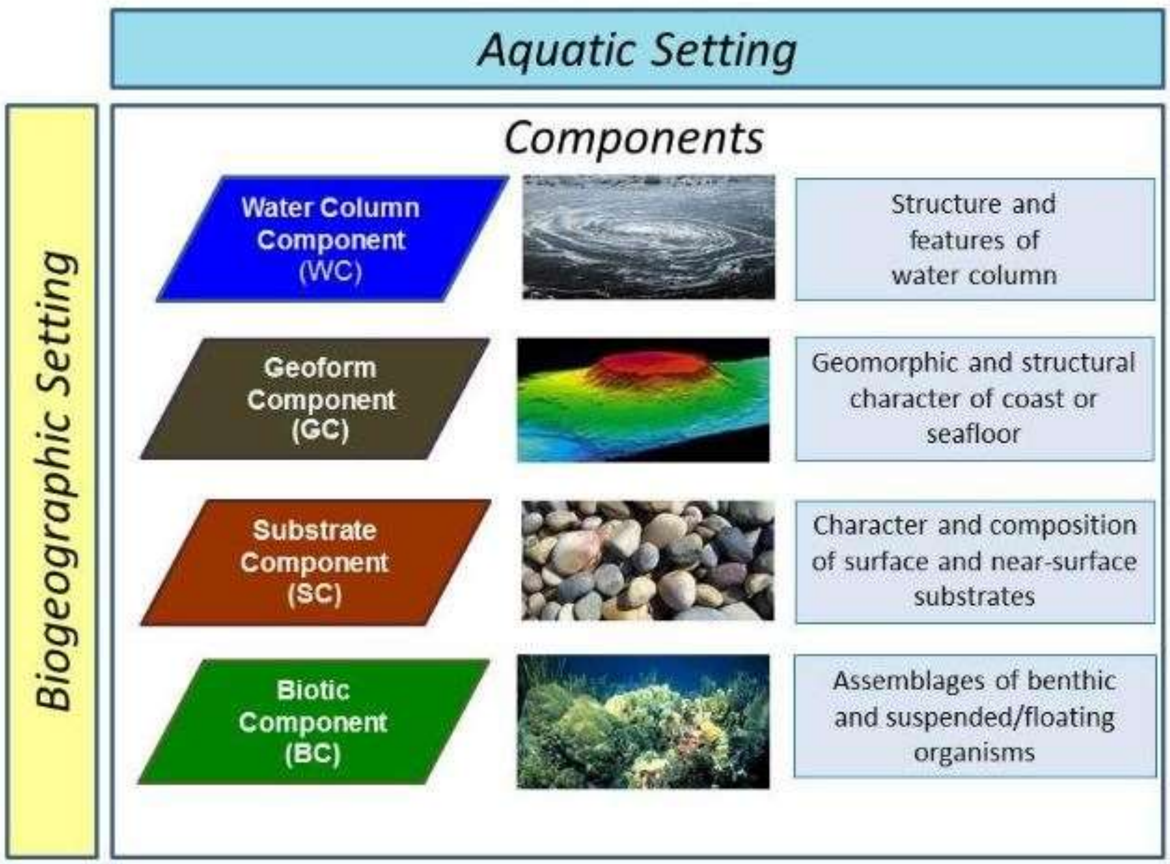


Figure 14. CMECS settings and components.

At the highest level of the organization, CMECS adopts the terms Marine System, Estuarine System, and Lacustrine System; these correspond to terms found in FGDC-STD-004 (FGDC 1996b). The marine and coastal environments are described in terms of two settings, Biogeographic and Aquatic, which offer alternate but complementary approaches for partitioning the marine and coastal world. The Biogeographic Setting identifies ecological units based on species aggregations and features influencing the distribution of organisms, therefore coastal and marine waters are classified as per Spalding et al. (2007) in Marine Ecosystems of the World (MEOW). The Aquatic Setting divides the coastal and marine environment into three Systems: Marine, Estuarine, and Lacustrine.

The CMECS framework also includes four Components (Geoform, Substrate, Water Column, and Biotic) that are used to define environmental and biological attributes within each setting. The Components can be used independently or in combination with one another. Within CMECS, biotopes, defined as "*combination of abiotic features and associated species*", are not defined, but can be “*derived by* *identifying repeating biotic communities that are consistently associated with combinations of environmental units from any of the other CMECS settings or components.*"

In this study, the Substrate, Geoform, and Biotic Components are applied. The Substrate Component is compatible with sediment-related elements of FGDC-STD-004 (FGDC 1996b). Substrate, natural or manmade, is defined in CMECS as the non-living materials forming an aquatic seafloor, or that provide a surface (e.g., floating objects, buoys) for growth of attached biota. Marine sediments traditionally have not been considered soils, therefore the Substrate Component follows the approaches of Wentworth (1922) to define sediment particle sizes and Folk (1954) to describe mixes.

The Geoform Component describes major geomorphic and structural characteristics. It is hierarchically organized into tectonic province, physiographic province, origin, geoform, and geoform type. In addition, the geoform subcomponent is comprised of two levels, with level 1 describing large scale features (typically > 1 square kilometer) and level 2 describing small-scale surficial characteristics (> 1 square kilometer).

The Biotic Component is hierarchically organized into biotic setting, biotic class, biotic subclass, biotic group, and biotic community. The biotic setting indicates whether the biota are attached or closely associated with the benthos or are suspended or floating in the water column. Biotic classes and biotic subclasses describe major biological characteristics at a coarse level. Biotic groups are descriptive terms based on finer distinctions of taxonomy, structure, position, environment, and salinity levels. Biotic communities are descriptions of repeatable, characteristic assemblages of organisms. Classes and subclasses of the biotic component are determined by the percentage cover of the substrate by the dominant biota; this approach refers to units identified in FGDC-STD-004 (FGDC 1996b). The system presents a protocol for the addition of new biotic groups and biotopes, which is modeled on the one proposed in FGDC-STD-005-008, and it also draws from the Marine Habitat Classification for Britain and Ireland (Connor et al. 2004).

2.4.2 CMECS Biotope Classification

The term "biotope" is specific in that it integrates biotic-abiotic data within a given area to offer more ecologically meaningful information. In this study, the Geoform, Substrate, and Biotic Component were integrated to define biotope classifications for the turbine areas. As such, biotopes reflect the relationship between macrofaunal communities and associated geological characteristics within the defined map units. In this study, the biotopes are considered preliminary because, although the biotic-abiotic relationships identified in this study are statistically significant and ecologically meaningful, they have not been demonstrated to be consistent through time, as this study represents the first of its kind at this resolution (i.e., very site specific, whereas the OSAMP was conducted at a regional scale).

Preliminary biotope classifications were determined for each of the three turbine study areas using a top-down classification approach following that of LaFrance et al. 2014. Extensive studies and discussion on 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. In this approach, biotope map units are geologically defined based on the presumption that geologic environments or features contain distinct biological assemblages.

The geological depositional environments that were developed and that served as the boundaries for the biotope map units in the OSAMP study by LaFrance et al. (2010) were also used in this study (refer to **Figures 5** through **7**). There were several reasons for this decision. First, these depositional environments are well-established. Second, comparison of side-scan and video data collected in this study to previous studies in the area suggests these units have not changed over time, and, thus are still relevant and accurately describe the geological characteristics of the BIWF study area (**Figure 2**). Third, the use of the same depositional environment as the biotope map units allows for more direct comparison of pre- and post- construction macrofaunal community structures and biotope classifications.

Following classification, the degree of distinctness among the defined biotope types was statistically assessed using the ANOSIM and SIMPER routines in PRIMER. ANOSIM was used to test the hypothesis that there are no differences between macrofaunal communities among biotope types. SIMPER was then used to assess the degree of macrofaunal similarity within each biotope type and the degree of similarity across biotope types, as well as examine the degree to which individual species contribute to the within-biotope similarity.

The biotope(s) within each turbine area were classified according to the dominant species and the associated geologic depositional environment within the given biotope unit. The nomenclature follows the Biotic, Geoform, and Substrate Components of the CMECS classification framework. Dominant species is defined as the species with the highest abundance combined across all of the macrofaunal samples present within the given biotope unit within the given turbine area. The classification was completed in ArcGIS (Esri ARCMap version 10.2) by color-coding and labeling each distinct biotope type.

3 Results

The cluster grab samples and underwater video were collected concurrently at 39 sample stations within three turbine and three control areas, for a total of 117 samples (refer to **Figures 10** and **11**, and **Table 3**). With the addition of the four QC samples, the final total is 121 samples. Samples are named according to turbine (T) or Control (C) area, followed by station number (1 to 9) and sample number (1 to 3). Therefore, the name T1-1_1 represents the first cluster sample taken at station 1 from Turbine 1, and the name C2-3_2 the same second cluster sample taken at station 3 within Control 2.

Grab sample and underwater video data acquisition occurred over three days between December of 2016 and March of 2017 (**Table 5**). The delay between sample days was because of inclement weather. However, that the sampling was completed over this time period is not considered to be concerning, as data from previous studies supports that this region is stable and that there are minimal seasonal effects (refer to Section 1.2 for further details). Also, all the samples were collected in the winter season, so the conditions were constant throughout the data collection period. Data from this study also supports that there are minimal seasonal changes. Specifically, **Figure 28** shows that the QC samples collected at each turbine in March of 2017 are comparable to the samples collected in December 2016 and January 2017.

Table 5. Dates of grab sample data collection.

Study Area	Number of Samples	Date of Data Collection
Turbine 1	27	20 December 2016
Turbine 3	27	
Turbine 5	27	20 January 2017
Control 1	12	
Control 2	12	
Control 3	12	21 March 2017
QC Samples	4	

3.1 Particle Size Distribution (PSD) Analysis

Detailed results of the sediment grain size are presented in **Appendix 2**. The sediment grain size analysis confirms the turbine and control areas are sandy environments, with all samples being dominated by medium or coarse sand (**Table 6, Figure 15**). Within the grab data, medium and coarse sand fractions, combined with very coarse sand, comprise greater than 90 percent of the sediment composition at 115 of the 121 sample. Regarding finer sediments, clay and silt sized particles were recorded within 14 of the 121 samples collected. These fractions were recovered in minimal quantities, comprising less than 1 percent of total sediment composition. Video data (see S**ection 3.2** below) recorded the presence of larger cobble and gravel sediments in places, as well as boulders at some stations in Control area 1.

The proportion of fine grain sand (particles of diameter 150–250 µm) within the samples varied between 0 and 17.9 percent (**Table 7**). Highest levels tended to be associated with Turbine 1 (mean 5.5 percent). Levels at stations at Turbines 3 and 5 were lower, averaging 0.7 percent (Turbine 3) and 1.6 percent (Turbine 5). Among the Control areas, the mean levels of fine sand were 0.1 percent, 4.5 percent, and 4.2 percent, for Control 1, 2, and 3, respectively.

The proportion of medium grade sand (particles of diameter 250–500 µm) within the samples varied between 2.9 and 62.2 percent. Highest levels tended to be associated with Turbine 1 (mean 49.6 percent). Levels at stations at Turbines 3 and 5 were, in general lower averaging 29.0 percent (Turbine 3) and 25.9 percent (Turbine 5). Among the Control areas, the mean levels of medium sand were 25.7 percent, 34.7 percent, and 43.9 percent, for Control 1, 2, and 3, respectively.

Table 6. Summary of grain size analysis of sediment samples collected within study areas.

Study Area	Total Samples	Number of Samples Where: Dominant Grain Size = Medium Sand	Dominant Grain Size = Coarse Sand	Combined Sand Fraction > 90%	Combined Clay and Silt > 0%
Turbine 1	28	20	8	25	0
Turbine 3	28	0	28	28	2
Turbine 5	28	3	25	28	4
Control 1	12	0	12	12	1
Control 2	12	2	10	10	6
Control 3	13	7	6	12	1

Note: All samples were dominated by medium or coarse sand and few samples contained any fine sediments. Sand fraction is defined as the combination of medium sand, coarse sand, and very coarse sand. Note for the combined clay and silt fractions, total contribution was less than 1 percent for all samples. Grain size fractions are classified according to the Wentworth scale.

Table 7. Average of each sediment grain size fraction across samples within each study area.

Study Area	Average Fraction of: Clay and Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand
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%

Note: The range of each grain size fraction within is study area is also provided. Grain size fractions are classified according to the Wentworth scale.

The proportion of the coarse sand fractions (particles of diameter 500–1,000 µm) across the study area varied between 28.8 and 64.0 percent. Highest levels were generally associated with Turbines 3 and 5 (mean 55.3 percent and 50.3 percent, respectively), whilst levels at Turbine 1 were comparatively lower (mean 41.6 percent). Values at the Control areas were 60.4, 48.4, and 45.9 percent at Control 1, 2, and 3, respectively.

The proportion of very coarse sand (particles of diameter 1,000–2,000 µm) within the samples varied between 0.5 and 42.3 percent. Highest levels tended to be associated with Turbines 5 and 3 (mean 22.1 and 17.9 percent, respectively). Levels at stations at Turbine 1 were lower, with an average of 3.4 percent. Among the Control areas, the mean levels of very coarse sand were 13.6, 11.5, and 6.0 percent, for Control 1, 2, and 3, respectively.

Examination of the distribution of sediment within each turbine area indicates grain size increases across the study area from Turbine 1 to Turbine 5 (refer to **Table 7** and **Figure 15**). Turbine 1 exhibits the highest fractions of fine and medium sand, and, conversely, the lowest fractions of coarse and very coarse sand. The sediment becomes coarser moving to Turbine 3, Turbine 5, and Control 1, which all share similar characteristics. These three areas have greater amounts of coarse and very coarse sand and less fine and medium sand, relative to Turbine 1. The Control 2 and 3 areas fall mid-way along this spectrum.

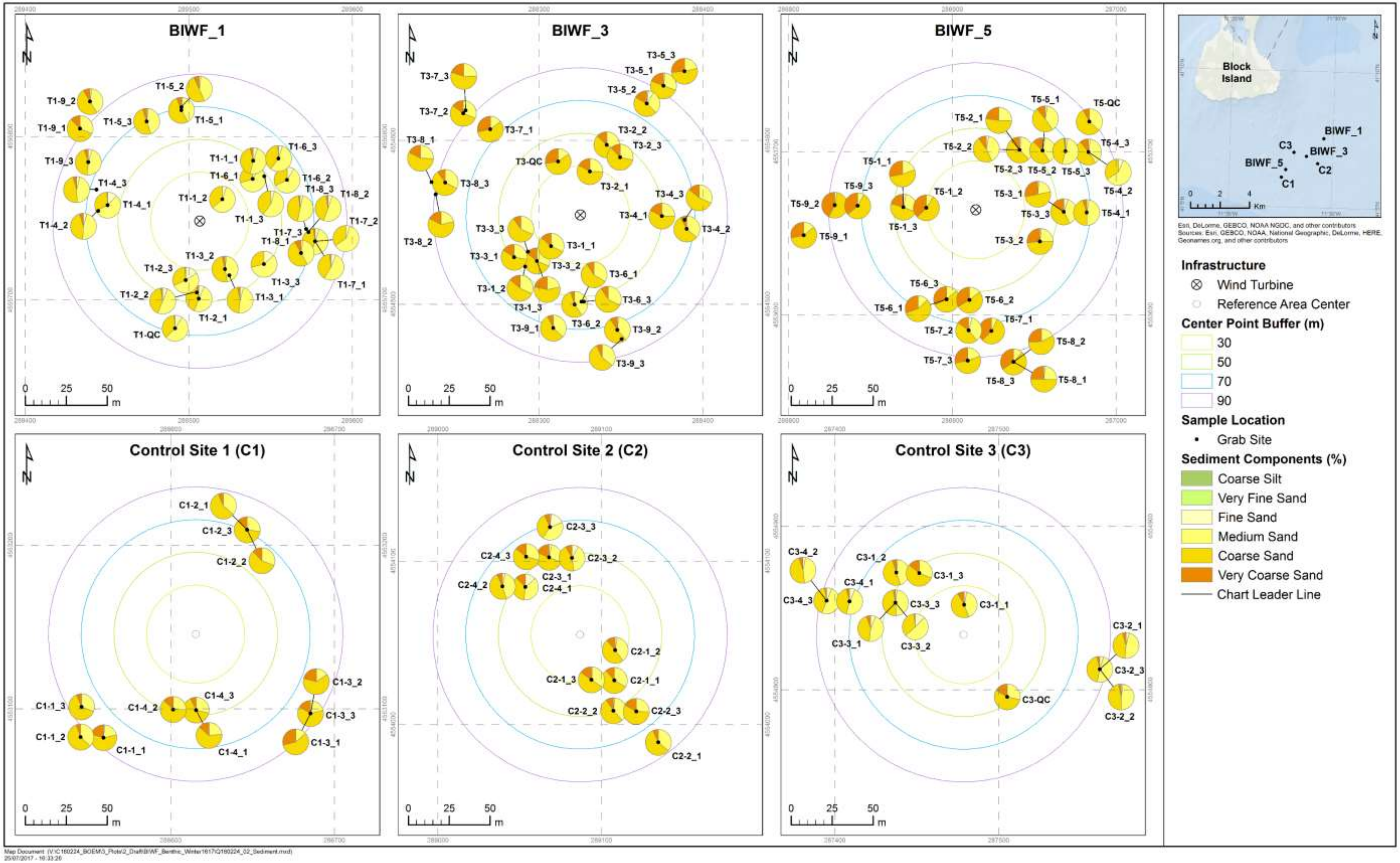


Figure 15. Distribution of sediment fractions (clay silt and fine, medium and coarse grade sand).

Scatter plots of the levels of combined clay, silt and fine sand particles (particles <250 µm) for all samples collected within the vicinity of each of the three turbines with respect to distance from turbine foundations revealed no strong correlations (**Figure 16**). Though, a weak inverse relationship (R^2 = 0.1912) of increasing fine sediment levels with decreasing distance to Turbine 1 was found.

3.2 Seabed Video and Photography Analysis

Visual analysis of the underwater video footage confirms the turbine and control areas are dominated by coarse seabed deposits, and also provides a details the distribution of various sediment types (e.g., boulders, cobble, gravel, sand) and overall homogeneity of the sample locations. With the exception of Control 1, the turbine and control areas were found to have comparable sedimentary environments, consisting of cobble, gravel and sand. Sand waves were visible at most of the sample stations. The overall geological environment of the area surrounding each sample site was noted to be homogeneous.

Contrastingly, Control 1exhibited areas of boulders, in addition to cobble, gravel, and coarse sand. Control 1 also contained the only two sample sites found to have areas of patchiness (e.g., alternating patches of cobble and gravel and of bare coarse sand). Acoustic data acquired for Control Area 1 (**Figure 11a**) further indicates a coarser and more topographically variable seabed at this location compared to the wider survey array.

Regarding biological features, shell hash was absent in 26 percent of the sample sites, present in small amounts in 62 percent of sites, and present in high densities at 12 percent of sites. Fauna was visible within the video footage collected at Turbine 5 and the three Control areas. Specifically, barnacles were present at 31 of these sample sites, starfish at 8 sites, bivalves believed to be *Astarte borealis* or *Astarte castanea* at 15 sites (all within Turbine 5), and spider crabs at one site. Detailed descriptions of the video analysis and a representative image from each sample site are presented in **Appendix 3**.

The seabed photography using the Lagrangian floating camera produced hundreds of images during each of the 15 total dives. Field survey records for the floating camera deployment are presented in **Appendix 4**. Example still images are presented in **Figure 17**. The high-resolution images allow for clear interpretation of the seabed, including geological characteristics (e.g., sand, gravel, boulders), biological characteristics (e.g., organisms, shell hash), and artificial features (e.g., concrete mats overlaid on portions of the buried cable). Photo mosaics for a subset of the turbine and control areas are also presented in **Figure 17**. These high-resolution mosaics present the turbine and control areas in a broader context and provide detailed information regarding heterogeneity. The imagery from the float camera further supports that Control 1 is a boulder and more variable environment than the remaining control areas and the turbine areas, which are more directly comparable to each other.

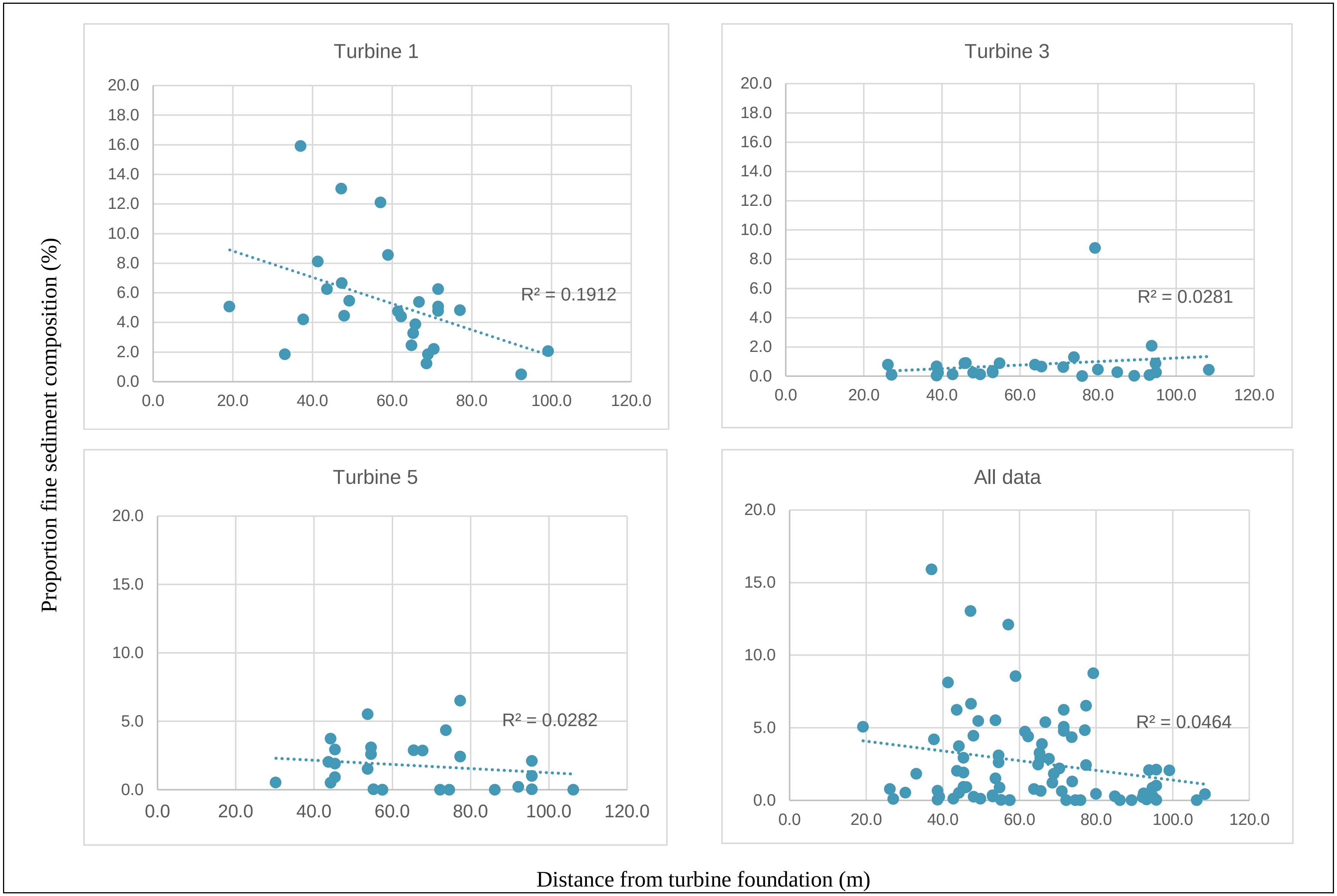
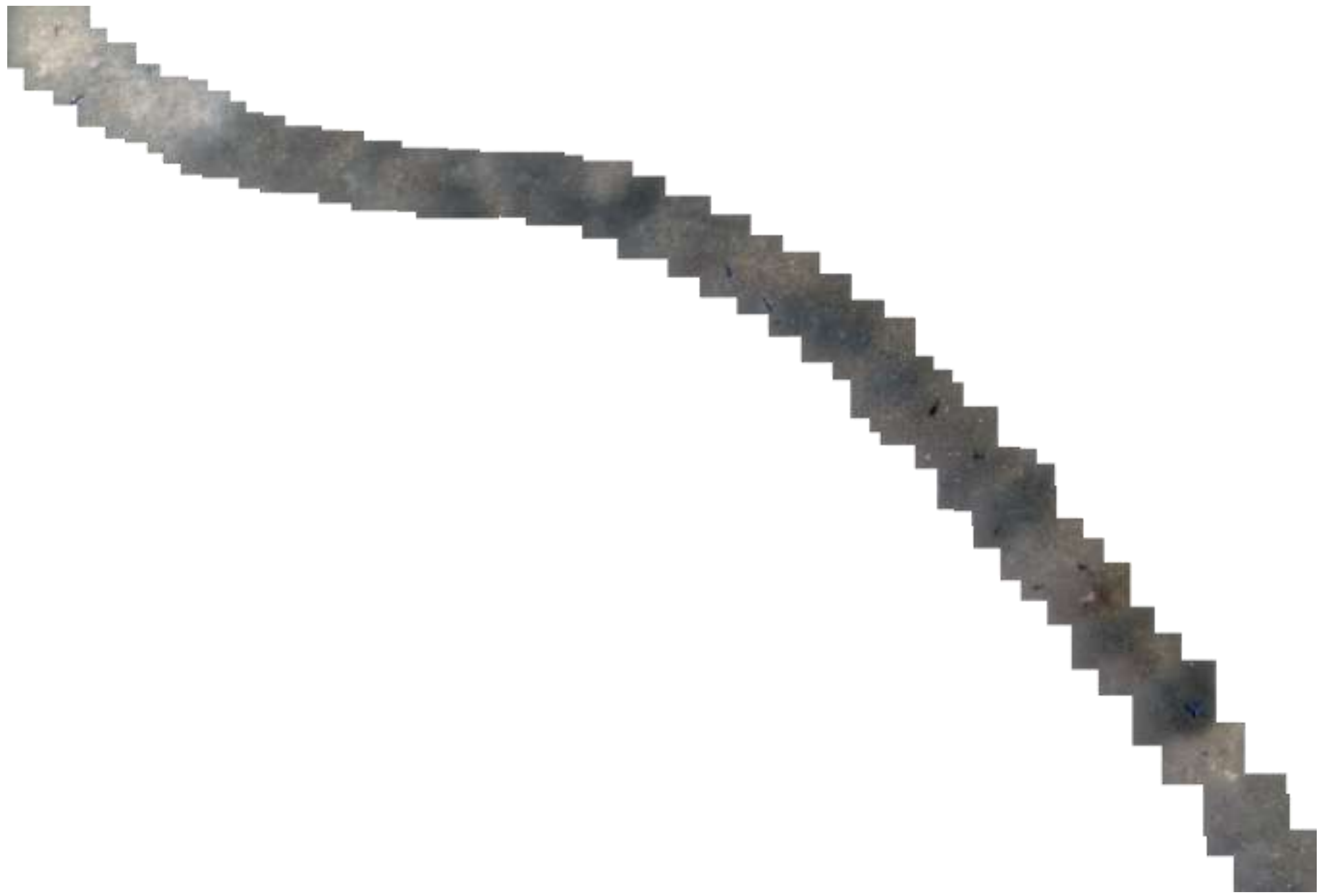


Figure 16. Proportion of fine sediment (particles <250 µm diameter) with distance from the center point under each turbine foundation structure at BIWF (refer to Section 2.1.2 and Figure 8).

Figure 17a. Example images and mosaics from float camera system. The images show (a) concrete mat overlaid on portions of the buried cable; (b) a winter skate over bare sandy seafloor; (c) school of scup (*Stenotomus chrysops*) and one longhorn sculpin (*Myoxocephalus octodecemspinosus*; dark fish in center right of image) above a gravelly seafloor mixed with shell hash; and (d) a bare gravelly seafloor.

(e)



(f)

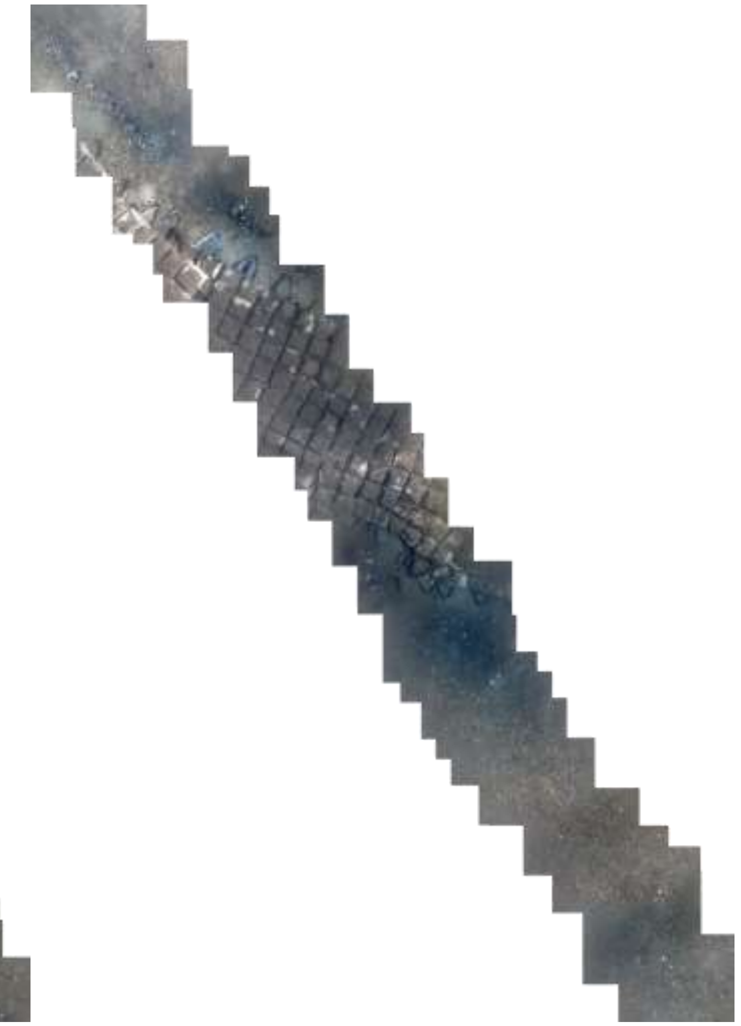


Figure 17b. Example images and mosaics from float camera system. The mosaics show (e) a portion of one transect completed by the float camera, in which fish and winter skates are clearly visible, as are transition zones between gravelly and sandy seabed environments; and (f) a segment of one transect showing a section of the concrete mat overlaid on a portion of the buried cable. Fish, shell hash, and sedimentary transition zones are also visible in this mosaic.

3.3 Sediment Organic Carbon

The results of the analysis of sediments for total organic and organic carbon content are presented in **Appendix 5**. Summary TOC levels with distance from each of the center point of the turbine foundations are presented in **Figure 18**. No significant relationship between organic carbon levels and distance from the turbine was evident.

Levels of organic content in the sediment samples collected ranged between 0 and 1 percent with an average of 0.4 percent for the entire study area. Average levels calculated for each turbine location and for each control area were broadly similar (0.4–0.5%) although a slightly lower average level of organic carbon was recorded for Turbine 1 (0.3%).

Levels of sediment organic carbon ranged between 0 and 0.5 percent and averaged 0.2 percent across the study area. Average levels calculated for turbine and control were again broadly comparable between turbine and controls areas (0.2%) but were lower at Turbine 1 (0.1%).

3.4 Relationships Between Environmental Samples

Investigation of the biotic-abiotic relationships revealed sediment type is influential in determining macrofaunal community composition. Specifically, in the nMDS plot, macrofaunal samples separate out to a large degree based on dominant grain size (as recovered in each grab sample) (**Figure 19**).

Principal Components Analysis (PCA) (**Figure 20**) indicated a combination of fine, medium and coarse sand contributed most to the variation between environmental samples (38.2%), as is evident along the PC1 axis. Coarse silt, very fine sand and organic matter were also important contributors to the sample variation, though to a lesser degree, as illustrated by the distribution of samples along the PC2 axis (21.5%). The PCA plot also shows that, on the whole, there was little spatial separation between control samples and those collected at each of the turbines suggesting that the control locations were generally representative in terms of grain size, depth and organic content. Three samples lie outside of the principal cluster mainly because of differences in gran size. These include samples C2_3.3 and C3_3.2 which contained comparatively high levels of fine and very fine same, silt and clay and sample C1_1.1 which contained comparatively high concentrations of sediment organic matter. The other control samples, however where clustered together with those collected at the turbines in the PCA ordination. In this respect, control stations were generally well chosen and are recommended for use in subsequent monitoring surveys.

Overlaying the nMDS ordinations by sample location (i.e., turbine) further support that there is a gradual shift in macrofaunal community composition across the study area, likely associated with the continuum of increasing sediment grain size moving from Turbine 5 to Turbine 1.

3.5 Macrofaunal Analysis

3.5.1 Overall Results

A total of 139 macrofaunal species represented by 18,315 individuals were recorded from the grab samples. A species abundance matrix is presented in **Appendix 6**. Summary species statistics including species richness, abundance and derived univariate measures for each sample are presented in **Appendix 7**. The majority (96.5 percent) of recovered macrofauna were annelids (i.e., polychaetes), nematodes, and crustaceans (i.e., amphipods) (**Figure 21**). By phylum, the dominant faunal group was Annelida, all of which were polychaetes except one Oligochaeta species (with 42 individuals found within 14 samples). These polychaetes accounted for 61 percent of the total abundance and 42 percent of the total numbers of species.

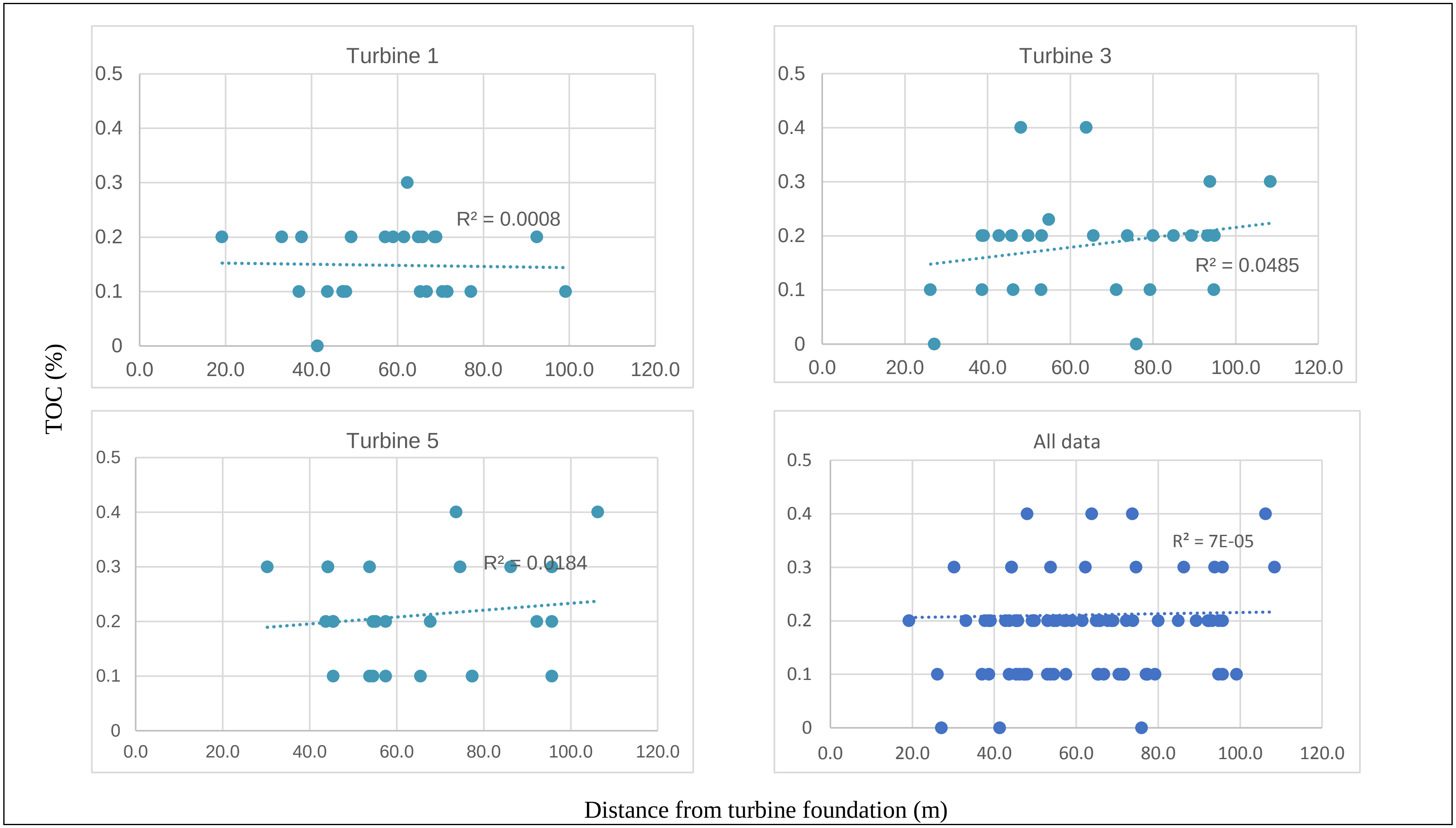


Figure 18. Levels of sediment % organic carbon with distance from the center point under each turbine foundation structure at BIWF (refer to Section 2.1.2 and Figure 8).

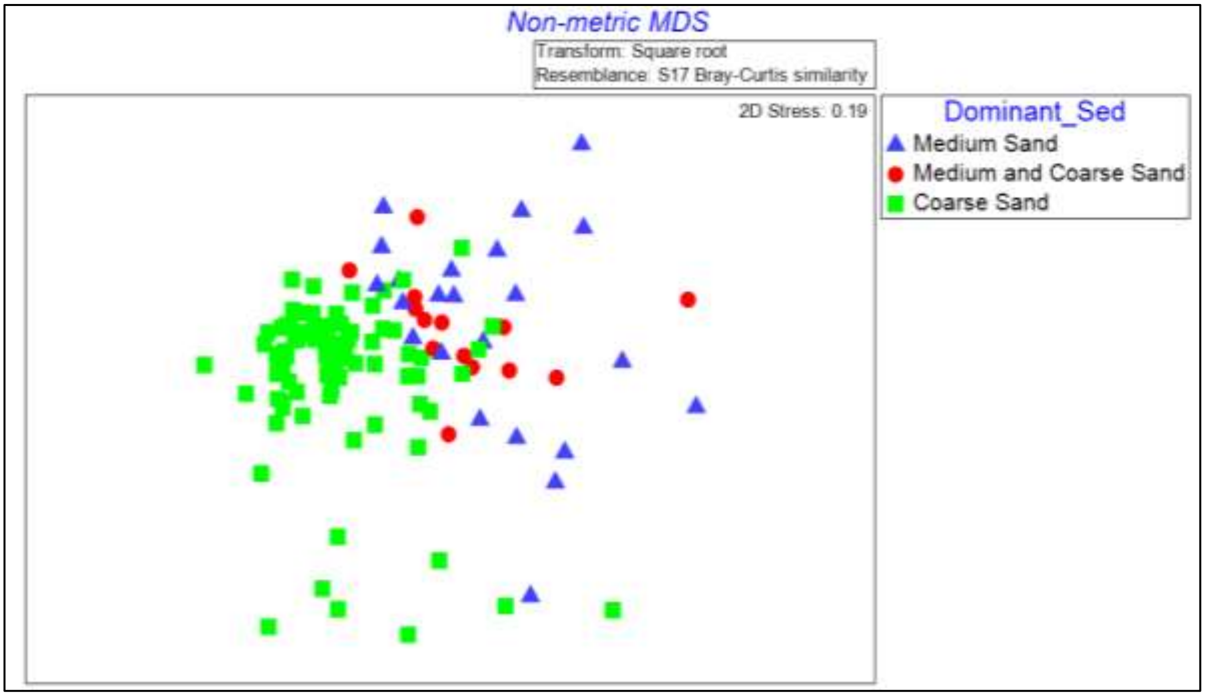


Figure 19. nMDS plot of turbine samples coded by dominant sediment type, as recovered in each grab sample.

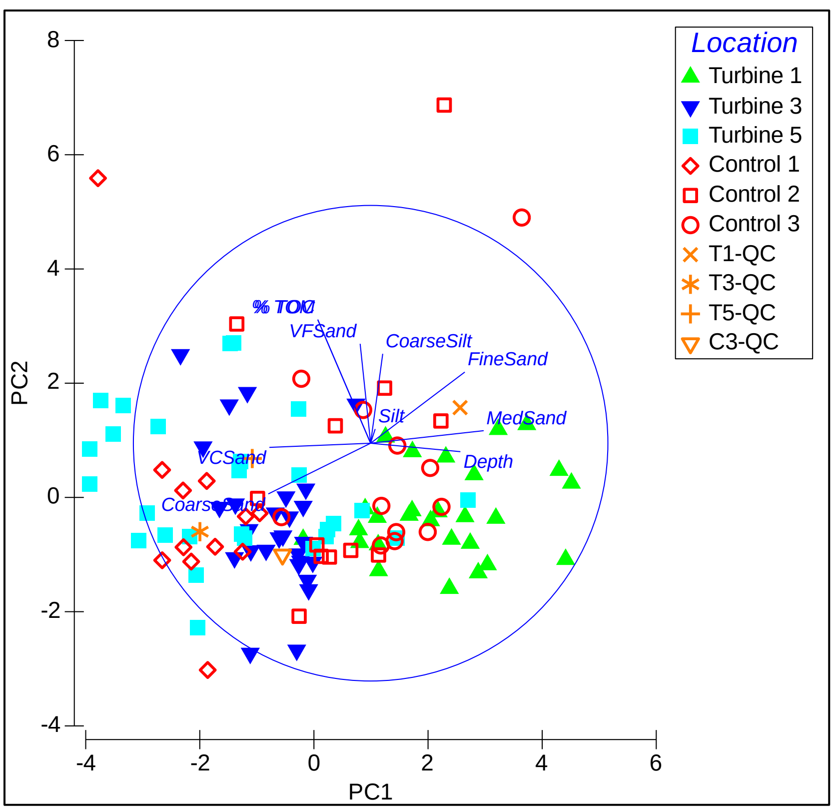


Figure 20. PCA ordination of environmental data (grain size, organic content and depth) (Euclidean distances) (normalized data).

(a)

(b)

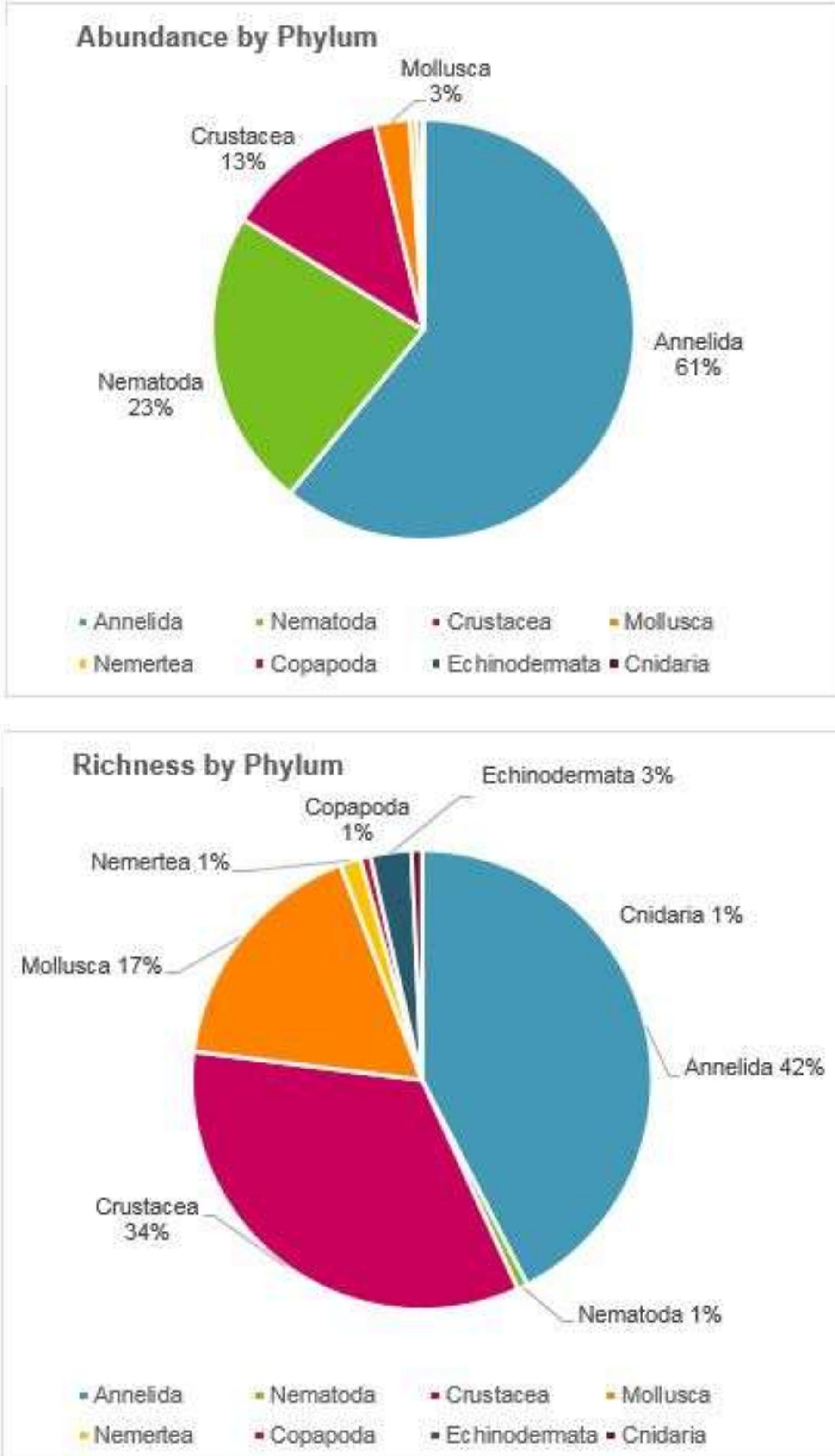


Figure 21. Proportion contribution of each faunal group (by phylum) to the (a) total abundance and (b) total species richness.

The second dominant phylum was Nematoda, comprising 23 percent of all fauna. Nematodes were identified to the phylum level, and, therefore, the number of species present cannot be provided. Crustaceans, principally amphipods, were 12.5 and 34 percent to the total species abundance and richness, respectively. The remaining phyla were Molluska, Nemertea, Copepoda, Echinodermata, and Cnidaria, with a combined contribution of 3.5 and 23 percent to the total abundance and richness, respectively.

Spatially, polychaetes, nematodes, crustaceans, and mollusks were broadly distributed over the BIWF study area, being recovered within 121, 119, 115, and 103 samples, respectively, of the 121 total samples. Polychaetes dominate 27 and co-dominate 57 samples, and nematodes dominate 25 and co-dominate 49 samples. Polychaetes and/or nematodes dominate or co-dominate all of the samples collected, with the exception of one sample within Turbine 1, one sample within Turbine 5, and eight samples within the Control areas. Within these ten samples, five are dominated by amphipods and five by the barnacle, *Balanus Amphitrite*. Amphipods and barnacles also co-dominate 14 samples within Turbine 1 (9) and Control areas (4).

The most conspicuous species present across all samples within both the turbine and control areas, in terms of highest overall abundances, include the polychaetes *Polycirrus eximius, Polygordius* spp., *Lumbrinereis acuta, Pisione* sp., *Goniadella gracilis, Spirorbis* sp., *Sabellaria vulgaris, Parapionosyllis longicirrata, Aricidea catherinae* and *Cirrophorus* sp. (**Table 8**). Also abundant are the amphipods *Unciola irrorata, Ampelisca vadorum, Erichthonius rubricornis, Tanaissus psammophilus, Gammaropsis maculata* and *Corophium* spp, as well as the barnacle *Balanus amphitrite*. Although comparatively less well represented within the samples, key mollusk species included the bivalves *Mytilus edulis, Spisula solidissima* and *Lyonsia arenosa*.

Despite being numerically superior, a number of these species were patchily distributed (refer to **Table 8**). Populations in some instances appeared to be highly localized and limited to a few grab samples only. For instance, high numbers of *Spirobis* spp. (650 individuals) were recorded in one of the cluster samples collected from Control 1 (sample R1-1_2), but only one individual of this species was recorded within the other two cluster samples collected at this station.

Elsewhere, *Spirorbis* sp. only occurred at two other sample stations at densities between 1 and 50 per sample. Additionally, high numbers (225 individuals) of the polychaete *Sabellaria vulgaris* (sand builder worm) were recorded within one of the samples collected at Turbine 1 (sample T1-3_30, but was only present at 21 additional stations (40 samples) at densities between 1 and 41 individuals per grab. Also, 102 individuals of the barnacle *Amphibalanus amphitrite* were recorded within sample R3-4_2, but this species was absent from the other two samples collected at this station and was only found at a further 15 stations (within 27samples) throughout the study areas.

3.5.2 Cluster Samples

Investigations of the similarity of macrofaunal community composition among cluster samples indicates some variability is present. While there were some cluster samples that were collected close together (<3 m) and some that were separated up to 40 m, most of the cluster samples were taken within 5 to 20 m of one another and within one distance band (refer to **Figures 10a, b &c** and **Figures 11a, b & c**). As such, the variability that exists represents changes in macrofaunal community composition across small spatial scales (i.e., tens of meters). Evidence of this variability is shown in the nMDS plot (**Figure 22**) and SIMPER analysis. SIMPER reports the average similarity of cluster samples within a given sample station ranges from 28.32 to 76.44 percent, with most stations exhibiting a similarity between 50 and 69 percent (**Table 9**). The range of similarities is lowest at Turbine 1 (**Table 10**). Turbine 3, Turbine 5, and the control areas all have higher and comparable ranges.

Table 8. Top 10 most abundant and frequently occurring species across all study areas.

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

Most frequent			
Species	**Taxonomic Group**	**Total Abundance**	**Occurrence (n=121)**
Nematode	Nematoda	4,196	119
Polygordius	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

Table 9. Summary of similarity ranges exhibited by cluster samples within a given sample station.

SIMPER Similarity Range	Occurrences (n=39)
28% - 35%	4
36% - 49%	7
50% - 69%	21
70% - 77%	7

Table 10. Summary of SIMPER results showing ranges of similarities of macrofaunal communities within cluster samples across all study areas and individual study areas.

	SIMPER Similarity Range
All Areas	28.32% - 76.44%
Turbine 1	28.32% - 48.68% (with the exception of one station with 59.64% similarity)
Turbine 3	56.90% - 71.23%
Turbine 5	50.55% - 76.44% (with the exception of one station with 37.08%)
Control 1	51.54% - 71.27% (with the exception of one station with 35.55%)
Control 2	52.02% - 67.48%
Control 3	53.64% - 66.36% (with exception of one station with 32.75%)

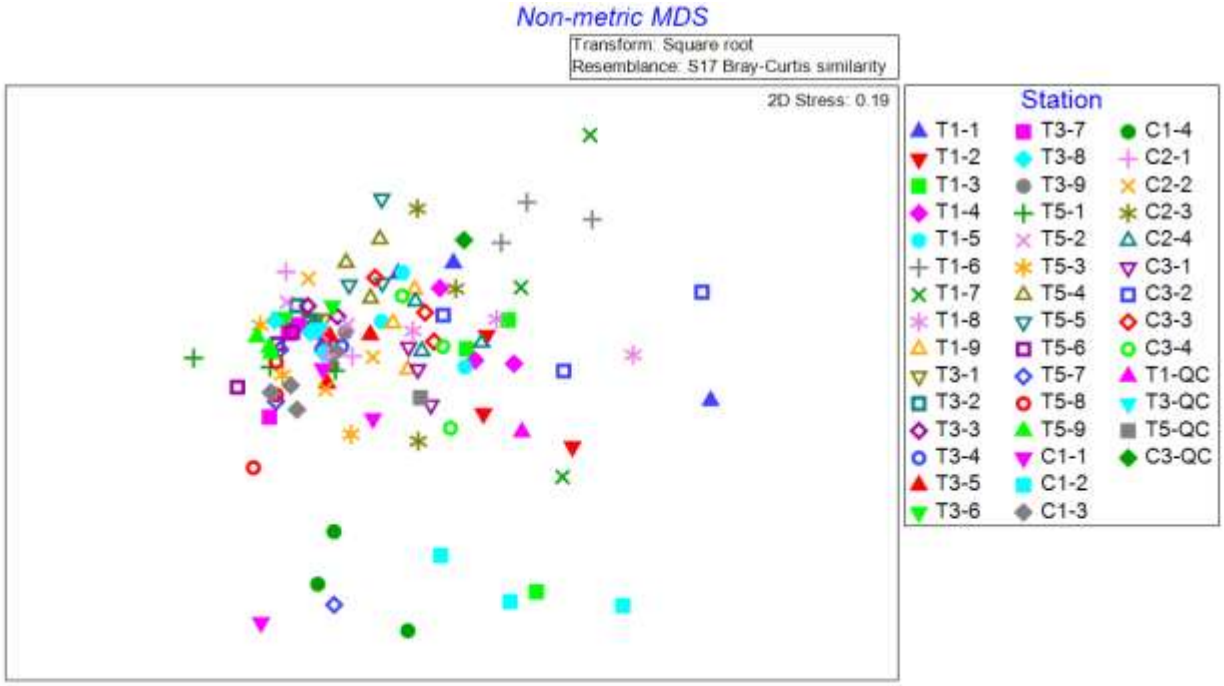


Figure 22. Non-metric MDS plot of cluster samples at each sample station.

Variability within cluster samples is further evident through detailed examination of the dominant species at a given station. Within some stations, cluster samples are dominated by the same species, whereas at other stations, each cluster sample is dominated by a different species, and, yet, at other stations, the pattern is somewhere in the middle of the spectrum. These analyses support the need for following a cluster sampling strategy (or similar strategy) to account for the small-scale spatial variability and complex structure of benthic macrofaunal communities. Combined, the cluster samples provide a more comprehensive understanding of the sample stations and the study areas.

Examination of data in terms of the phylum represented by the dominant species within each sample reduces the variability. Further amalgamating the entire macrofaunal dataset based on phylum, rather than species, eliminates variability among cluster samples almost entirely. However, the trade-off for this is resolution, with 109 samples being dominated or co-dominated by polychaetes, and the remaining 12 samples by crustaceans. This generalization greatly reduces the ability to identify patterns in the data.

3.5.3 Comparison of Grouped Turbine and Control Areas

The data suggests that there are no substantial differences between the macrofaunal communities within the turbine and control areas when considered as two general groups. The nMDS plot shows there is no clear separation between the two groups (**Figure 23**). The ANOSIM results also support this finding, having an R value of 0.18 ($p = 0.001$), which indicates the two areas are not very distinct with respect to one another. Furthermore, the SIMPER analysis shows the similarity among all samples collected is fairly high (38.92 percent). SIMPER also reports that similar species, primarily polychaetes, are responsible for the overall similarity within each group, including *Nematoda*, *Goniadella gracilis*, *Polygordius* spp., *Lumbrinereis acuta*, and *Polycirrus eximius*.

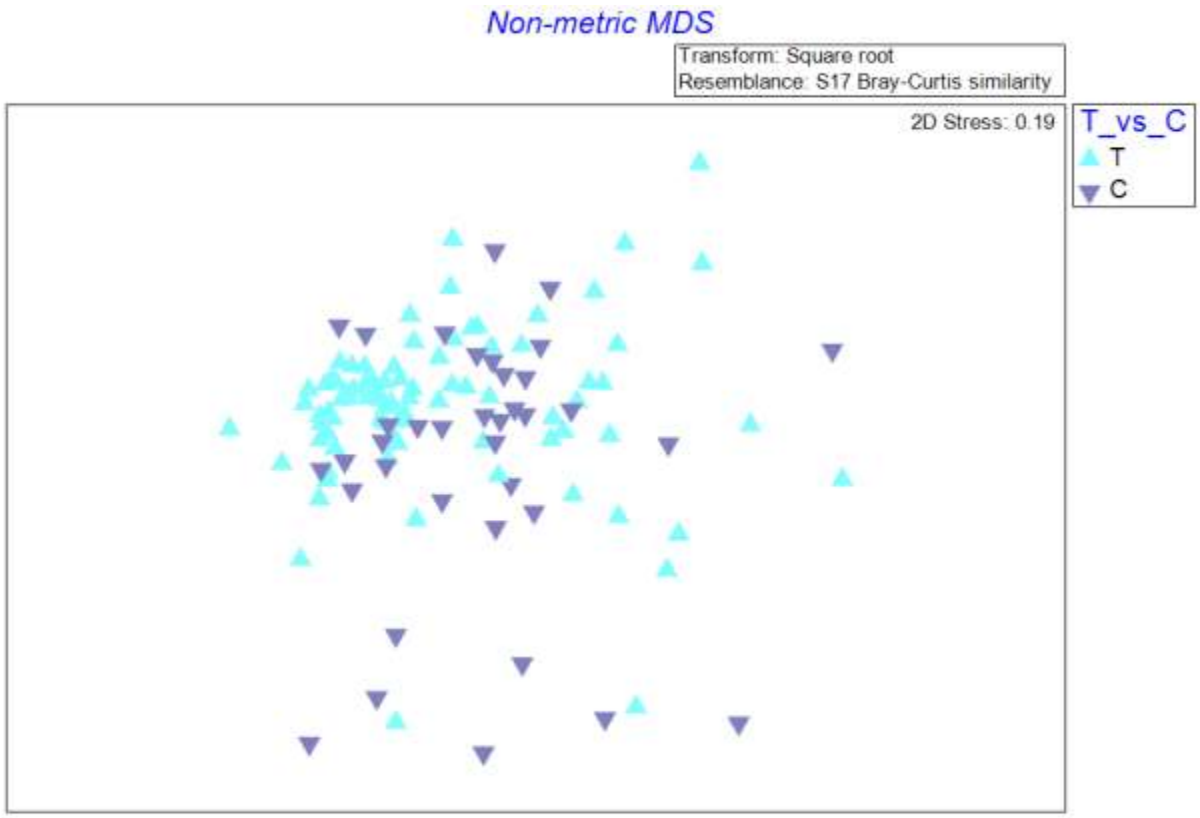


Figure 23. Non-metric MDS plot of Turbine versus Control areas.
Note: The plot shows that there is no clear distinction between sample groups.

Further ordination of the faunal data based on the month of sampling suggested that despite the survey being conducted over December, January and March, this had had little or no effect on macrofaunal composition.

3.5.4 Comparison of Individual Turbine and Control Areas

Macrofaunal patterns of species richness, abundance, the Shannon Weiner index of diversity (H') and the Margalef's index of richness (d') are broadly comparable across all of the individual study areas (**Figures24-26**). These figures also show that there are no clear patterns in spatial distribution with respect to the turbine or control areas. Specifically, species richness was similar across the turbine and control areas, ranging from 64 to 80 species (**Table 11**). The mean species richness within a given area ranged from 16.6 species to 22.6 species, although the variance around the mean differed considerably, particularly amongst the control samples (**Figure 27**).

Species abundance varied across the turbine areas, with Turbines 3 and 5 both having substantially higher abundances (approximately 5,000 individuals) compared to Turbine 1 (approximately 2,000 individuals) (refer to **Table 11**). Abundances within the control areas were comparable (approximately 1,500 to 2,200 individuals).

The mean value of the Shannon diversity index (H') was comparable across Turbines 1 and 3 and the combined control areas (ranging between 2.16 to 2.28) but was lower at Turbine 5 (1.184). A similar pattern was recorded for mean values of Marglalef's richness index (d). This measured 3.79 and 3.82 at Turbines 1 and 3 respectively but was lower at Turbine 5 (3.23) (**Table 11**). Mean richness for all the control areas was comparatively high (4.42).

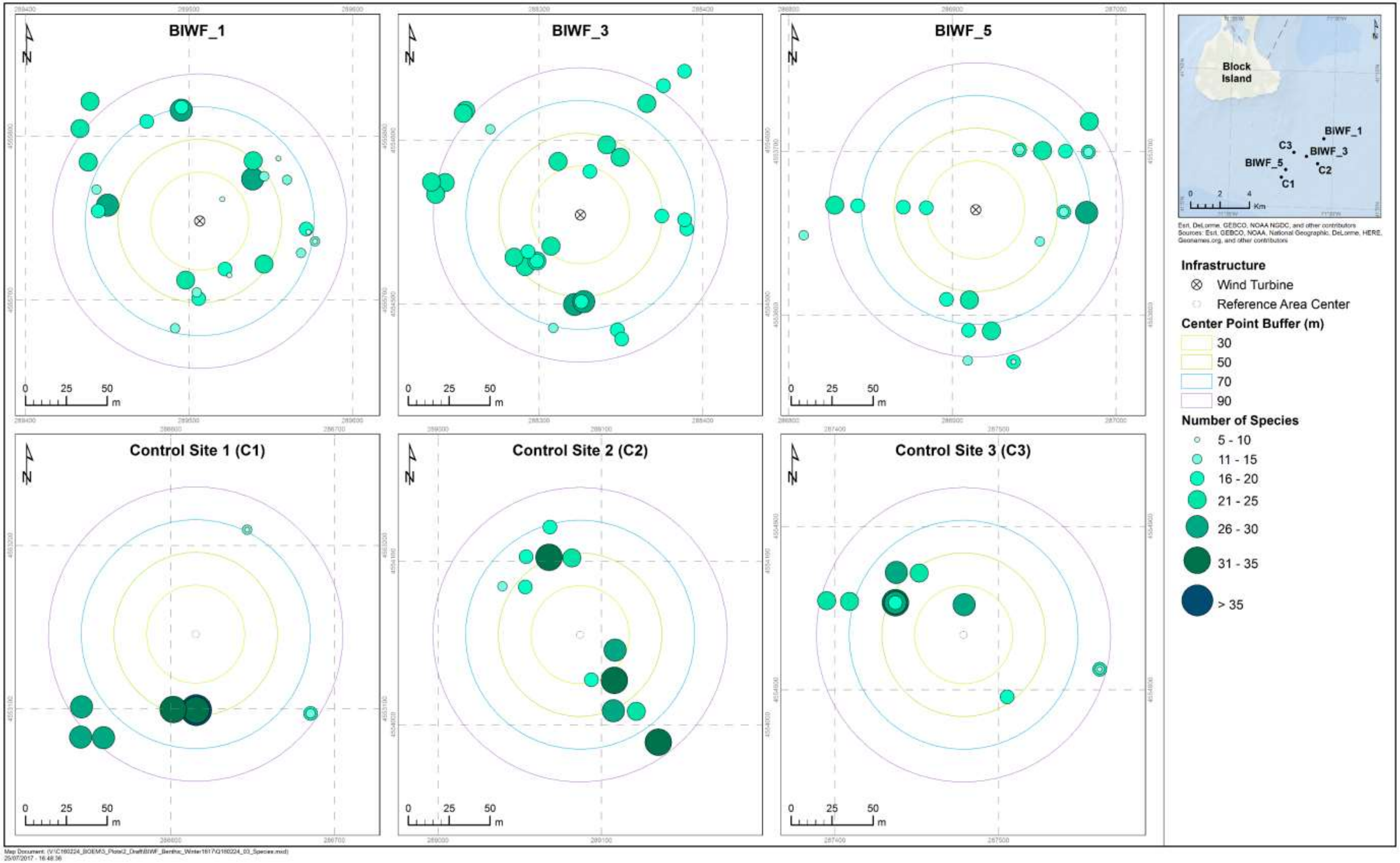


Figure 24. Distribution of numbers of species.

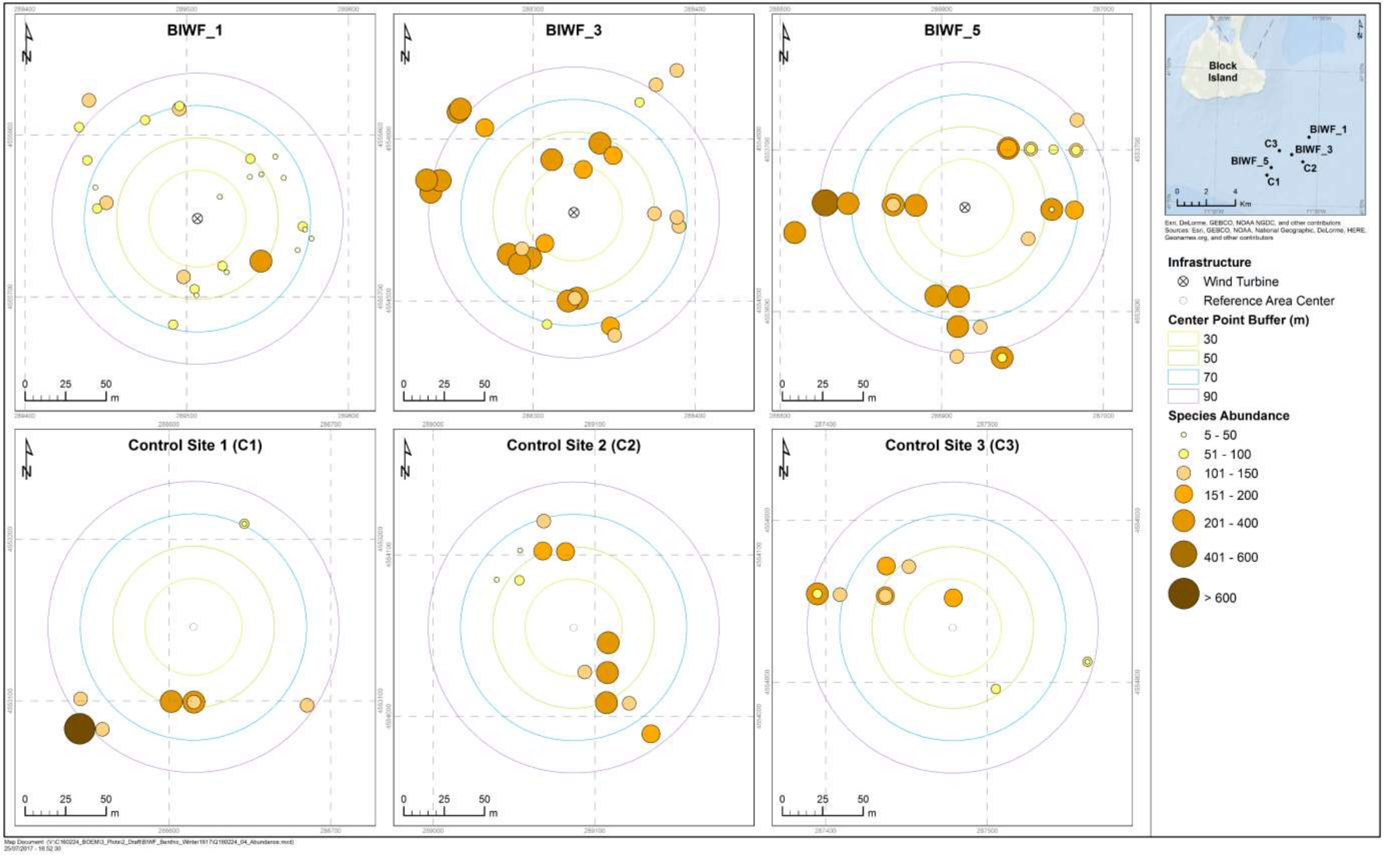


Figure 25. Distribution of numbers of individuals.

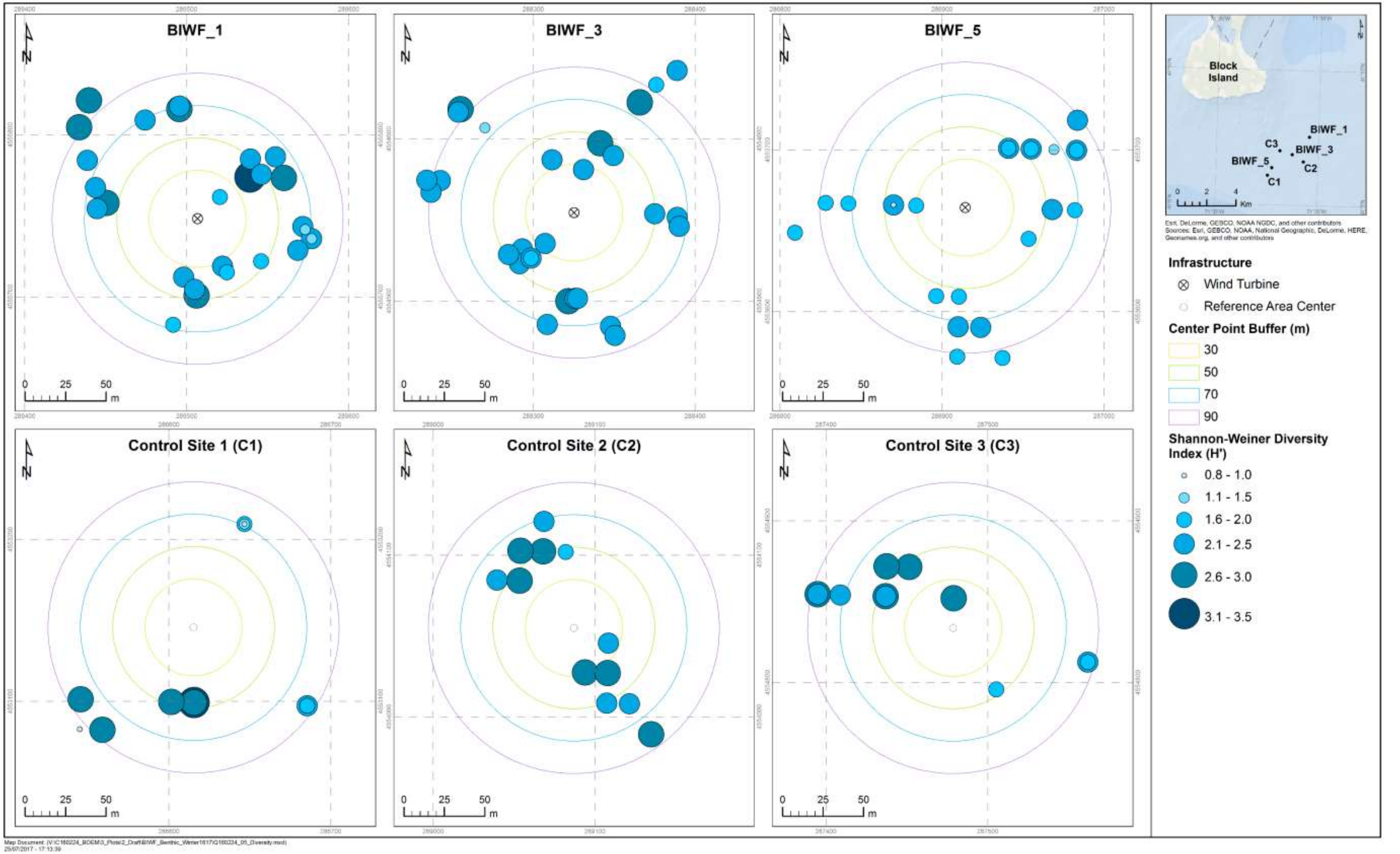


Figure 26. Distribution of the Shannon Weiner index of diversity (H').

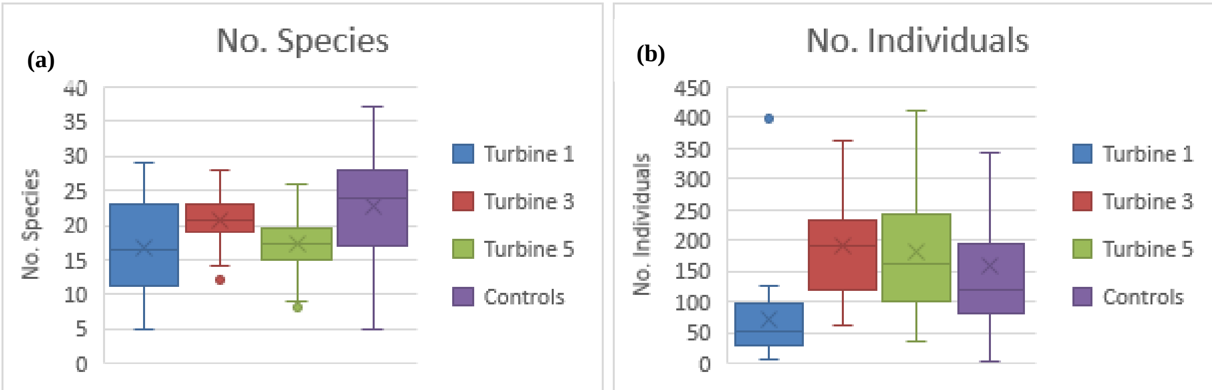


Figure 27. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of (a) species richness (a) and species abundance at each turbine station and across all reference areas.

Table 11. Summary of macrofaunal indices. (Excludes QC samples totalling 510 individuals_.

	Total Species Richness	Total Species Abundance	Mean Species Richness	Mean Species Abundance	Mean Diversit y (H)	Mean Richness (d)
Turbine 1	78	1,939	16.6	71.1	2.18	3.82
Turbine 3	64	5,182	20.7	191.9	2.21	3.79
Turbine 5	80	4,925	17.3	182.4	1.84	3.22
Control 1	77	2,213				
Control 2	69	2,092	22.6	160.0	2.26	4.42
Control 3	66	1,454				
Total (excl. QC samples)	139	17,805				

Assessment of macrofaunal community structure at individual turbine and control areas using a nMDS plot shows sample stations are fairly clustered together and exhibit a high degree of overlap (**Figure 28)**. This suggests macrofaunal community structure is not highly unique with respect to individual areas. ANOSIM, though, reports an R value of 0.459 (p=0.001), which suggest there is distinction within each of the six areas. The pair-wise tests between turbines and control areas was repeated using Permanova and confirmed significant differences between all groups of turbine and control sample data (p(perm) <0.0001), as indicated by the ANOSIM.

Furthermore, a PermDisp test (**Table 12**) revealed significant differences in terms of the relative dispersions of community structure between all pair-wise comparisons except for the comparison between Turbine 1 and the control areas. With regards to the individual mean data dispersions (**Table 12**) community data was less disperse at Turbine 3 compared to that for the other turbines and grouped control areas. This may be visually represented, in part, within the nMDS ordination of faunal data coded with study area (**Figure 28**) and which shows a tight clustering of Turbine 3 samples whilst the other turbine samples are comparatively more dispersed.

Table 12. Mean and pairwise comparison of multivariate dispersion of faunal sample data.

Mean Dispersions				Pairwise Comparisons		
Group	Size	Average	SE	Groups	t	P(perm)
Turbine 1	27	42.363	1.8408	(Turbine 1, Turbine 3)	7.6917	1.00E-04
Turbine 3	27	26.055	1.0519	(Turbine 1, Turbine 5)	2.8977	1.18E-02
Turbine 5	27	34.219	2.1236	(Turbine 1, Control)	0.85726	0.4513
Control	36	44.545	1.7179	(Turbine 3, Turbine 5)	3.4448	2.40E-03
				(Turbine 3, Control)	8.4599	1.00E-04
				(Turbine 5, Control)	3.8178	1.90E-03

SE = standard error

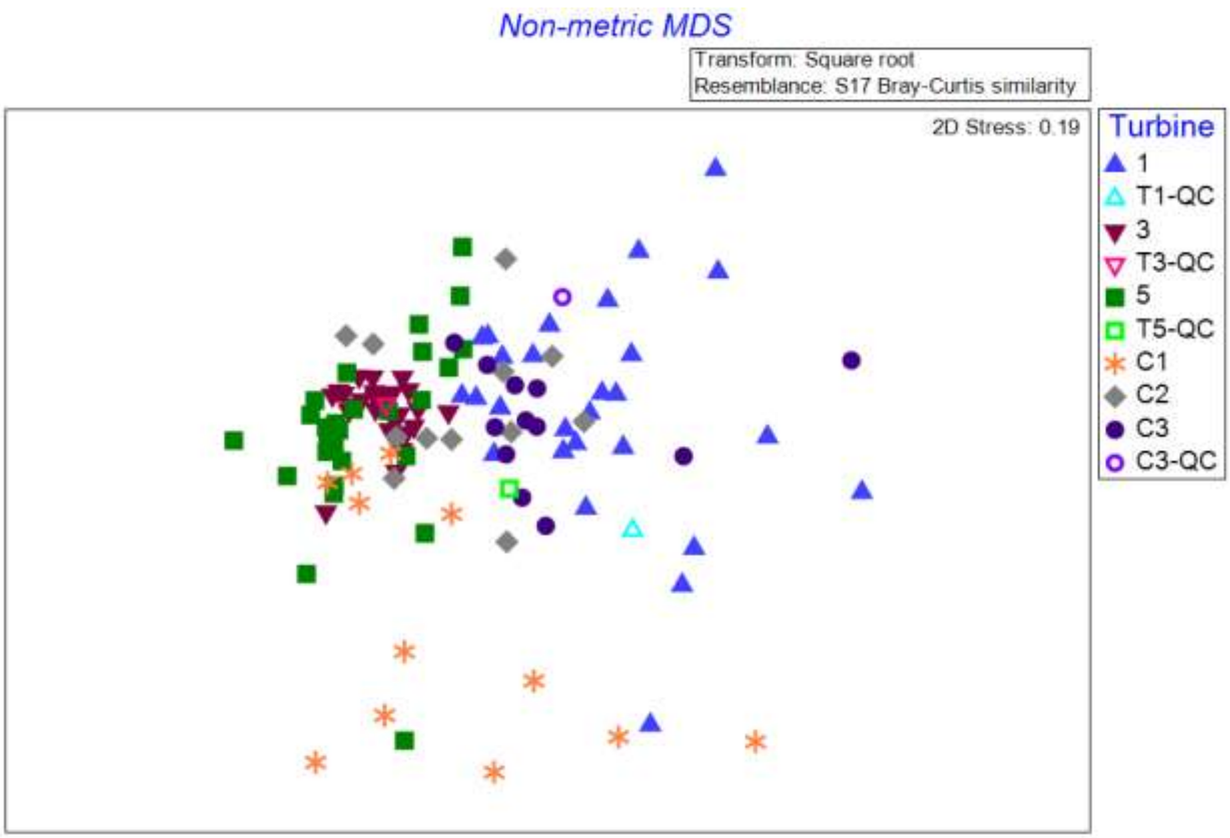


Figure 28. Non-metric MDS plot of samples collected within each turbine and control area.
Note: The plot shows no distinct separation of any of the study areas (turbine or control). Some possible exception is seen with some of the samples in Control 1 and one sample from Turbine 1 and 5.

A closer inspection of the species characterizing each turbine and control area shows broad agreement in dominant species and general composition across the different areas, although differences in species abundances were apparent (**Tables 13** and **14**). This discrepancy in species abundances, rather than the species composition, between areas likely accounts for the differences in macrofaunal community structure identified in the ANOSIM and Permanova tests. Dominant species include Nematodes, *G. gracilis*, *P. eximius*, *Polygordius* spp, *L. acuta, Scoletoma fragilis, U. irrorata, S. vulgaris* and Maldanidae, all of which were common to two or more of the turbine and control areas. Conspicuous difference in species identities between areas were not apparent.

Table 13. Top five dominant species within each turbine area.

	Dominant Species	Taxonomic Group	Abundance	Occurrence (n = 27)
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

Table 14. Summary SIMPER analysis to compare species identities across turbine and control areas (untransformed data).

Turbine 1		Turbine 3		Turbine 5		Controls	
Species	**Mean No.**	**Species**	**Mean No.**	**Species**	**Mean No.**	**Species**	**Mean No.**
Nematoda	9.7	Nematoda	49.78	Nematoda	55.59	Nematoda	28.14
Goniadella gracilis	6.3	*Polycirrus eximius*	31.37	*Polycirrus eximius*	31.96	*Polygordius*	7.14
Polygordius	6.3	*Pisione*	23.89	*Polygordius*	31.85	*Goniadella gracilis*	10.97
Unciola irrorata	3.7	*Lumbrinereis acuta*	17.63	*Pisione*	16.07	*Lumbrinereis acuta*	9.44
Nephtys bucera	2.11	*Polygordius*	17.81	*Lumbrinereis acuta*	14.26	*Unciola irrorata*	6.61
Sabellaria vulgaris	14.15	*Goniadella gracilis*	6.41	*Goniadella gracilis*	4.96	*Amphibalanus Amphitrite*	9.58
Lumbrinereis acuta	3.89	*Aricidea (Acmira) catherinae*	6.41			*Polycirrus eximius*	5.94
Kirkegaardia baptisteae	1.22	*Cirrophorus*	6.22			*Ampelisca vadorum*	11.78
Parapionosyllis longicirrata	1.52	Maldanidae	4.56			*Pisione*	5.28
Scoletoma fragilis	0.96					*Sabellaria vulgaris*	3.89
Tanaissus psammophilus	0.81					*Scoletoma fragilis*	2.44
Maldanidae	1.44					*Maldanidae*	2.03

The separation of samples in Control 1 (C1) likely reflects a more distinct macrofaunal community structure because of clear differences in environmental characteristics relative to the other study areas, most notably the presence of boulders (as identified in the video footage), coarser substrates, as evidenced by the acoustic data, and shallower water depths, rather than activities associated with the BIWF project.

Although the macrofaunal communities were not found to be highly unique to their respective areas, patterns are still present. For example, the nMDS plot indicates that macrofaunal communities within Turbine 1 are more variable (**Figure 28**), which is supported by SIMPER results stating sample stations within Turbine 1 exhibit the lowest average similarity (38.91 percent), versus Turbine 3 (62.49 percent) and Turbine 5 (50.49 percent). Additionally, the nMDS plot suggests macrofaunal community composition changes along a gradient moving across the BIWF study area from Turbine 1 to 5.

There is also substantial evidence to indicate macrofaunal communities at Turbines 3 and 5 are more similar to one another compared to Turbine 1 (e.g., refer to **Tables 13** and **14**, and **Figure 28**). More detailed examination of the nMDS plot further elucidates this pattern (**Figure 29**). SIMPER complements the nMDS plot, reporting an average similarity of 53.69 percent for Turbine 3 and 5 samples combined. Comparatively, the combined averaged similarities for Turbines 1 and 3 and for Turbines 1 and 5 are 41.93 and 37.01 percent, respectively. ANOSIM also shows the same pattern, with Turbines 3 and 5 exhibiting the lowest degree of distinction (R = 0.251, p = 0.001), compared to Turbines 1 and 3 (R = 0.582; p = 0.001) and Turbines 3 and 5 (R = 0.552; p = 0.001).

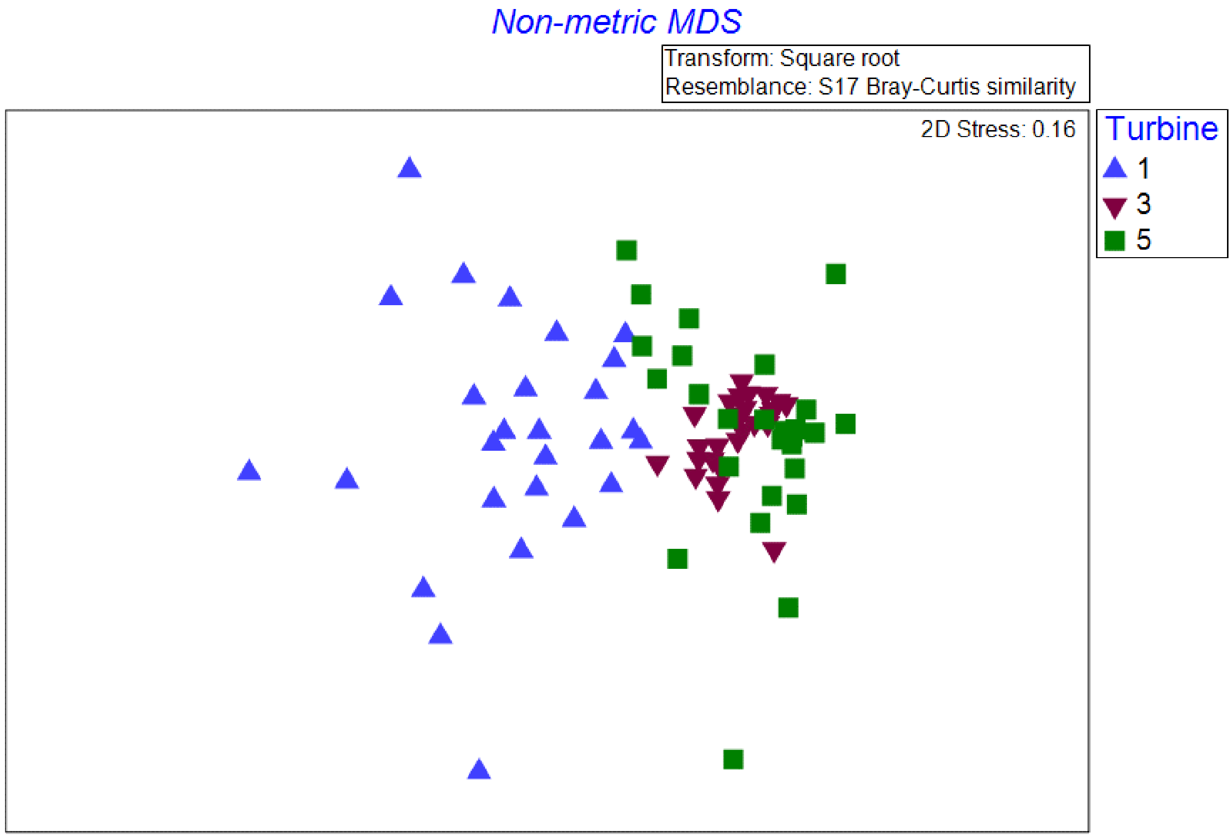


Figure 29. Non-metric MDS plot of Turbine area samples only.
Note: The plot further elucidates that Turbines 3 and 5 share similar macrofaunal communities as compared to Turbine 1, and that samples collected at Turbine 1 are more variable.

3.5.5 Cluster Analysis

An initial SIMPROF analysis of the grab sample data identified 19 significant faunal sample groupings ($p<0.05$) together with 5 outlier samples which were not classified at this level (**Figure 30**). Despite being significantly different, many of the groupings formed at this similarity level were found to share common species and differed only in terms of the abundances of characterizing fauna. **Tables 13** and **14** illustrates this point, and shows that many of the characterizing species were present at two or more locations. The data provide little evidence for the presence of distinct community groupings for the sample clusters created by SIMPROF.

To reduce the number of sample groups, the SIMPROF dendrogram was manually collapsed to a more manageable, and potentially more ecologically meaningful, set of sample groups based on shared species identities as indicated by a SIMPER analysis (**Figure 31**). The resultant (collapsed) dendrogram retained four of the original sample groups (groups a, d, c, and x) and created a fifth larger group (group (A)) which contained all the remaining samples (total 100 samples). **Figure 32** presents the corresponding nMDS ordination of the grab samples created following the rationalization of the faunal grouping. All samples are presented within the plot.

One sample collected within 50 m of Turbine 5 (sample T5-1_3) remained unclassified following this process and was deemed an outlier. It is likely that this sample represented a variant of the main faunal sample group (group (A)) and was only differentiated on the basis of the presence of very high numbers of the polychaete *Polygordius* spp. (total 312 individuals).

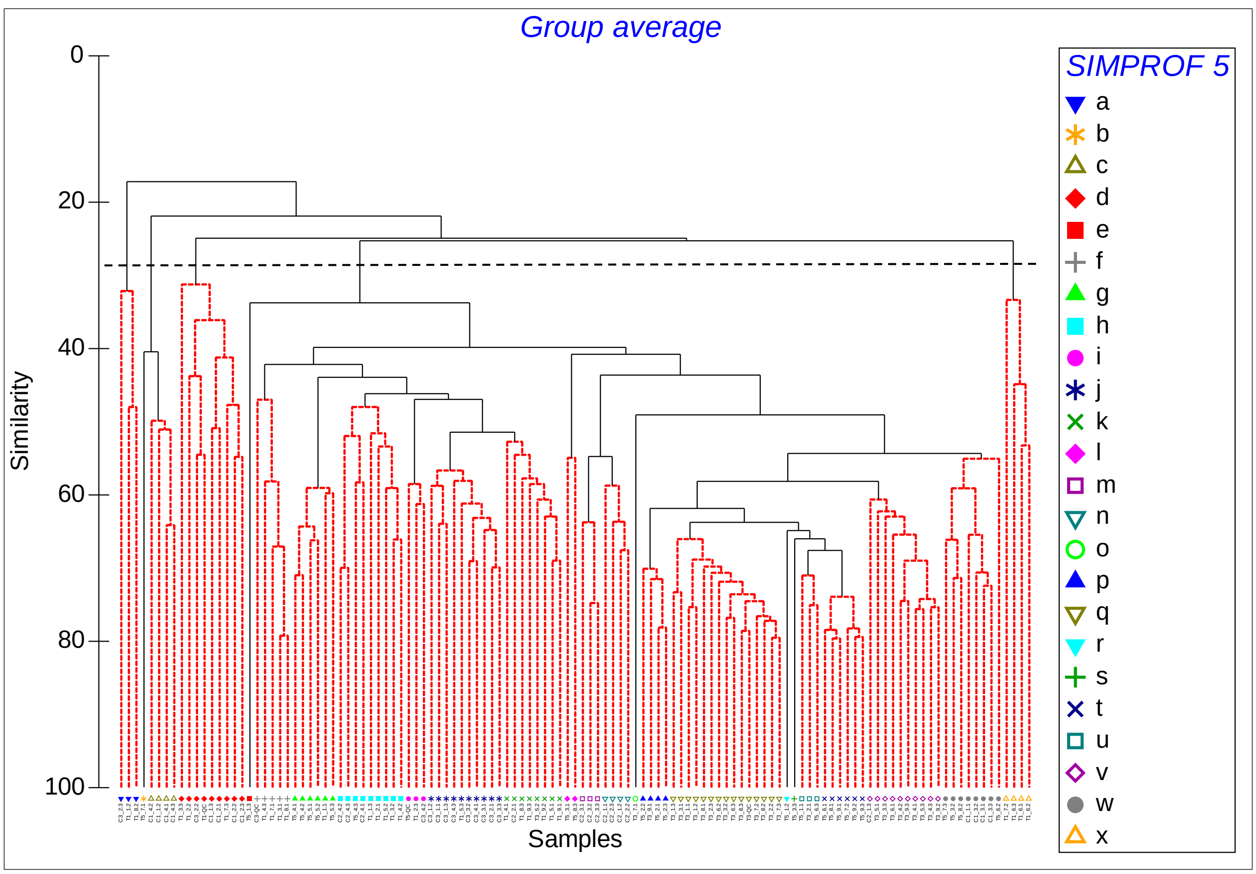


Figure 30. Group average sorting dendrogram of grab sample data (sqrt transformed).

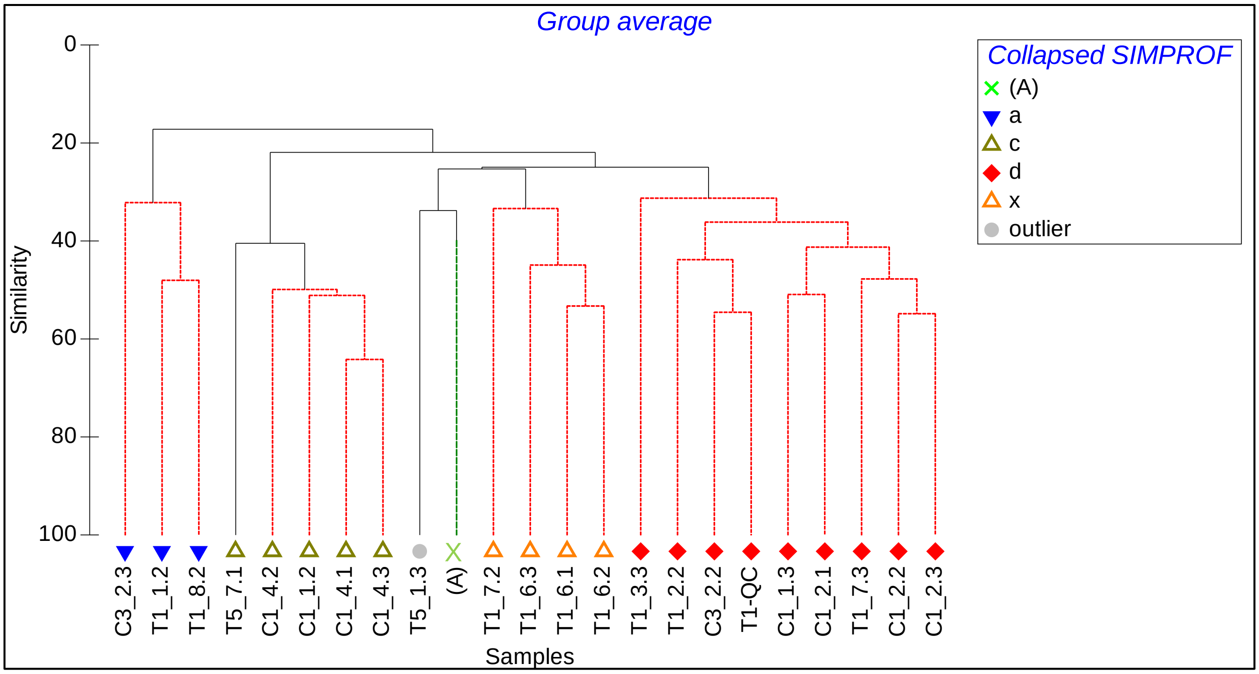


Figure 31. Collapsed Bray-Curtis similarity dendrogram of macrofaunal data (sqrt transformed).

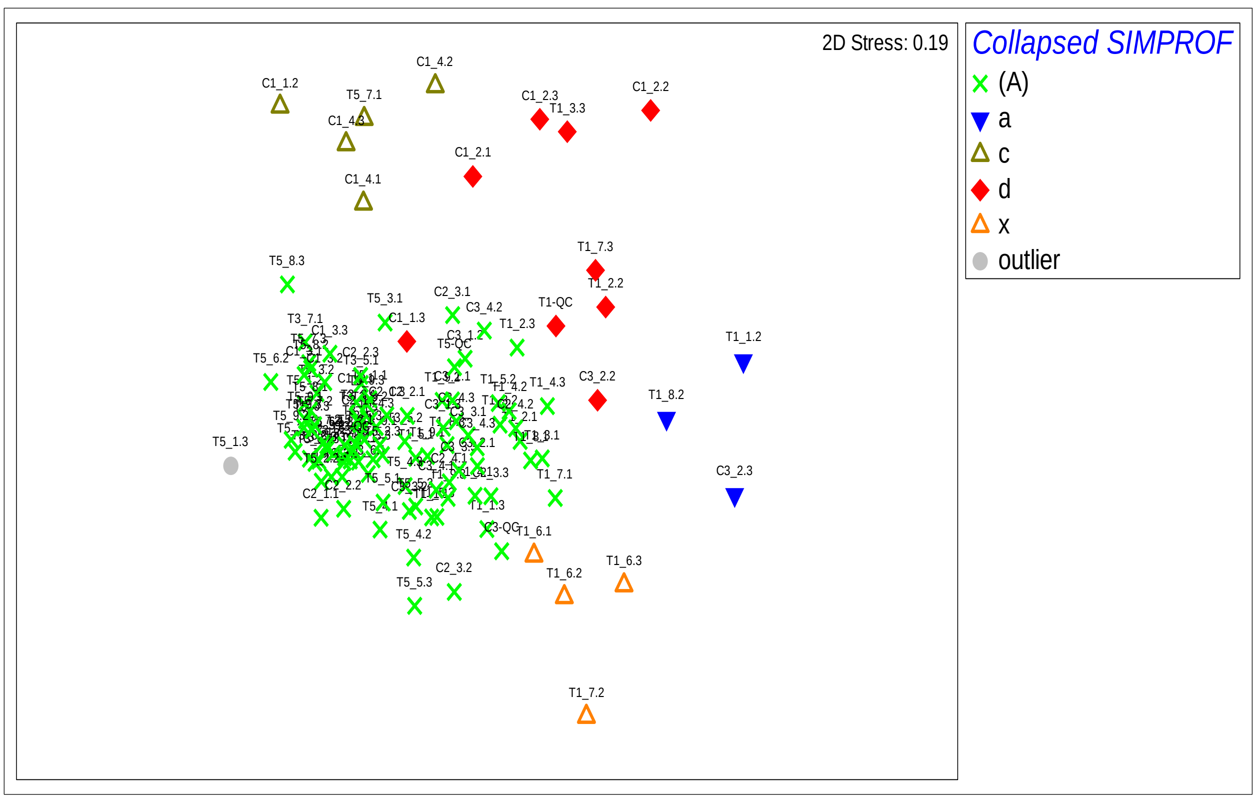


Figure 32. nMDS ordination of faunal data (sqrt transformed).

All four QC samples were clustered within the principal sample groupings. The QC sample for Turbine 1 was grouped together with three other samples from Turbine 1 and five samples from Control 1 within the group d. The remaining three QC samples were grouped within the main cluster of samples (group (A)).

Control samples were similarly grouped within the principal sample clusters. The exceptions were the four samples collected within Control 1 which formed their own small group (group c).

Table 15 presents a summary of the sediment and biological characteristics of each of the groups created by the cluster analysis and further highlights the presence of broadly comparable species identities and sediment types across the study areas. Nevertheless, clearly a number of samples have been partitioned from the main cluster suggesting some departure from the consensus community type in some areas. Most notable are the few samples comprising Control area 1 which have been partitioned to created sample group C and which appear to be characterized by hard and coarse substrata including rock and boulders supporting spirobid worms, amphipods (*Gammaropsis maculata*, *Corophium* sp. and *Ericthonius rubricornis*) and barnacles. The clustering of this group is interesting as the samples have been collected within close proximity to one another such that they may represent a distinct sediment/faunal assemblage.

3.5.6 Examination of Biology with Respect to Distance Bands

Several analyses were undertaken to investigate local differences in macrofaunal communities as a function of turbine distance. ANOSIM performed on the sample data between distance bands for each turbine revealed no significant differences ($P>0.05$) between any of the pairwise comparison, suggesting comparable macrofaunal communities within a 90 m radius of each turbine. These findings are further supported by regression plots comparing species abundance and richness within distance bands (**Figures 33** and **34**), nMDS plot of macrofaunal assemblages coded by distance band (**Figure 35**), and examination of the spatial distribution of species abundance, richness, diversity (refer to **Figures 24** to **26**).

Table 15. Summary of species data and sediment descriptions for each of the samples groups created by the Bray-Curtis clustering of the grab sample data.

Group	Top Ranking Species		Summary species data Mean (st.dev)	Summary sediment descriptions	Example photo
	SIMPER (top 80% contribution)	Ranked abundance (top 80% abundance)			
Group (A) X (100 samples)	*Nematoda* *Polygordius* *Lumbrinereis acuta* *Goniadella gracilis* *Polycirrus eximius* *Pisione* *Parapionosyllis longicirrata* *Unciola irrorata* *Maldanidae* *Cirrophorus* *Kirkegaardia baptisteae*	*Nematoda* *Polycirrus eximius* *Polygordius* *Lumbrinereis acuta* *Pisione* *Goniadella gracilis* *Ampelisca vadorum* *Unciola irrorata* *Sabellaria vulgaris* *Aricidea (Acmira) catherinae* *Parapionosyllis longicirrata*	No. Species = 120 Mean No. species = 20.1 (5.7) Mean abundance = 155.3 (91.8)	From grab Cobble, gravel, sand Medium sand Fine sand From video	
Group a ▼ (3 samples)	*Polygordius* *Nematoda* *Unciola irrorata* *Tanaissus psammophilus*	*Polygordius* *Unciola irrorata* *Tanaissus psammophilus* *Nephtys bucera* *Nematoda*	No. Species = 10 Mean No. species = 5.3 (0.6) Mean abundance = 8.3 (4.2)	From grab Cobble, gravel sand From video	

Group	Top Ranking Species		Summary species data Mean (st.dev)	Summary sediment descriptions	Example photo
	SIMPER (top 80% contribution)	Ranked abundance (top 80% abundance)			
Group c ♀Δ (5 samples)	*Nematoda* *Spirorbis* *Ericthonius rubricornis* *Pista* *Gammaropsis maculata* *Corophium* *Proboloides holmesi* *Polygordius* *Anomia* *Proceraea* *Amphibalanus amphitrite* *Lembos websteri* *Eumida sanguinea* *Jassa marmorata* *Pisione* *Unciola irrorata*	*Spirorbis* *Nematoda* *Gammaropsis maculata* *Amphibalanus amphitrite* *Ericthonius rubricornis* *Corophium* *Pista* *Polygordius* *Lembos websteri* *Caprella penantis*	No. Species = 64 Mean No. species = 30.4 (5.8) Mean abundance = 314.2 (276.3)	From grab Rocks, cobble, gravel sand. From video	
Group d ♦ (9 samples)	*Amphibalanus amphitrite* *Nematoda* *Sabellaria vulgaris* *Polygordius* *Unciola irrorata* *Goniadella gracilis*	*Sabellaria vulgaris* *Amphibalanus amphitrite* *Ericthonius rubricornis* *Nematoda* *Polygordius* *Unciola irrorata* *Goniadella gracilis*	No. Species = 69 Mean No. species = 14.3 (6.8) Mean abundance = 99.0 (114.7)	From grab Cobble, gravel, sand From video	

<table>
<tr><th rowspan="2">Group</th><th colspan="2">Top Ranking Species</th><th rowspan="2">Summary species data Mean (st.dev)</th><th rowspan="2">Summary sediment descriptions</th><th rowspan="2">Example photo</th></tr>
<tr><th>SIMPER (top 80% contribution)</th><th>Ranked abundance (top 80% abundance)</th></tr>
<tr><td>Group x
Δ
(4 samples)</td><td>Nematoda
Kirkegaardia baptisteae
Rhepoxynius epistomus
Nephtys bucera
Ericthonius rubricornis
Tanaissus psammophilus
Goniadella gracilis
Scoletoma fragilis</td><td>Nematoda
Goniadella gracilis
Kirkegaardia baptisteae
Lumbrinereis acuta
Nephtys bucera
Rhepoxynius epistomus
Spisula solidissima
Ericthonius rubricornis
Parametopella cypris
Tanaissus psammophilus
Astarte borealis
Mytilus edulis
Scoletoma fragilis
Harpacticoida
Deutella incerta
Pseudunciola obliquua</td><td>No. Species = 31
Mean No. species = 14.3 (9.3)
Mean abundance = 24.8 (14.6)</td><td><u>From grab</u>
Cobble, gravel, sand
<u>From video</u></td><td></td></tr>
<tr><td>Outlier
▲
(T5_1.3)</td><td>n/a</td><td>Polygordius
Nematoda</td><td>No. species = 19
Abundance = 384</td><td><u>From grab</u>
Coarse sand
<u>From video</u></td><td></td></tr>
</table>

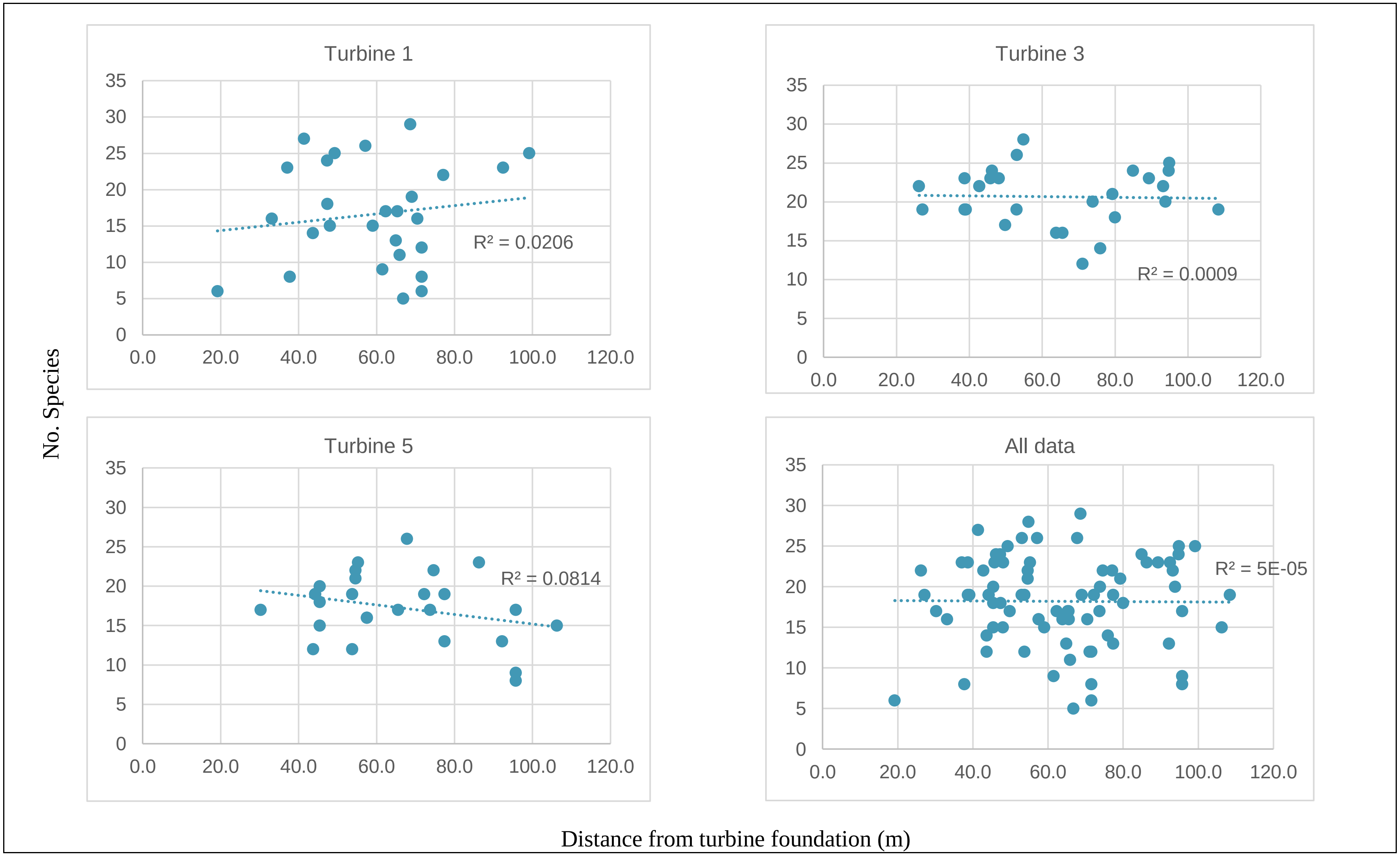


Figure 33. Numbers of species per grab sample with distance from the center point under each turbine foundation structure at BIWF (refer to Section 2.1.2 and Figure 8).

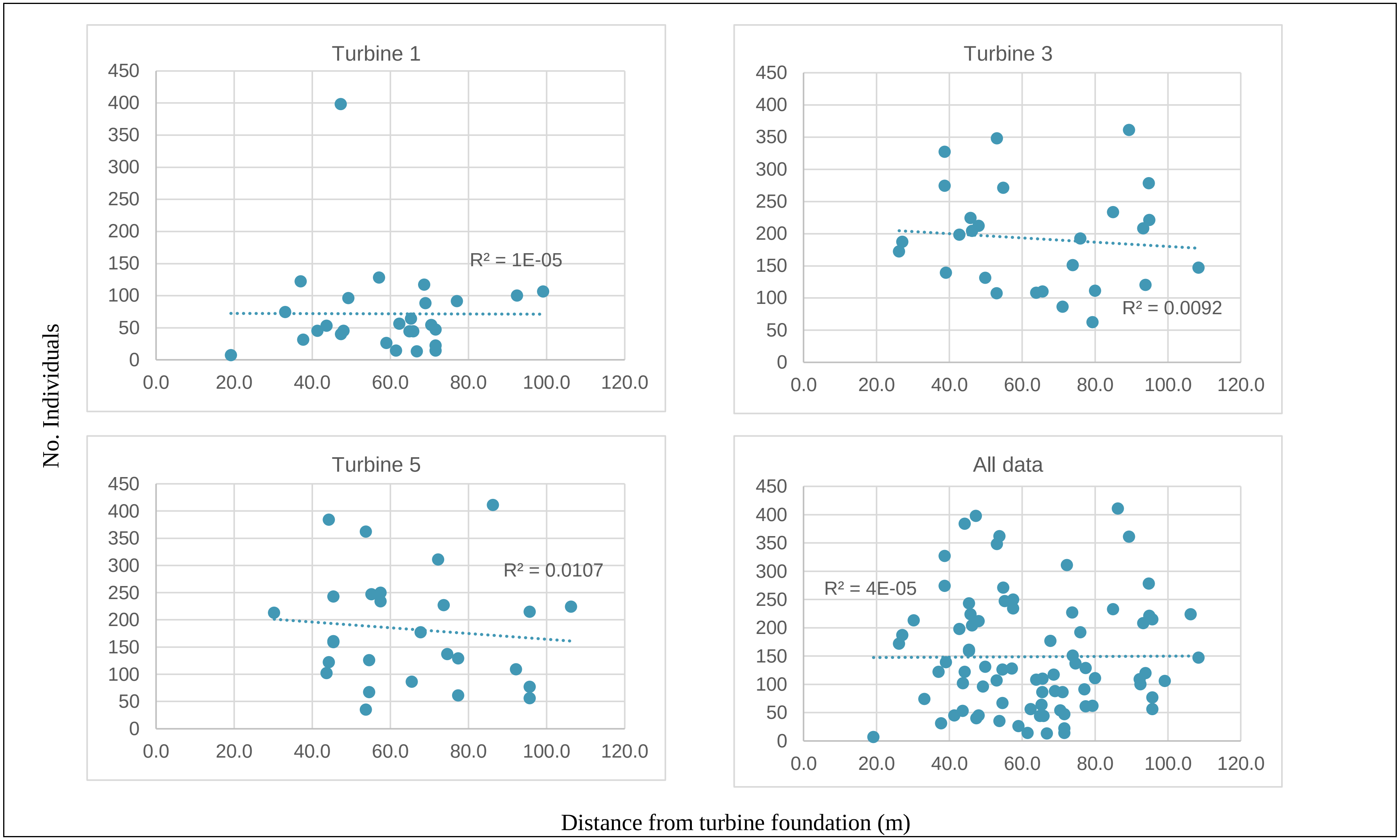


Figure 34. Numbers of individuals per grab sample with distance from the center point under each turbine foundation structure at BIWF (refer to Section 2.1.2 and Figure 8).

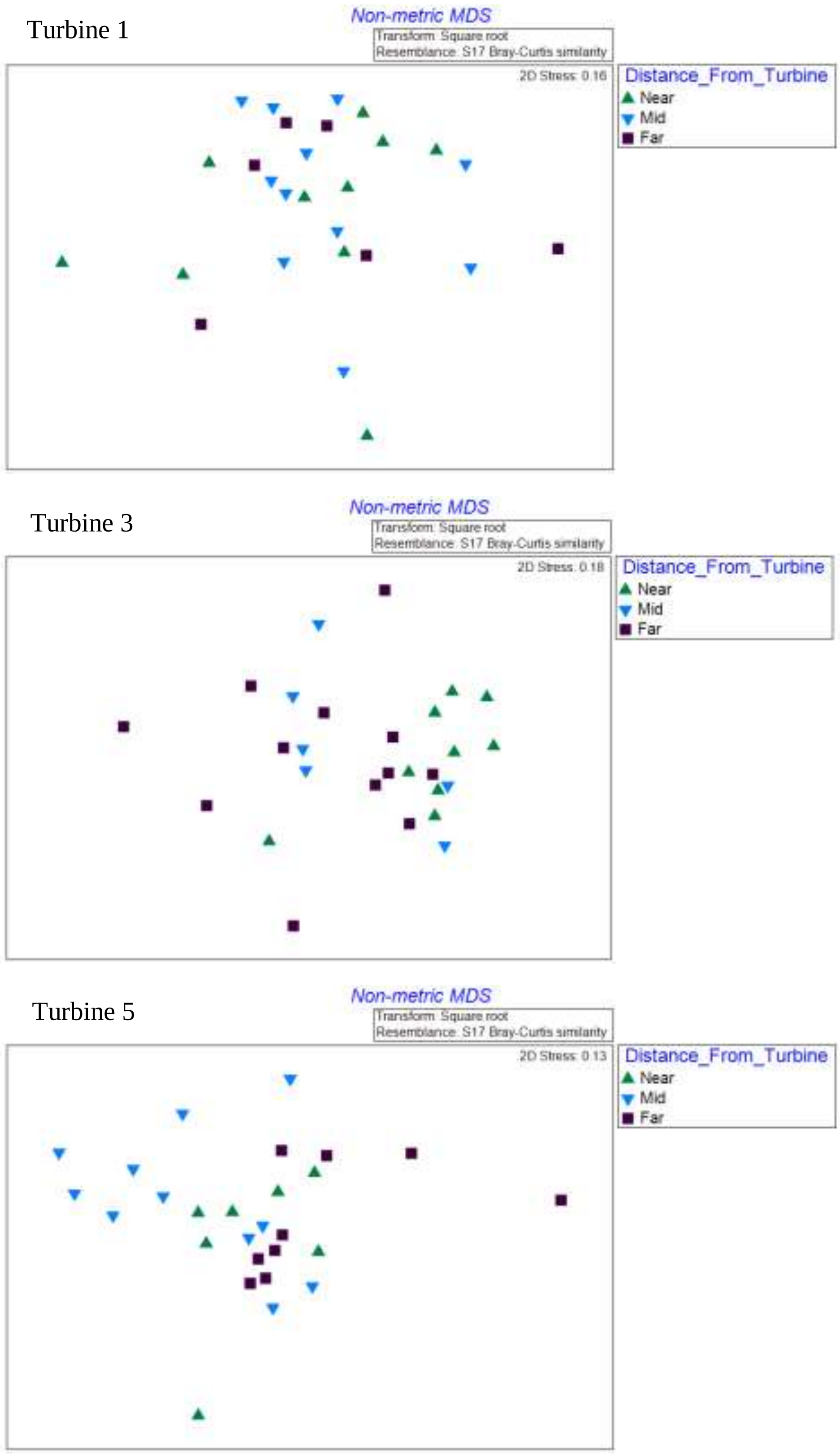


Figure 35. nMDS plots of macrofaunal samples according to distance from turbine for each turbine area. "Near," "Mid," and "Far" represent the 30- to 49-meter, 50- to 69-meter, and 70- to 90-meter distance bands, respectively.

These findings of the ANOSIM were partially replicated following analysis by Permanova. No significant fine scale spatial differences between the distance bands at Turbine 1 (P>0.05) were found, but the analysis did detect significant differences between the different distance bands at Turbines 3 and 5 (P<0.05). The results of these pair-wise Permanova comparisons between distance bands for each turbine are presented in **Table 16**.

Table 16. Results P(perm) of the Permanova pairwise comparisons between distance bands for each Turbine location (sqrt transformed grab sample data).

Distance band	Turbine 1		Turbine 3		Turbine 5	
	30-50	50-70	30-50	50-70	30-50	50-70
50-70	0.5450	-	0.1050	-	0.0616	-
70-90	0.3570	0.8031	**0.0030**	0.8521	0.1962	**0.0043**

BOLD = significant result P (perm<0.05)

Nonetheless, upon closer inspection of the data, these finer scale differences were also related to the relative mean abundances of characterizing species, rather than differences in species identities. For example, stations positioned within the inner most distance band (30 to 50 m from the foundation) at Turbine 3 contained the same but fewer individuals of the polychaete *Polycirrus eximius* and the amphipod *Unciola irrorata*, but greater numbers of nematodes, *Pisione* spp., *Polygordius* spp. and *Lumbrinereis acuta* compared to stations positioned <50 m. Similarly, variations in the relative abundances of characterizing species accounted for the greatest dissimilarity between distance bands at Turbine 5 as revealed by SIMPER rather than any conspicuous differences in species identities. For example, top ranking species present within the 50-70 m distance band at turbine 5 included *Polycirrus eximius*, Nematoda, *Polygordius* sp. and *Pisione* sp. These species were also present in high abundance within the 70 to 90 m distance band albeit in different densities.

3.6 CMECS Biotope Classifications

The term "biotope" is specific in that it integrates biotic-abiotic data within a given area to offer more ecologically meaningful information. In this study, the Geoform, Substrate, and Biotic Component were integrated to define biotope classifications for the turbine areas. As such, biotopes reflect the relationship between macrofaunal communities and associated geological characteristics within the defined map units. In this study, the biotopes are considered preliminary because, although the biotic-abiotic relationships identified in this study are statistically significant and ecologically meaningful, they have not been demonstrated to be consistent through time, as this study represents the first of its kind at this resolution (i.e., very site specific, whereas the OSAMP was conducted at a regional scale).

3.6.1 Rectifying OSAMP and BIWF Macrofauna Datasets

During the classification process, a few nomenclature discrepancies were discovered in comparing species identifications between the BIWF and OSAMP macrofaunal datasets. These discrepancies were rectified through expert knowledge. The two most relevant cases involve the polychaete worms *Lumbrinereis* and *Polycirrus*. Within the OSAMP dataset, *Lumbrinereis hebes* was identified in high abundances and is responsible for defining several of the OSAMP biotopes.

Within the BIWF dataset, *L. hebes* was not identified, but *L. acuta* was. Moreover, *L. acuta* was found in high abundances in areas where *L. hebes* was previously identified and *L. acuta* is responsible for defining one of the BIWF biotopes. Similarly, *Polycirrus medusa* was identified in the OSAMP dataset and *Polycirrus eximius* in the BIWF dataset. Both species are abundant within their respective datasets, do not occur across datasets, and are biotope-defining species. In both cases, it is highly likely that these species are one in the same. Though, taking a conservative approach, identification at the genus level is used for biotope classification.

Furthermore, nematodes were not enumerated in the OSAMP dataset, though they were in the BIWF dataset. Analyses were run both with nematodes included and excluded for comparison purposes, including nMDS plots, SIMPER, and ANOSIM. The differences between the two sets of results were minor, indicating nematodes have little influence in terms of assessing of macrofaunal community structure and biotic-abiotic relationships. Given this finding, nematodes were retained in the analyses for the sake of presenting the most complete understanding of the data. However, nematodes were removed from biotope classification to allow more direct comparisons of the OSAMP and BIWF biotopes.

3.6.2 CMECS Biotope Classification Considering Turbines as One Study Area

The macrofaunal samples were initially considered as belonging within one study area, rather than three separate areas, to remove arbitrarily defined study area boundaries and promoted biotope classification based solely on geologic depositional environment type. This process resulted in three distinct biotopes, all dominated by polychaetes (**Table 17**). The study areas for Turbines 1 and 3, as well as a portion of Turbine 5 are located within the same geological depositional environment (i.e., biotope map unit). As such, the samples within this biotope unit were grouped together for analyses and classification.

The merged biotope is characterized by polychaetes, with four species dominating 19 and co-dominating 28 of the 66 samples spanning all sample stations (refer to **Table 17**). The four species are *Polycirrus* sp., *Pisione* sp., *L. acuta*, and *Polygordius* spp. In addition, nematodes dominate 18 and co-dominate 23 samples, amphipods co-dominate seven samples, and barnacles dominate 1 and co-dominate 4 samples. The dominant species across all samples, *Polycirrus* sp., also dominates or co-dominates the most number of samples (16) and contributes to the overall biotope similarity (5.18%). Moreover, most of the other species that dominate or co-dominate the samples are also responsible for the biotope similarity. The remaining two biotopes located within the Turbine 5 study area remained unchanged (refer to **Table 18** in the following section).

The overall biotope similarity of the merged biotope is 42.32 percent. This is lower compared to the biotope similarities of Turbine 3 and 5 when considered as individual areas (62.49 and 52.37 percent, respectively), but marginally higher than that of Turbine 1 (38.91 percent). Closer examination of the data revealed that though the samples were collected within the same depositional environment, the macrofaunal community assemblages within this environment at Turbines 1, 3, and 5 have distinctive characteristics (as described in **Table 17** and throughout **Section 3.5**). This understanding could not be overlooked and warranted considering each turbine area as an independent study area for analysis and biotope classification.

3.6.3 CMECS Biotope Classification Considering Turbines as Three Independent Study Areas

Biotopes were classified for the three Turbine study areas (**Figure 36; Table 18**). The biotope units adhered to boundaries of the geologic depositional environments defined in the OSAMP. As such, Turbines 1 and 3 were each classified as one biotope and Turbine 5 as three biotopes. Each biotope is classified according to its biotic (the dominant species) and abiotic (geologic depositional environment) characteristics. Two species are listed when both occurred in nearly equal abundances. Abundance is calculated as the average number of individuals of a given species among all stations belonging to a given biotope. In general, all five biotopes are defined by polychaetes in depositional environments containing coarse sand.

The Turbine 1 study area is characterized by polychaetes (refer to **Table 17**). Specifically, four species of polychaetes dominate seven samples and co-dominate 13 samples across eight of the nine samples stations. These four species are *Sabellaira vulgaris*, *Polygordius* spp., *Goniadella gracilis*, and *L. acuta*.

Table 17. Description of CMECS classification of BIWF biotopes considering samples to belong to one study area.

CMECS Classification of BIWF Biotopes	Sample Stations Within Biotope (# Samples)	Dominant Species Across All Samples Within Biotope	Dominant / Co-Dominant Species Within Each Sample Within Biotope (# Samples of 66)	Overall Biotope Similarity	Species Most Responsible for Biotope Similarity (% Contribution)
All Samples					
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan	T1 and T3: All samples; T5: 2, 3, 4, 5 (66)	*Nematoda (2,323)*	*Nematoda (41)*	42.32%	*Nematoda (20.25%)*
		Polycirrus sp. *(1,026)*	*Polycirrus* sp. *(16)*		*Polygordius* spp. *(12.07%)*
		Pisione sp.*(782)*	*Lumbrinereis acuta (12)*		*Goniadella gracilis (10.55%)*
		Lumbrinereis acuta (774)	*Polygordius* spp. *(12)*		*Lumbrinereis acuta (10.02%)*
		Polygordius spp. *(749)*	*Pisione* sp. *(9)*		*Pisione* sp. *(5.51%)*
			Goniadella gracilis (8)		*Polycirrus* sp. *(5.18%)*
			Sabellaria vulgaris (6)		*Parapionosyllis longicirrata (4.07%)*
			Unciola irrorata (6)		*Unciola irrorata (3.68%)*
			Balanus amphitrite (5)		
			Erichthonius rubricornis (1)		
Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf environment	T5: 6, 7, 8, 9 (10)	*Polycirrus* sp.*(468)*	*Polycirrus* sp. *(9)*	55.90%	*Polycirrus* sp. *(25.09%)*
		Nematoda (442)	*Nematoda (7)*		*Nematoda (18.00%)*
			Polygordius spp. (2)		*Polygordius* spp. *(16.32%)*
			Gammaropsis maculata (1)		*Pisione* sp. *(13.64%)*
			Erichthonius rubricornis (1)		
Polygordius spp. in coarse sand with small dunes / sand waves within moraine shelf environment	T5: 1, 9 (5)	*Polygordius* spp. *(526)*	*Nematoda (4)*	58.74%	*Nematoda (19.68%)*
		Nematoda (342)	*Polygordius* spp. *(3)*		*Polygordius* spp. *(19.40%)*
			Polycirrus sp. *(2)*		*Polycirrus* sp. *(11.89%)*
					Lumbrinereis acuta (9.70%)
					Pisione sp. *(8.26%)*
					Eumida sanguinea (6.14%)

Note: Included are the dominant species among all macrofaunal samples within a given biotope and the species that dominate/co-dominate each individual sample. Also provided are the SIMPER reports of overall biotope similarity and the species contributing a cumulative contribution of 70 percent to the biotope similarity. Cells are color-coded by taxonomic group. Yellow cells are polychaetes, blue cells are amphipods, and green cells are crustaceans (barnacles). Grey cells are nematodes, which were excluded in biotope classification.

(a)

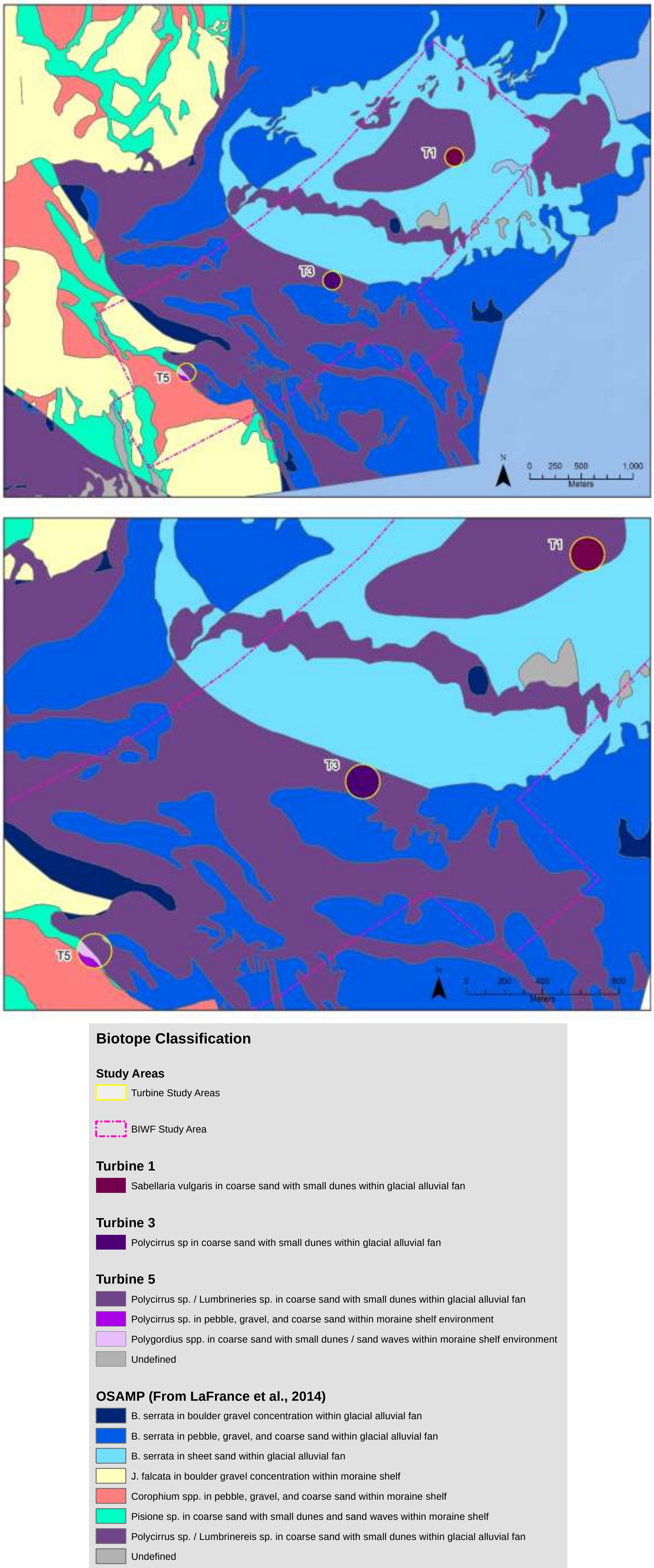


Figure 36. Biotope classification map of the turbine areas within the BIWF study area (a) zoomed out and (b) zoomed in.
Note: Figure “(a)” shows a broader perspective, while Figure “(b)” shows the biotopes in more detail. Biotope units are classified according to dominant species and geologic depositional environment. Dominant species is defined as the most abundant species among all macrofaunal samples within the given biotope. .

Table 18. Description of CMECS classification of BIWF biotopes with Turbine areas assessed as independent study areas.

CMECS Classification of BIWF Biotopes	Dominant Species Across All Samples Within Biotope (# Individuals)	Dominant / Co-Dominant Species Within Each Sample Within Biotope (# Samples of 27)	Overall Biotope Similarity	Species Most Responsible for Biotope Similarity (% Contribution)
Turbine 1				
Sabellaria vulgaris in coarse sand with small dunes within glacial alluvial fan	*Sabellaria vulgaris (382)*	*Nematoda (13)*	38.91%	*Nematoda (20.45%)*
	Nematoda (262)	*Sabellaria vulgaris (7)*		*Goniadella gracilis (12.33%)*
		Polygordius spp. *(7)*		*Polygordius* spp. *(11.54%)*
		Goniadella gracilis (8)		*Nephtys bucera (8.85%)*
		Unciola irrorata (6)		*Unciola irrorata (6.82%)*
		Lumbrinereis acuta (4)		*Lumbrinereis acuta (6.15%)*
		Balanus amphitrite (5)		*Sabellaria vulgaris (5.22%)*
Turbine 3				
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan	*Nematoda (1,344)*	*Nematoda (17)*	62.49%	*Nematoda (14.20%)*
	Polycirrus sp. *(847)*	*Polycirrus* sp. *(13)*		*Polycirrus* sp. *(12.46%)*
		Pisione sp. (7)		*Pisione* sp. *(11.05%)*
		Lumbrinereis acuta (5)		*Lumbrinereis acuta (10.37%)*
		Polygordius spp. *(4)*		*Polygordius* spp. *(10.14%)*
				Goniadella gracilis (6.21%)
				Cirrophorus sp. *(5.59%)*

CMECS Classification of BIWF Biotopes	Dominant Species Across All Samples Within All Biotopes	Dominant / Co-Dominant Species Within Each Sample All Within Biotopes (# Samples of 27)	Overall Combined Biotope Similarity	Species Most Responsible for Combined Biotope Similarity (% Contribution)
Turbine 5 (Overall)				
Polycirrus sp. / Lumbrinereis sp. in coarse sand with small dunes within glacial alluvial fan; *Polycirrus sp.* in pebble, gravel, and coarse sand within moraine shelf environment; *Polygordius spp.* in coarse sand with small dunes / sand waves within moraine shelf environment	*Nematoda (1,501)*	*Nematoda (22)*	50.49%	*Nematoda (24.63%)*
	Polycirrus sp. *(863)*	*Polycirrus* sp. *(14)*		*Polygordius* spp. *(13.68%)*
	Polygordius spp. (860)	*Polygordius* spp. *(6)*		*Polycirrus* sp. *(13.06%)*
		Lumbrinereis acuta (3)		*Pisione* sp. *(11.36%)*
		Pisione sp. *(2)*		*Lumbrinereis acuta (10.49%)*
		Gammaropsis maculata (1)		
		Erichthonius rubricornis (1)		

CMECS Classification of BIWF Biotopes	Sample Stations Within Biotope (# Samples)	Dominant Species Across All Samples Within Biotope	Dominant / Co-Dominant Species Within Each Sample Within Biotope (# Samples)	Overall Biotope Similarity	Species Most Responsible for Biotope Similarity (% Contribution)
Turbine 5 (By Biotope)					
Polycirrus sp. / Lumbrinereis sp. in coarse sand with small dunes within glacial alluvial fan	2, 3, 4, 5 (12)	*Nematoda (717)*	*Nematoda (11)*	52.37%	*Nematoda (25.28%)*
		Lumbrinereis acuta (193)	*Polycirrus* sp. *(3)*		*Lumbrinereis acuta (11.43%)*
		Polycirrus sp. *(175)*	*Lumbrinereis acuta (3)*		*Goniadella gracilis (10.14%)*
			Pisione sp. *(2)*		*Polygordius* spp. *(9.75%)*
			Polygordius spp. *(1)*		*Pisione* sp. *(9.23%)*
					Polycirrus sp. *(5.03%)*
Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf	6, 7, 8, 9 (10)	*Polycirrus* sp.*(468)*	*Polycirrus* sp. *(9)*	55.90%	*Polycirrus* sp. *(25.09%)*
		Nematoda (442)	*Nematoda (7)*		*Nematoda (18.00%)*
			Polygordius spp. *(2)*		*Polygordius* spp. *(16.32%)*
			Gammaropsis maculata (1)		*Pisione* sp. *(13.64%)*
			Erichthonius rubricornis (1)		
Polygordius spp. in coarse sand with small dunes / sand waves within moraine shelf	1, 9 (5)	*Polygordius* spp. *(526)*	*Nematoda (4)*	58.74%	*Nematoda (19.68%)*
		Nematoda (342)	*Polygordius* spp. *(3)*		*Polygordius* spp. *(19.40%)*
			Polycirrus sp. *(2)*		*Polycirrus* sp. *(11.89%)*
					Lumbrinereis acuta (9.70%)
					Pisione sp. *(8.26%)*
					Eumida sanguinea (6.14%)

Note: The dominant species among all macrofaunal samples within a given biotope and the species that dominate/co-dominate each individual sample is provided. Also provided are the SIMPER reports of overall biotope similarity and the species contributing a cumulative contribution of 70 percent to the biotope similarity. Cells are color-coded by taxonomic group. Yellow cells are polychaetes, blue cells are amphipods, and green cells are crustaceans (barnacles). Grey cells are nematodes, which were excluded in biotope classification.

In addition, nematodes dominate 6 and co-dominate 7 of the samples, the amphipod, *Unciola irrorata*, co-dominates six samples, and the barnacle, *Balanus Amphitrite*, dominates and co-dominates 1 and 4 samples, respectively. The dominant species across all samples is the polychaete, *S. vulgaris*, which also dominates or co-dominates seven of the samples and contributes 5 percent to the overall biotope similarity. Similarly, there is a high degree of overlap between the dominant and co-dominant species within the samples and the species that contributes the most to the biotope similarity, with five of the six species being listed in each category. While Turbine 1 can be characterized as a polychaete dominated area, there is some variability. This is indicated by the number of taxonomic groups dominating or co-dominating individual samples, as well as by the overall biotope similarity (38.91 percent), which is the lowest of the three turbine areas.

The samples collected within Turbine 3 provide a well-defined representation of the turbine study area. Polychaetes are the only characterizing species, with four species dominating 10 and co-dominating 13 of the 27 samples spanning all nine sample stations. These four species are *Polycirrus* sp., *Pisione* sp., *L. acuta*, and *Polygordius* spp. The remaining four samples are solely dominated by nematodes, which also co-dominate 13 samples (with polychaetes). The dominant polychaete across all samples, *Polycirrus* sp., also dominates or co-dominates the most number of samples (13) within the turbine area and contribute the greatest to the overall biotope similarity (12.46 percent). Moreover, the other species that dominate or co-dominate the samples are also responsible for the biotope similarity, and are listed in the same order. The high degree of cohesiveness within Turbine 3 is reflected in the overall biotope similarity (62.49 percent), which is the highest of the three turbine areas.

Turbine 5 was investigated as a single biotope, as well as according to the biotope units used in the OSAMP study for comparison purposes. In both cases, the biotopes are characterized by polychaetes. When considered as one biotope, four species of polychaetes dominate four and co-dominate 13 samples across seven of the sample stations. These four species are *Polycirrus* sp., *Lumbrinereis acuta*, *Pisione* sp., and *Polygordius* spp. In addition, nematodes solely dominate nine samples and co-dominate 13 samples with polychaetes, and two amphipod species, *Gammaropsis maculate* and *Erichthonius rubricornis*, co-dominate one sample. The two polychaetes that co-define the biotope, *Polycirrus* sp. and *Polygordius* sp., also dominate or co-dominate the greatest number of samples (20) and are the most responsible for the overall biotope similarity (approximately 13 percent each). The remaining two polychaetes that dominant and co-dominate the samples also contribute the most to the biotope similarity.

The Turbine 5 samples based on the OSAMP biotope units were located within three distinct biotopes, each of which were characterized by polychaetes. Of the 12 samples within the biotope co-defined by *Polycirrus* sp. and *Lumbrinereis* sp., these polychaetes, in addition to the polychaetes *Pisione* sp. and *Polygordius* sp., dominate one and co-dominate (with nematodes) three samples. The remaining eight samples are solely dominated by nematodes. These species also contributed the most to the overall biotope similarity (ranging from 11.43 to 5.03 percent each).

Polycirrus sp., also solely defines another biotope within the Turbine 5 study area. Within this biotope, of the ten samples, the polychaetes *Polycirrus* sp. and *Polygordius* spp. dominate two samples and co-dominate seven (with nematodes). In addition, two species of amphipods *Gammaropsis maculate* and *Erichthonius rubricornis*, co-dominate one sample. *Polycirrus sp.* also dominated or co-dominated the greatest number of samples (9) and is the most responsible for the overall biotope similarity (25.09 percent). The other characterizing polychaetes in this biotope are *Polygordius spp.*, dominating or co-dominating two samples and contributing 16.32 percent to the overall biotope similarity, followed by *Pisione* sp. responsible for 13.64 percent.

The third biotope defined by the polychaete *Polygordius* spp. Of the five samples within this biotope, one is dominated by *Polygordius* spp. and three are co-defined by *Polygordius* spp. and/or *Polycirrus* sp. along with nematodes. The remaining sample is dominated by nematodes. As such, *Polygordius* spp. and *Polycirrus* sp. are the dominant or co-dominant species for three and two samples, respectively, and most responsible for the overall biotope similarity, contributing 19.40 and 11.89 percent, respectively.

Defined as one or as three biotopes, Turbine 5 exhibits a high level of cohesiveness among the sample groups. The overall similarity of the Turbine 5 samples considered as a single biotope (50.49 percent) suggests the samples within Turbine 5 share similar macrofaunal community assemblages. Examining the samples separated out according to the three OSAMP biotope units increases the overall similarity, with the similarity of each biotope ranging from 52.37 to 58.74 percent. This result could be interpreted as evidence that the Turbine 5 study area should not be considered a single biotope. However, the species that dominate or co-dominate and that are responsible for the overall similarity within each biotope are identical, suggesting the three biotopes are quite similar. The distinction appears to be based on variations in abundances of the characterizing species, rather than the species themselves.

Statistical analysis of the biotopes showed there is a significant relationship between the geological depositional environments within each study area and the associated macrofaunal community assemblages (ANOSIM R = 0.413; p = 0.001). The nMDS plot also supports this finding (**Figure 37**).

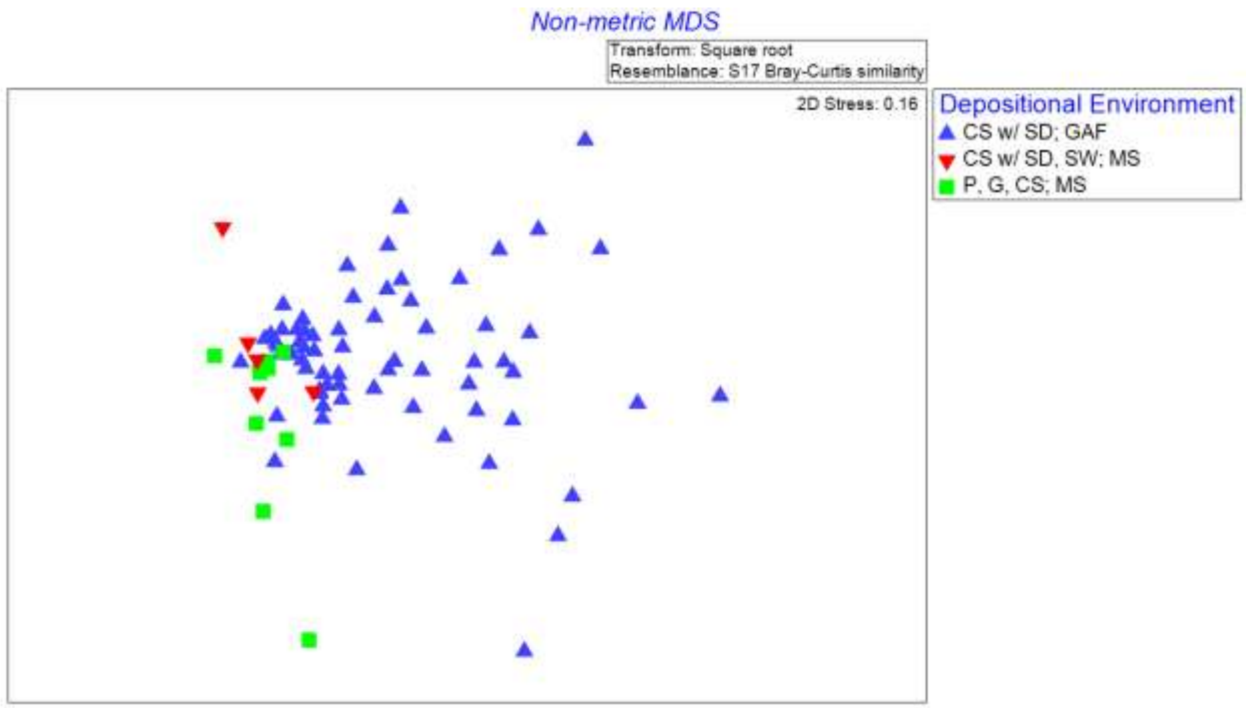


Figure 37. nMDS plot displaying macrofaunal samples according to depositional environment type.
Key: "CS w/ SD; GAF" = Coarse sand with small dunes within glacial alluvial fan; "CS w/ SD, SW; MS" = Coarse sand with small dunes and sand waves within moraine shelf; "P, G, CS; MS" = Pebble, gravel, and coarse sand within moraine shelf.

3.7 Significant Testing of Univariate Measures

A two-way ANOVA was used to detect differences in group means followed by a series of post hoc pairwise comparison tests to detect significant difference between groups depending on the individual normality and variance characteristics of the data under test. The two-way aspect of the analysis reflected the two levels tested including between turbine and control groups and between individual stations at each turbine and the combined control areas. **Table 19** summarizes the results of the ANOVA test conducted on the faunal and TOC data.

- The combined control areas had a greater number of species than Turbines 1 and 5, but not significantly for Turbine 3. They also exhibited significant within area variance but this may reflect the comparatively wider geographical area over which these samples were collected.

- The control areas and Turbine 3 had greater diversity than Turbine 5 (P<.001), and Turbine 1 had greater diversity than Turbine 5 at p=0.001. This indicated that Turbine 5 had the lowest diversity.
- For TOC, a non-parametric test showed that the combined control areas had greater values than Turbine 1.
- Values of Margalef's species richness were significantly higher in the control areas than at the turbine areas. Samples collected at Turbine 5 had the lowest values for Margalef's richness in line with that noted for diversity and potentially species numbers.
- For the numbers of individuals, a non-parametric test showed that Turbine 1 had the lowest value. Turbines 3 and 5 had noticeably higher species abundance than Turbine 1 and the combined control areas.
- Overall Turbine 5 appears to have the most depauperate ecological community, but clear patterns for species numbers, numbers of individuals, etc. did not readily emerge.

Table 19. Summary of results of the two-way ANOVA turbines on benthic data for the turbines and combined control areas.

Test	Results Between Turbines & Control	Results Within Turbines / Control |Areas –	Comment on a priori and post hoc tests
2 way ANOVA. No. Species.	Control > turbines 1& 5 (P<0.001). Turbine 3 had greater species numbers than 1 & 5, but not accepted (P<0.05)	Within turbine 1, station 9 had a greater species number than station 7 (P<0.05).	A priori normality and equal variance passed. Post hoc Holm Sidak test used to elucidate between and within station comparisons for significant results
2 way ANOVA. Shannon Weiner (H')	Control & turbine 3 > turbine 5 (P<0.001). Turbine 1 > than turbine 5 (p=0.001)	No differences between stations within turbines.	A priori normality and equal variance passed. Post hoc Holm Sidak test used to elucidate between and within station comparisons for significant results
Kruskall Wallis one way ANOVA on TOC	Significant difference indicated (control > turbine 1), (P<0.05)	NA	A priori test (Shapiro Wilk) failed for normality (p<0.05). Data could not be transformed at sqrt and ln. Revert to non-parametric Kruskall Wallis one way ranked ANOVA on median values. Tukey test used for interactions.
2 way ANOVA. Richness	Control > turbines, 1, 3 and 5 (P<0.001). Difference indicated between turbines 1 & 3 > turbine 5 (P<0.05)	Within turbine 1, stations 9 & 6 had greater richness than station 7 (P<0.05).	A priori normality and equal variance passed. Post hoc Holm Sidak test used to elucidate between and within station comparisons for significant results
Kruskall Wallis one way ANOVA on No. Inds	Control & turbines 3 & 5 > turbine 1 (P<0.001). Comparisons of median values. Turbines 3 and 5 had markedly higher numbers of individuals.	Data were re-analyzed for station (within turbine/control) using Dunns multiple comparisons, but tests could not clearly resolve which zones were significantly different within turbine/control areas. Overall however, agglomerated data showed turbines 3 and 5 had higher numbers of individuals.	A priori test (Shapiro Wilk) failed for normality (p<0.05). Data could not be transformed at sqrt and ln. Revert to non-parametric Kruskall Wallis one way ranked ANOVA on median values. Tukey test used for interactions.

3.8 Retro-active Power Analyses

3.8.1 Abiotic Factors

The current survey design was found to have high Power (> 0.9) for the detection of differences in numbers of species, Shannon diversity index and Marglalef's richness index between grouped turbine and control samples. The survey design was also found to have moderate power for detecting difference in species numbers and diversity between stations at each turbine. These findings suggested that there was 10% or less chance of committing a Type II error in failing to reject the Null hypothesis when significant differences ($p<0.5$) are present between turbines and a 25 percent chance of this occurring during testing between sample stations at each turbine.

Outputs from post hoc Power analyses indicated a reasonably high level of test Power for the majority of ANOVAs conducted. Summary Power results for the 2-way ANOVAs performed are presented in **Table 20**.

Table 20. Summary Power of ANOVA tests performed with α = 0.05.

Variable	Between turbines	Between distance bands within turbines
Number of species	0.992	0.746
Shannon Weiner (H')	0.996	0.774
Richness	1.00	0.336

Furthermore, the Power analysis estimated that the MDE size was 6 species at Power level of 0.8, i.e., a mean difference of 6 species and 98 individuals between groups could be detected under the current design at a relevant level of power.

The high power achieved is not unexpected, as the significance tests employed have already detected significant differences at an appropriate P level ($P<0.05$). As such, the tests possessed sufficient power.

3.8.2 Biotic factors

Consideration of the sample numbers being representative of the overall community was tested by plotting the standard error of the running mean against the number of observations. This simple routine results in a qualitative judgment on if the samples are of suitable replication to provide meaningful outcomes.

For this purpose, plots for species numbers for each of the turbines and control areas are presented in **Figures 38** to **41** and indicate that around 22 to 27 samples were required to establish a reasonable estimate of the species numbers for each turbine and around 36 samples were required at the control areas. From this preliminary analysis, the sample design was thus sufficient to adequately describe species numbers at all locations.

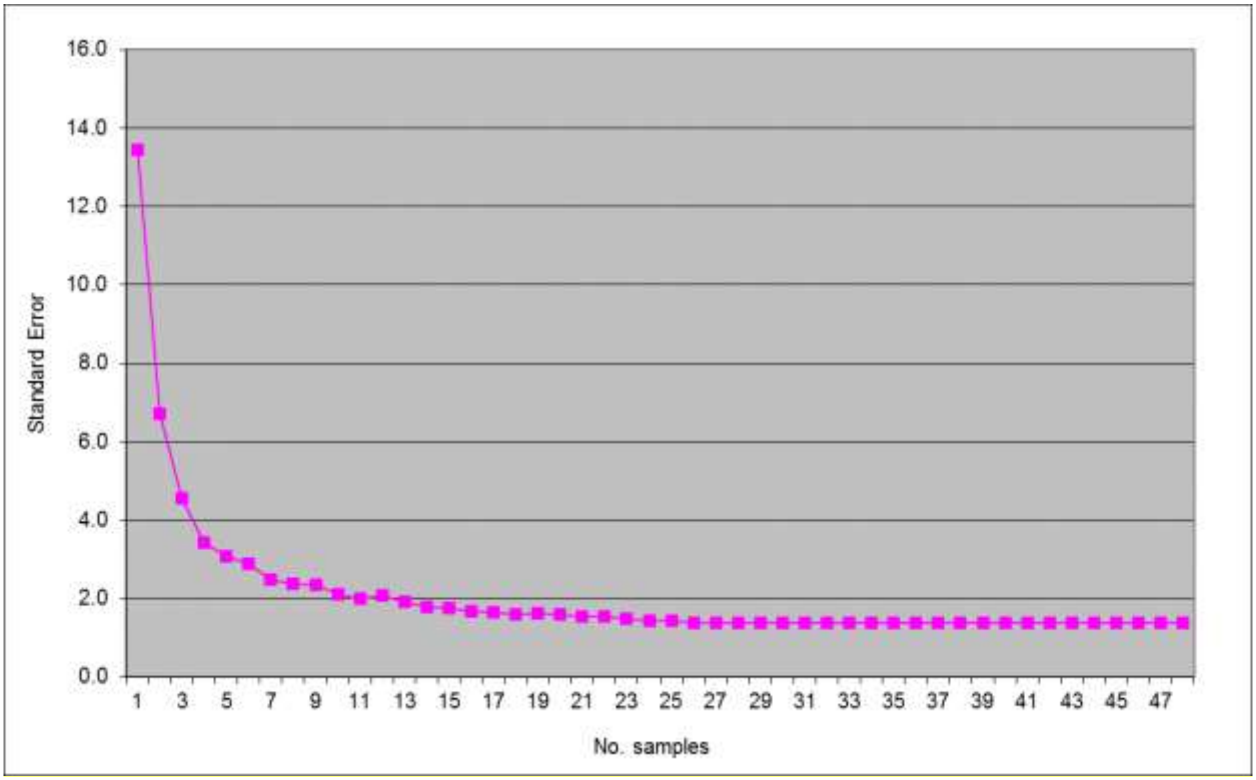


Figure 38. Sample standard error reduction, Turbine 1, No. species.

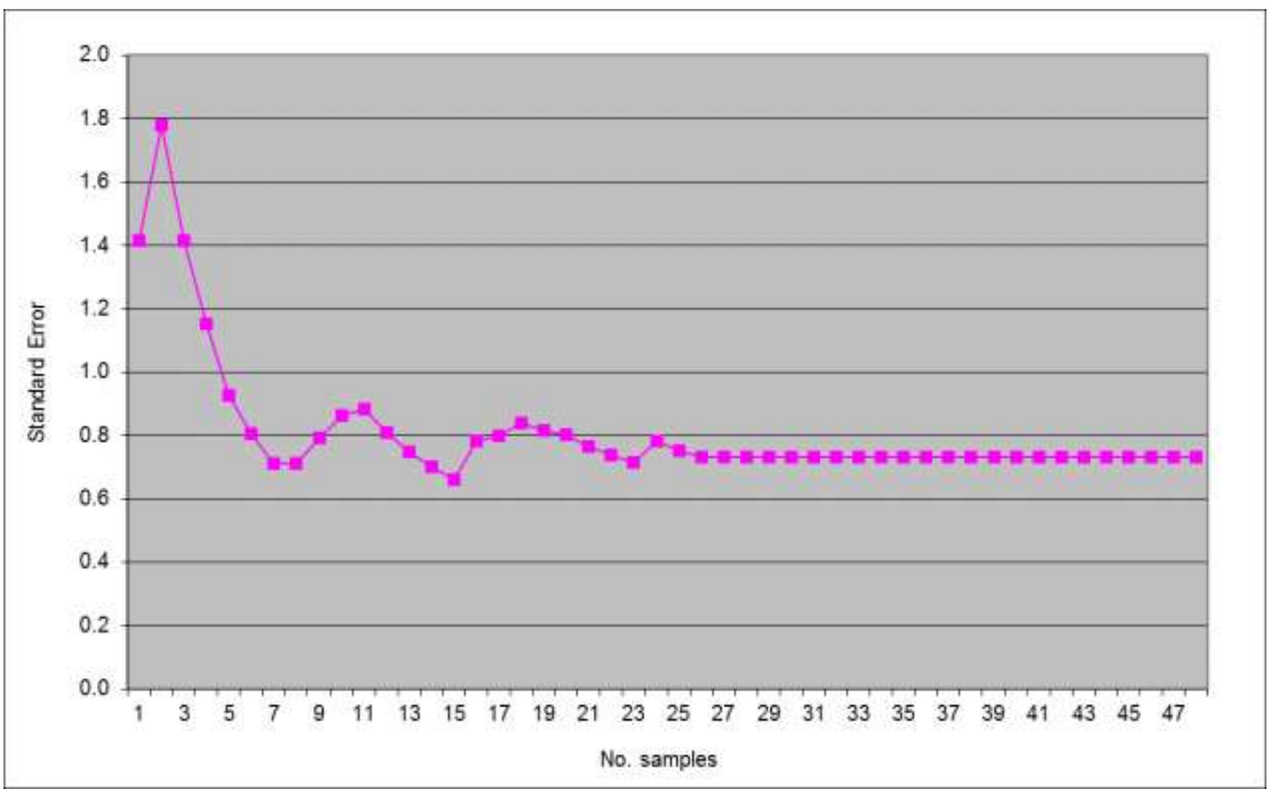


Figure 39. Sample standard error reduction, Turbine 3, No. species.

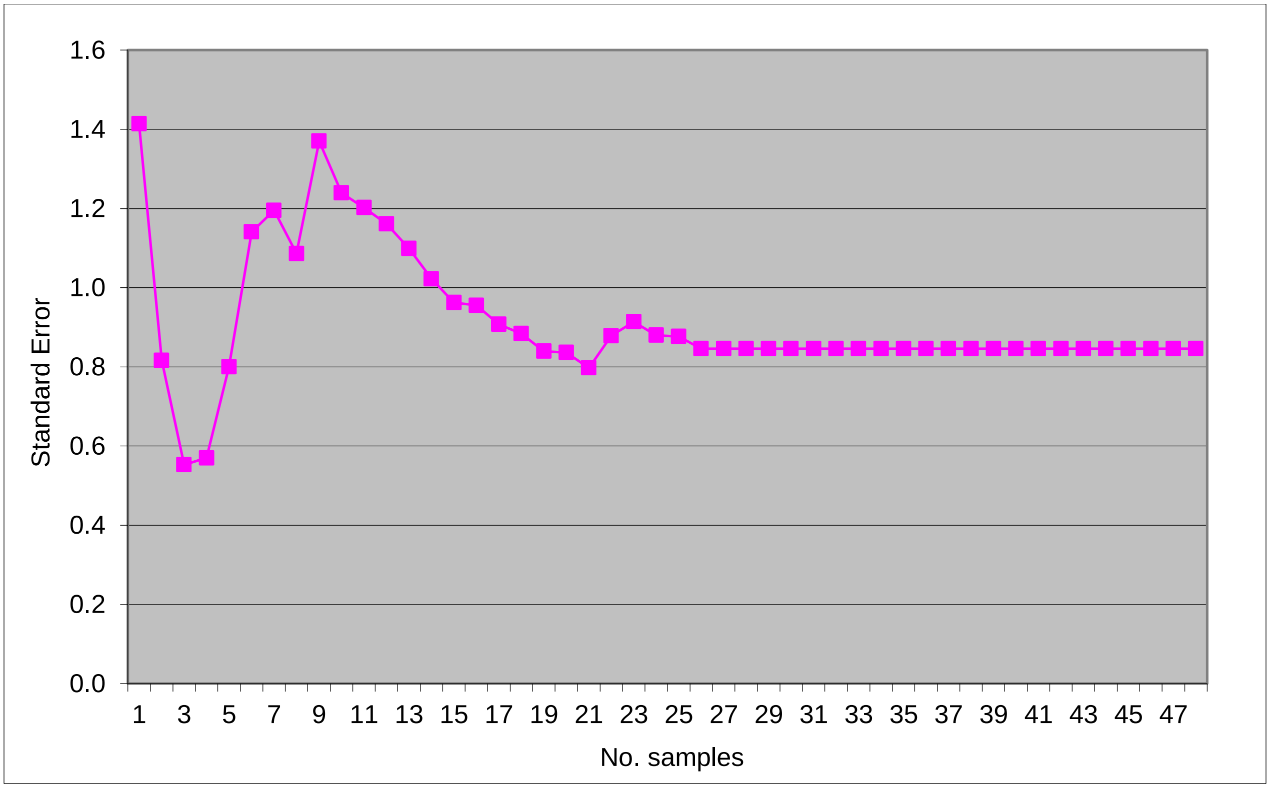


Figure 40. Sample standard error reduction, Turbine 5, No. species.

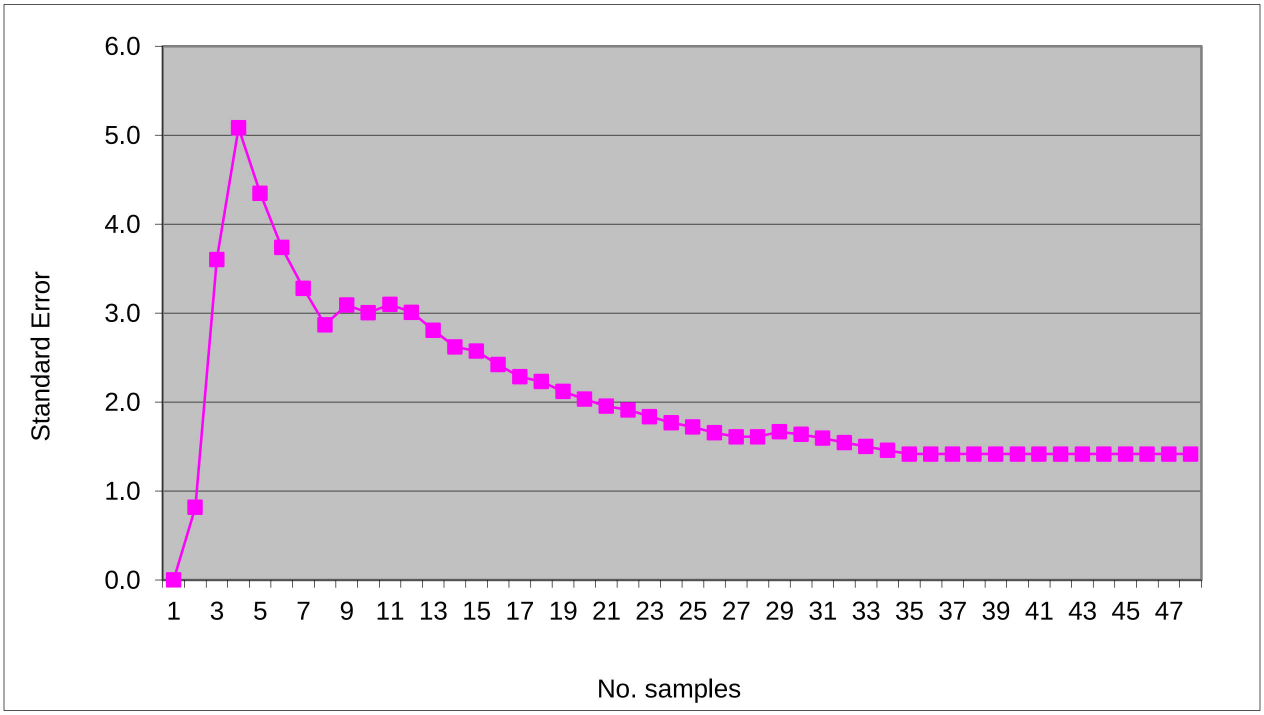


Figure 41. Sample standard error reduction, control areas, and no. of species.

4 Discussion

4.1 Current Monitoring Practice

To date, there is little, if any, consensus on the level of acceptable benthic ecological change because of offshore wind farm (OWF) construction and operation or on the relevant spatial scales over which such changes may occur. Permit conditions typically do not establish thresholds relating to the severity or spatial extent of benthic impacts, above which effects are deemed undesirable. Instead, OWF benthic monitoring campaigns are typically hypothesis driven and aim to detect significant changes in benthic communities which are then inferred as impacts. This approach often fails to acknowledge the validity of the results in terms of (i) severity and spatial extent aspects against established value systems, (ii) the metrics used or (iii) the context of the power of the test design. Without established thresholds, offering meaningful context for assessment is challenging. Wilding et al. (2017) critiques current approaches to benthic monitoring of offshore renewables and offers a compelling argument for reducing attention on detecting significance in impact assessment and instead adopting justifiable thresholds around which meaningful management decisions can be based.

Potential localized impacts due to the operation of OWFs on benthic ecology have so far received little attention in Europe. Here, statutory monitoring has largely been conducted at medium and broad scales, with no significant impacts reported, and with limited or no coverage of areas close to turbine foundations. There is thus currently, little evidence on which to base assessments of localized impacts of OWFs. While impacts across finer scale distances may seem trivial, multiplied across 100 or more grounded foundations within a typical commercial scale OWF, the total area of impacted seabed could become important especially where gross local change has occurred. For example, benthic modification over an area of 50 m radius from a turbine would equate to a potential impact area of 785,000 square meters for an offshore wind farm comprising 100 turbine foundations. Whilst the potential ecosystem benefits of artificial structures in the water column are recognized, for example the rigs-to-reef initiative the Gulf of Mexico, longer term ecological consequences at offshore wind farm sites remain unknown. Equally, the consequences of aggregated areas of enriched and modified seabed habitats and communities at the base of foundations over the period of an offshore wind farm license are unclear. Furthermore, the potential consequences of such changes on wider benthic linked ecosystem functions remain unknown.

As well as a paucity of data on local impacts, current monitoring efforts have only covered short timescales (5 years or less). Considering that OWFs may have license terms of around 25 years (or longer where the facility is re-powered), then the available time-series data could be insufficient to have fully captured the severity and spatial extent of benthic impacts which have developed over time.

The lack of longer term (>5 years) study of potential localized impacts at OWFs is curious given the benthic ecological changes that have been documented around fixed oil and gas structures off the west coast of the United States (Wolfson et al. 1979, Page et al. 2005, Manoukian et al. 2010), although it is acknowledged that these are likely regional specific phenomena. Here, conspicuous changes in sediment and benthic species composition have been recorded up to 100 m from piled foundations because of the accumulation of biomass (mostly dead mussel shell) which has fallen from epifouling communities attached to the structures. Effects have included changes to sediment structure, modified infaunal community structure and localized increases in the densities of larger mobile predator—scavenger fauna, although it is acknowledged that these changes may be specific to the region. The water depths within which these shell mounds have been studied range between 18 m and around 50 m and so encompass the depth ranges of the current study area. However it is not clear whether the total surface area available for colonization by fouling communities in the studies cited are comparable with the current study.

Nonetheless, observations of epifouling on renewables infrastructure and jacket foundations (Emu Ltd. 2008a, 2008b, Picken 1986, Schörder et al. 2006) suggest considerable quantities of additional biomass could be introduced to offshore areas. Studies on the soft sediment macrobenthos around a gravity base at the Thorntonbank OWF (Belgium) have also reported local benthic modification attributable to the operation of the wind farm (Coates et al. 2012, 2014).

Localized benthic change due to the presence of infrastructure have in general been detected and characterized by grab sampling and seabed video surveillance techniques, which are suitable for the derivation of quantitative and semi-quantitative data and subsequent univariate and multivariate analysis for assessment purposes.

Recognizing that achieving consensus on acceptable benthic impacts and threshold levels may be difficult, and will likely require considerable multi-stakeholder discussion, the collection of empirical evidence on the severity and spatial scale of benthic changes close to OWF infrastructure should be straightforward and could substantially help inform such discussions and facilitate consensus finding.

The RODEO initiative has provided opportunity to study short-range interactions between OWF and benthic macrofaunal communities at Block Island over the longer term and has allowed relevant benthic information to be collected from as close as possible to the foundations of the United States's first commercial scale offshore wind farm at Block Island. The data presented here therefore establish a comprehensive baseline 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 OWF (i.e., Wilhelmsson et al.2006) and provide valuable information to underpin future OWF management objectives.

4.2 Sediment Data

4.2.1 Particle Size Data

The underwater video, grab samples, and associated field descriptions supported a heterogeneous seabed dominated by mixed coarse and medium grade sand, gravel and cobble sediments, reflecting previous accounts of re-worked glacial moraine deposits within the region. 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 does observations of dense cobble and boulder concentrations within Control 1.

The low values of silt and clay within the sediments sampled 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. Most samples (106) contained no silt or clay particles. From the video data, a degree of local seabed mobility and disturbance is suggested by the presence of sand waves in some places.

Historic studies have recorded significantly finer sediments (mean grain size) close to a gravity base foundation at Thorntonbank OWF (within 15 to 50 m) compared to sediments positioned 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 15m of the foundation when compared to those further away and demonstrated considerable inter-annual variability. These observations were attributed, in part, to the effects of the construction of the OWF and to modification to the local hydrodynamic conditions as a result of the presence of the foundation. 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 locale foundation depending on tidal orientation and current speeds (Coates 2014).

The experiences at Thorntonbank were not replicated at BIWF. Rather, based on the whole sediment data available (clay, silt and sand), no substantial differences in sediment composition occurred between distance bands for each turbine suggesting comparable sediment composition within 90 m of each foundation. The differences in sediment trends between the two wind farms may be a result of foundation type. At Block Island, the foundations are jacket type structures, as opposed to gravity base, and so water may be able to flow through the structure with less influence on bottom current speeds. A more useful analogue for comparison might be the FINO1 renewables research platform in Germany, which also uses a jacket foundation. Benthic observations via fixed camera and diver sampling (Schröder et al. 2006), recorded changes in the local hydrodynamic regime and associated modifications to the sediment composition nearby. In the direct vicinity of the piles (up to 5 m away) the sediment was found to be much more heterogeneous compared to pre-construction conditions. It contained more dead shells which were 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 to 1.5m deep in which the heavier shell material had been retained.

At BIWF, the current sampling array for benthic assessment does not allow for measurement of sediment faunal changes within 30 m distance from the center point under the foundation structures, which is equivalent to 15 m to 20 m from the foundation structures themselves. As a result, very fine scale sedimentological modifications occurring close to the foundations are unknown at present. In a parallel study, a pair of scour monitors were installed on one of the BIWF foundations and changes in seabed elevations up to 10 m from the foundation were tracked using acoustic signals in real time over a 14-month period. Results indicated that the seabed elevations changed at different periodicities corresponding to natural physical drivers. Changes in seabed elevations were observed at less than 1 day consistent with the periodicity of the local tidal forcing; over the course of a week to a month, appearing to coincide with perturbations to the tidal current flow resulting from increased wave energy; and a seasonal signal consistent with increased wave activity in the winter months, and calmer conditions in the summer months. For future benthic assessments, incorporation of scour monitoring data into the benthic assessment could potentially provide additional insights. Furthermore, if possible, detailed analysis of the acoustic signals from the scour monitoring could also reveal particle size data for comparative purposes to assess changes in grain sizes over time.

Control and QC sediment data were dispersed within the principal multivariate groupings and were not classified as outliers. This suggested that these stations were suitable as controls for the turbine locations.

4.2.2 Total 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 (Valente et al. 1992) according to classic models (e.g., Pearson and Rosenberg 1978) (**Figure 42**). Such changes can include reduced oxygen levels and increased toxin levels (e.g., ammonia and sulphide), which can lead to depletions in species richness, abundance, and biomass.

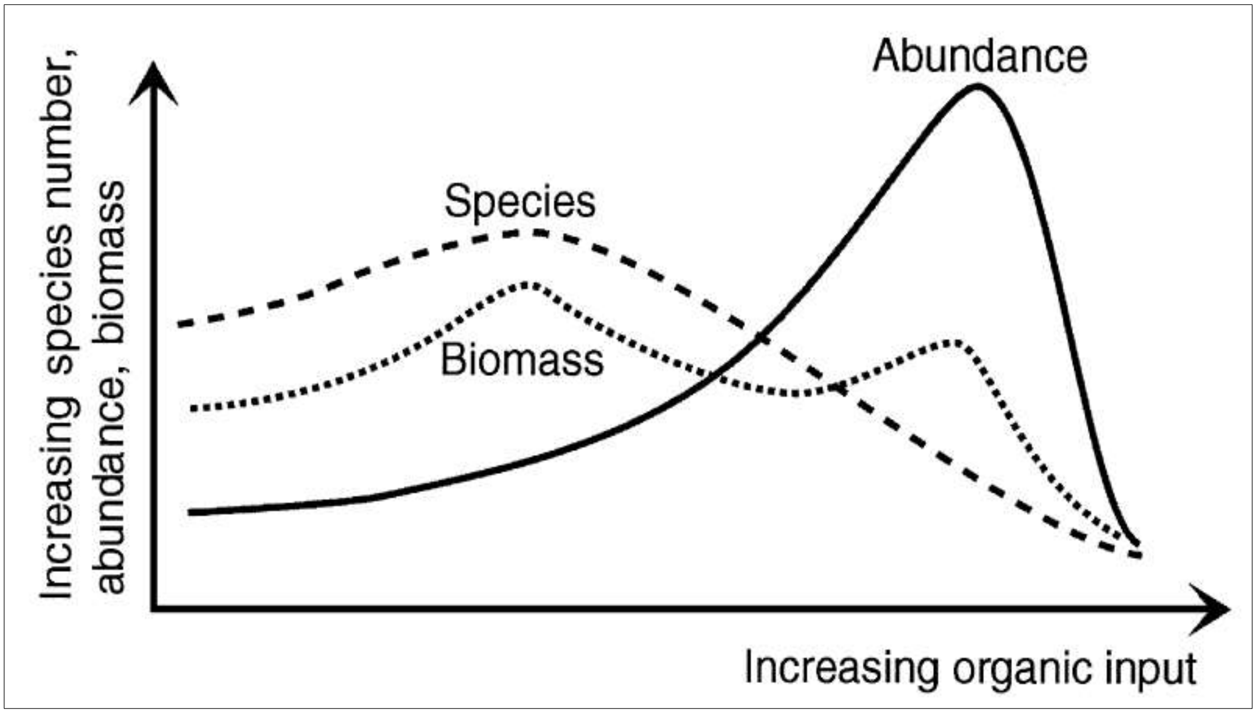


Figure 42. Pearson and Rosenberg's model of increasing organic inputs on species numbers, abundance and biomass SAB.

Hyland et al. (2005) advises that benthic communities are at high risk from organic loading and other stressors where total organic carbon levels in sediments exceed 3.5 percent, at low risk at levels that are less than 1.0 percent and are at intermediate risk at levels in between. The researchers calculated a range of benthic indices from various global macrofaunal datasets and selected Hurlberts species richness $E(S_n)$ for analysis of benthic relationships with TOC levels in sediments owing to its independence of sample size. They found an overall pattern of decreasing species richness with increasing TOC, as predicted by the Person and Rosenberg model (**Figure 42**) and suggested that this could be used to identify ranges of TOC for the assessment of 'low,' 'medium,' and 'high' risk of impaired benthic communities. Mean richness values were found to peak at concentrations of approximately 2.5 to 5 $mg.g^{-1}$ and decline at concentrations between 5 and 10 $mg.g^{-1}$ reaching a minimum at 30 to 40 $mg.g^{-1}$. To define critical lower and upper TOC points, the researchers used the outputs of ANOVA to identify the TOC values which resulted in the greatest differences (F-statistic) and also used regression of richness values as a function of TOC to find the major inflection points of the regression curve. Both methods produced similar results indicating step changes in richness values at 10 mg/l and 35 $mg.g^{-1}$. Thus the likelihood of detecting a decline in benthos in relations to increasing TOC is low at values of of TOC that are less than 10 $mg.g^{-1}$ high at concentration of TOC above 35 $mg.g^{-1}$ and intermediate at value of TOC 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 percent, respectively. Using these values as guidance, TOC levels in the sediment at Block Island are unlikely to be indicative of impaired conditions.

At BIWF, input of organic material may derive from the fall of biomass from epifouling communities colonizing the turbine foundations. 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. Other possible sources of organic material within local sediments include estuarine/fringing plant communities, municipal wastewater discharges and spring and autumn plankton blooms, though the inputs from these sources have not been well evaluated within the region of the BIWF.

A picture of epifouling colonization and development at BIWF can be drawn from observations on jacket structures at the FINO1 research platform and installations at the Beatrice Field in the outer Moray Firth, Scotland (Picken 1986). For example, Schroder (2006) describes a very rapid initial colonization of the underwater surfaces of the FINO 1 jacket structure within 2 weeks of construction followed by development of distinct patterns of vertical zonation within 2 years. Mussels (*Mytilus*) and tube building amphipods (*Jassa*) constitute most of the biomass at the FINO 1 platform although other fouling organisms are conspicuous including, hydroids, anemones *Sagartiogeton undatus* and *Metridium senile*, starfish *Asterias rubens* and crabs, *Liocarcinus holsatus*. Edible crabs, *Cancer pagurus*, colonize the base of the piles. Within approximately the first year of operation of the FINO1 platform, the amount of biomass predicted to have accumulated on the jacket structure was 3.6 tons. Schroder (2006) reports that a part of this biomass is continually eroded from the structure resulting in increases in the organic matter content of sediments around the piles.

Almost immediately, benthic change within the vicinity of the FINO 1 piles (1 m) was noted but this 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 2 years after installation, the effects of the platform on benthos was noticeable up to 15 m distance.

The results suggest there have been no effects on TOC levels within the sediments due to the operation of the BIWF. TOC levels were comparable across the study area and no spatial distribution patterns were observed. The lack of effects in this study is not unexpected given that it was conducted less than a year after the installation of the foundations so that fouling communities may not have had time to develop, mature, and subsequently slough off of the structures, and thus contribute significantly to the organic carbon content of local sediments. That there was little evidence of the presence of fouling organisms (e.g., mussel clusters, shell hash) or increased predators or scavengers (e.g., starfish) visible in the video footage and recovered in the grab samples support that the turbines have not yet experienced heavy biofouling.

Similar studies in the future may detect higher TOC levels where the products of the fouling communities on the foundations accumulate on the seabed. For example, at Thorntonbank, a trend of increasing organic matter content was observed within 25 m of the foundation along the axis of the principal tidal movements but also within 15 m perpendicular to the main tidal flow 3 to 4 years after installation of a gravity base foundation (Coates et al. 2014). Factors other than the prevailing hydrodynamic regime were attributed to this observation (Coates et al. 2014).

4.3 CMECS Biotope Classification

4.3.1 CMECS Framework

In this study, CMECS demonstrated to be a comprehensive and well-suited framework for classifying data, developing preliminary biotope units, and identifying statistically significant relationships between macrofaunal communities and their associated environment. The Geoform and Substrate Components offered a high level of detail for classifying the seabed environments of the turbine and control areas. The Biotic Component was valuable for indicating the dominant species within the turbine and control areas. Though, the Biotic Component does not provide details of the composition of macrofaunal communities, which could be useful to understand.

CMECS also proved to be useful for comparing the BIWF data to previously collected data (i.e., OSAMP), as consistent terminology is used to classify attributes. Such is the case for comparing individual CMECS components, as well as biotopes. This comparability will allow the BIWF dataset to be more easily incorporated into and/or assessed against data collected in the future.

The biotopes are currently considered preliminary, because, although the biotic-abiotic relationships identified are statistically significant and ecologically meaningful, they have not been demonstrated to be consistent through time, as this study represents the first of its kind at this resolution (i.e., very site specific, whereas the OSAMP was conducted at a regional scale). However, the continuation of this study in the future could lend to the establishment of well-defined biotopes, given the biotic-abiotic relationships identified persist through time.

4.3.2 BIWF Biotopes

The preliminary biotopes defined in this study will serve as a reference point against which to compare biotopes defined from future monitoring surveys at the BIWF that employ the same or a similar sampling strategy. Each of the five biotopes identified within the turbine areas were characterized by polychaetes and coarse sediments. From a broader perspective, it can be considered that there are no substantial differences in benthic macrofaunal communities or ecological function at these sites. This finding is not unexpected given that the sedimentary environment is comparable throughout the BIWF study area, and given this study and others (e.g., LaFrance et al., 2014; LaFrance et al., 2010; Steimle, 1982) provide evidence that macrofaunal assemblages in this region are associated with sediment composition.

The benthic communities between and among the turbine and control areas can be considered comparable in terms of the key physical characteristics and associated faunal. While some distinctions were detected, these have been attributed to variations in species abundances, rather than species composition. For example, the study areas for Turbines 1 and 3 were each encompassed within the same biotope class unit (as defined previously as part of the OSAMP study). The study area for Turbine 5, however, spanned three OSAMP biotope classes. As such, it was expected that the Turbine 5 macrofaunal samples would exhibit the greatest variability in assemblage structure (i.e., in terms of characterizing species and overall similarity).

However, this distinction belongs to the Turbine 1 study area, despite being well-encompassed within a single biotope class. Moreover, Turbine 1 was found to have the lowest overall similarity among the 27 samples collected (SIMPER = 38.91%) and Turbine 3 was found to have the highest (SIMPER = 62.49%). Examination of these results indicated that the macrofaunal communities within Turbine 1 and Turbine 3 were quite different; an unanticipated result because the two study areas are located within the same biotope class. This difference was further exemplified in the ANOSIM analysis, which showed that the macrofaunal communities between Turbines 1 and 3 exhibited the greatest degree of distinction ($R = 0.582$; $p = 0.001$), as compared to between Turbines 3 and 5 ($R = 0.251$; $p = 0.001$) and Turbines 1 and 5 ($R = 0.552$; $p = 0.001$).

4.3.3 Comparison of BIWF Study to Previous Studies

4.3.3.1 BIWF Biotopes and OSAMP Biotopes

The biotope class boundaries used in this study followed those defined previously as part of the OSAMP study, which reflect the depositional environments that are present offshore of Block Island. The decision to use the OSAMP defined biotope class boundaries in this study was considered valid for several reasons. First, the depositional environments and their boundaries were interpreted from a suite of various high resolution datasets, and, therefore, can be considered accurate over a fine-spatial scale (i.e., tens of meters). Furthermore, comparisons of the side-scan and video data collected in this study to previous studies in the area indicate that the depositional environments have not been altered over time, and, thus are still relevant and accurately describe the geological characteristics of the BIWF study area (refer to **Figure 2**). Also, the use of the same depositional environment as the biotope map units allows for more direct comparison of pre- and post- construction macrofaunal community structures and biotope classifications.

With regard to the biological component, while the same methodology was employed for macrofaunal data acquisition and processing for both studies to ensure comparability of the datasets, sampling density varied. For the OSAMP, macrofaunal samples were collected over a much broader spatial scale, with 48 samples collected over a 56 square mile area (i.e., approximately one sample per square mile). Of these samples, only three were collected within the BIWF study area, with the nearest sample being located 320 m from Turbine 1, another 600 m from Turbine 3, and remaining 700 m from Turbine 5. In comparison, for this study, at each turbine, 27 macrofaunal samples were collected within a 30 m and 90 m radius of the turbine, which equates to a 0.01-square mile area.

This substantial difference in the resolution (i.e., sampling density) of the macrofaunal data made direct comparisons of the OSAMP and BIWF biotopes challenging. The OSAMP biotope map represents a regional perspective, whereas the BIWF biotopes are highly site-specific. However, despite these challenges, examination of the two biotope outputs in relation to one another is still a valuable exercise. The biotope outputs were found to be broadly similar (**Table 21**). This is particularly true when comparisons are based on overall taxonomic group and functional designation, rather than species. The inconsistencies that are noted are attributed to differences in data resolution, rather than changes that have occurred over time, such as the construction or operation of the BIWF facility.

Table 21. Comparison of CMECS biotope classifications within each Turbine area.

	BIWF Biotope	OSAMP Biotope
Turbine 1	*Sabellaria vulgaris* in coarse sand with small dunes within glacial alluvial fan	*Polycirrus* sp. / *Lumbrinereis* sp. in coarse sand with small dunes within glacial alluvial fan
Turbine 3	*Polycirrus* sp. in coarse sand with small dunes within glacial alluvial fan	*Polycirrus* sp. / *Lumbrinereis* sp. in coarse sand with small dunes within glacial alluvial fan
Turbine 5	*Polycirrus sp.* / *Lumbrinereis* sp. in coarse sand with small dunes within glacial alluvial fan	*Polycirrus* sp. / *Lumbrinereis* sp. in coarse sand with small dunes within glacial alluvial fan
	Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf	*Corophium spp.* in pebble, gravel, and coarse sand within moraine shelf environment
	Polygordius spp. in coarse sand with small dunes / sand waves within moraine shelf	*Pisione* sp. in coarse sand with small dunes / sand waves within moraine shelf environment
	Undefined	*Byblis serrata* in pebble, gravel, and coarse sand within glacial alluvial fan

Note: The BIWF study offers high resolution biotopes, whereas the OSAMP biotopes represent a regional perspective. Please refer to text in this section for more detailed discussion.

Because it has been determined that the depositional environments have not changed over time, this aspect of the biotope remained the same for both the OSAMP and BIWF biotope classifications. It is the biological component (i.e., dominant species) that had the potential to be re-defined for the BIWF biotopes. The BIWF and OSAMP biotopes at Turbine 1 were both defined by polychaete worms, though the species and their functional designations varied. The BIWF biotope was characterized by the sand-builder polychaete worm, *Sabellaria vulgaris,* whereas the OSAMP biotope was characterized by two polychaete worms, *Polycirrus* (soft tube-builder) and *Lumbrinereis* (burrower). However, *Lumbrinereis* is a dominant species within the Turbine 1 samples (total abundance = 106). The polychaete is also broadly distributed across the study area, being recovered in 20 samples, and is a top contributor to the overall macrofaunal similarity of the samples collected within Turbine 1 (refer to **Table 18**). *Polycirrus*, conversely, has a minimal presence at Turbine 1, with four individuals recovered across all 27 samples.

At Turbine 3, the soft tube-building polychaete, *Polycirrus sp.,* defined the BIWF biotope and co-defined the OSAMP biotope, along with the burrowing polychaete, *Lumbrinereis*. Similar to Turbine 1, while not the defining species, *Lumbrinereis* is considered a key species within the Turbine 3 study area, but to an even greater degree. In this area, *Lumbrinereis*, is a dominant species, being recovered in nearly every one of the 27 samples and having a total abundance of 476 individuals. The polychaete is also a top contributing species to the overall macrofaunal similarity.

Of the three biotope classes within Turbine 5, one was in complete agreement across the two studies. Both the BIWF and OSAMP biotope were co-defined by *Polycirrus* and *Lumbrinereis*. Within the BIWF samples, *Lumbrinereis* and *Polycirrus* were recovered in 11 and 9 of the 12 samples, respectively, totaling 193 and 175 individuals, respectively. Both species also contributed a high degree to the overall macrofaunal similarity of the biotope. Another biotope was similar in that it was defined by burrowing polychaetes, with *Polygordius* characterizing the BIWF biotope and *Pisione* the OSAMP biotope.

As was experienced at the other turbine areas, the species defining the OSAMP biotope was found to be a key species in the BIWF dataset. Specifically, *Pisione* is the fourth most abundant species among the samples collected at Turbine 5, with 96 individuals recovered within four of the five samples, and is a top contributor to the overall similarity. The third biotope within Turbine 5 exhibited the greatest level of disagreement between the BIWF and OSAMP designation on a species level. The BIWF biotope is defined by the polychaete, *Polycirrus*, whereas the amphipod, *Corophium,* defines the OSAMP biotope. Further, *Corophium* has a minimal presence, with eight individuals recovered within two of the ten samples. Examination of the roles of these defining species, though, reveals they are both tube-builders, and so the two biotopes are similar on a functional level from an ecological perspective.

4.3.3.2 Temporal Comparison of Local Benthic Communities

Whilst being undertaken at a comparatively local scale, the current study largely confirms the current understanding of the benthic ecological conditions within the wider area and as reported in the existing literature. For example:

- The dominance of polychaetes in coarser sediments (e.g., coarse sand, gravel) has been demonstrated within the region of the BIWF for several decades (e.g., LaFrance et al. 2014, Steimle 1982) and continues to be demonstrated in this study.
- For all three studies, polychaetes, amphipods, and mollusks account for the majority (>90%) of all benthic macrofaunal recovered in the samples.
- Comparison of the lists of species identified across all of the sample stations in this study and in the OSAMP study revealed a high degree of overlap. Specifically, 75 of the 130 (58%) species recovered in the BIWF samples were also recovered in the OSAMP samples.
- All of the species that characterize biotopes defined in both the OSAMP and in this study were also recovered in the Steimle study (1982). Similarly, Steimle (1982) noted that most of the species recovered in his samples (collected in 1976) were also recovered in samples collected in the mid-to-late 1940s in studies by Smith (1950) and Deevey (1952).

These studies suggest, overall, that benthic macrofaunal species, as well as their associations with the physical environment, have persisted in this region for over seven decades.

4.4 Discussion of Results with Respect to Hypothesis

The following three hypotheses were tested during this analysis:

1. H0 1 – There will be no difference in benthic communities among turbine areas.
2. H0 2 – There will be no difference in benthic communities between areas and turbine areas.
3. H0 3 – There is no impact on distance from the wind farm foundation regarding organic enrichment or benthic communities.

Hypothesis 1 and 2 were evaluated jointly, results are discussed in **Section 4.4.1**. A discussion of the testing of the third hypothesis is presented in **Section 4.4.2**.

4.4.1 Comparison of Turbine and Control Areas

Two of the hypotheses this study aimed to address were: 1) There will be no difference in benthic communities between turbine and control areas, and 2) There will be no difference in benthic communities among turbine areas.

Considered as two general groups, there are no substantial differences in macrofaunal community composition between the three turbine and three control areas. The statistical analyses (SIMPER, ANOSIM, nMDS plots) show there is a high degree of species overlap among the two groups and the primary differences are related to species abundance, rather than species composition. Both groups are predominantly characterized by polychaetes and nematodes. In this regard, the null hypothesis is accepted.

When the turbine and control areas are considered as individual groups, the two null hypotheses are also accepted. However, interpretation of the data and statistical analyses results are more complex. Both ANOSIM and Permanova+ revealed significant differences in benthic communities between turbine and control locations. On this basis, the two hypotheses are rejected in favor of the alternative hypotheses, i.e., that there are significant differences in benthic communities among turbine locations and that there are significant differences in benthic communities between turbine and reference locations. However, rejection of these hypotheses is confounded by SIMPER outputs, which demonstrated comparable identities of characterizing species across the different locations. The high degree of overlap of samples in the nMDS plot also suggest a lack of distinction in macrofaunal communities across locations. Some separation of some of the samples collected from Control Area 1 was noted and may relate to a comparatively coarser substrate type at this location as evidenced from the acoustic data.

Once again, examination of the grab data revealed that macrofaunal abundances were highly variable across sample stations, and led to the understanding that macrofauna were largely partitioned on the basis of variations in abundances of the characterizing fauna rather than the existence of distinct assemblages. Despite differences in sediment volumes, the grab sampled a consistent surface area of seabed and successfully collected the top-most surface layers where most of the macrofauna live at all sample locations. The distribution of abundance is thus considered to be well represented within the current data dataset. A number of species were patchily distributed and occurred in high densities within one or a few of the cluster samples only. This included encrusting epifaunal species such as the polychaetes Spirobidae and *Sabellaria vulgate* and the barnacle *Amphibalans* amphitrite, probably in response to localized hard substrate conditions. The species that tend to exhibit wide variations in abundances also tend to be less dominant, which reduces their overall influence on macrofaunal community structure from an ecological standpoint. Consequently, while differences may be detected, they do not tend to be representative of the characterizing species. The ANOSIM and Permanova+ showed to be more sensitive to variations in abundances among samples, whereas nMDS and SIMPER were able to consider the samples in a broader context.

The high degree of variability within the grab data may have implications for the interpretation of results from this and subsequent surveys. Multivariate techniques alone may lead to misleading conclusions and will likely need to be considered within the context of broader ecological frames of control such as that offered by SIMPER, nMDS plots, grab and video data, and biotope classification. Review of the outputs of multivariate significance tests against broader descriptive frameworks, as was conducted for this study, may be required in the future to account for the high natural spatial variability at Block Island, as well as any variation introduced by sampling efficiencies across the study area.

Key observations from the species data include the following:

- The control locations had a greater number of species than turbines 1 and 5, but not significantly for Turbine 3.
- The control locations showed significant within-area variance. This may be a function of the wider geographical scale over which they had been collected and the broader scale variability in sediment conditions.
- The controls and Turbine 3 had greater diversity than Turbine 5 (P<0.001), and Turbine 1 had greater diversity than Turbine 5 (P<0.001) suggesting that Turbine 5 had lowest diversity.
- The control locations supported the greatest species richness. Turbine 5 having the lowest richness in line with that for diversity and potentially numbers of species.
- Turbine 1 had significantly lower numbers of individuals than Turbines 3 and 5 and the control areas. Turbines 3 and 5 had noticeably higher numbers of individuals.

4.4.2 Comparison of Turbine, Organic Matter Enrichment, and Benthic Communities

The third hypothesis considered in this study concerned sediment organic content as a function of distance from the foundations. As explained in the results section above, TOC levels close to turbine foundations were not significantly different to those further away. This was not unexpected as the fouling communities on foundations may not have developed sufficiently in the time between foundation installation and the commencement of the current field sampling survey and so may not have contributed to the organic composition of adjacent sediments.

Levels of TOC detected suggest that local macrofaunal communities are not at risk of organic loading at present. In general, a tenfold increase in the concentrations of sediment total organic carbon is anticipated to be required to approach acceptable levels in terms of potential ecological risk. This level of increase could be useful in establishing an appropriate effect size for use in power testing of future monitoring designs.

ANOVA tests between the stations for each turbine study area did not detect any significant differences in TOC levels and benthic communities with distance from foundations.

5 Conclusions and Recommendations for Future Monitoring

This study establishes a comprehensive reference point, or baseline, of information that can serve as a point of comparison for measuring future changes, whether because of human activity or natural processes. Repeat monitoring studies should continue to employ the same sampling methods to ensure data consistency for comparison. Ideally, subsequent surveys should be undertaken at the same time of year to minimize potential seasonal variations. Though, surveys completed within the same season (e.g., winter or summer), as was done in this study, are also adequate for this area, given the habitats and benthic communities are understood to be stable over time.

The data acquired from the current study supports the following conclusions.

- The study area is characterized by a mixed coarse sediment seabed supporting typical coarse sand macrofauna, as reported within the prior literature. Cluster sampling demonstrated fine scale species heterogeneity (i.e., across tens of meters), most likely attributable to the natural patchiness of the seabed sediment types in the Block Island area. Analysis of the data support the need to employ cluster sampling or similar strategy to account for this fine-scale spatial variability and complex structure of benthic macrofaunal communities. Combined, the cluster samples provide a more comprehensive understanding of the sample stations and the study areas.

- Regarding the number of samples, the initial assessment indicated that 22 to 27 samples were needed to confidently detect and account for the variance in species richness. This validates the collection of cluster samples at nine stations as adequate (total of 27 samples).

- No appreciable change in biotic or abiotic variables with distance from each of the foundations was detected. This suggested that there were no strong localized benthic effects due to the presence of the turbine foundations at the locations sampled at this time. Effects due to the presence of the turbine foundations at the distances covered in this study may take a longer period of time than that already elapsed to manifest and/or may occur closer to the foundations than the current sampling design allows.

- Future monitoring will be required to identify and describe benthic change attributable to the presence of the foundations and may need to consider methods for data collection at closer distances to the foundations (e.g., within 25 meters) to capture benthic change at close ranges. Suitable data collection methods close to the foundations may include remote seabed camera surveillance or diver-based data acquisition (e.g., video footage, sampling). Acoustic data collection and assessment conducted during future benthic monitoring surveys and intervening periods could also be valuable in assessing changes over time by indicating areas of differing reflectivity or alterations in sediment acoustic boundaries.

- SIMPER and MDS suggested that benthic community types between turbine locations were comparable. The biotopes present were characterized by polychaetes and nematodes within mixed coarse sediment types and were typically of the wider region. Significant differences detected by ANOSIM were attributed to differences in species abundances.

- Permanova+ is recommended for use for future assessment purposes as the existing literature suggest that it is generally more powerful in detecting community change, and is less affected by the heterogeneity detected in the current study, compared to other techniques such as ANOSIM. However, it is important to couple the results of these more sensitive statistical analyses with other analyses and examinations to allow for understanding of the data in a broader ecological framework. Broader changes in benthos may be indicated with nMDS plots, SIMPER analyses, and examination of the raw data, as well as by alterations to the biotope classifications or changes to the biotope boundaries recorded here.

- Despite apparent variation in the performance of the grab sampler, broad consistency in the macrofaunal data was achieved as the same surface area and uppermost sediment surface layers where most macrofauna live was sampled during the grab sampling campaign.

Further 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. Observations of effects at the local level can be used to inform future predictions of potential wider scale and cumulative effects associated with larger, and multiple, offshore wind facilities.

Following completion of the initial benthic survey at BIWF, a number of methodological refinements and future monitoring initiatives are proposed below.

5.1 Plans for Future Monitoring

Recommendations for future relevant monitoring are discussed below.

5.1.1 Long Term Monitoring Plans

It is important the monitoring be continued over time to track changes in benthic community structure. Monitoring 1-year post installation would permit assessment of any short term changes whilst continued monitoring over 3 to 5 years and 10 years would permit assessment of effects over medium and longer terms, respectively. Extended monitoring is important for this BIWF study area because it is believed not enough time has elapsed for the alterations that are anticipated to take place to occur within the area sampled for this (i.e., > 30 m from the center point under the foundation structure). As such, this study has not yet successfully quantified changes caused by the BIWF in the defined study area. However, this study is valuable in recognizing minimal changes in this region are likely to take place over wind facility construction and initial operations conducted over extremely short time scales (e.g., < 1-2 years).

The present project involves sampling once per year. As such, it is recommended that sampling occur over the same time period each year, as to not introduce seasonality as a variable. However, for longer-term studies, it would be beneficial to sample across seasons to investigate any seasonality that may be present in the vicinity of the BIWF. A long term data set would be necessary to discern any seasonal patterns from variability caused by other factors (e.g., year-to-year, BIWF, food-web dynamics).

5.1.2 Other Parallel Studies

Rock or concrete placed on the seabed as cable or scour protection may not provide the same variety of micro-niches or surfaces for attaching epifauna and epiflora compared to the naturally occurring rock and may therefore support comparatively fewer species. Consequently, where imported rock or concrete is used over local hard seabed substrata, a net loss of species diversity may occur within the footprint of the protection material. The current benthic monitoring at BIWF provides opportunity to compare epifaunal communities attaching to the cable protection material with that present on the local natural rock substrates (i.e., at control area 1). Diver or remote video inspection may permit a qualitative assessment as to the species variety and species abundance on artificial and natural hard substrata for comparison. Results could help address issues relating to potential habitat loss due to the introduction of scour and cable protection material as part of renewables developments and whether this artificial material offers equivalent habitat quality.

Diver sampling studies are proposed to collect quantitative information on fouling communities on the foundations at BIWF. The data may be used to describe the presence of any non-native species, any important species contributing to the overall fouling biomass and the ecosystem services provided (i.e., increased feeding and refugia). The data could also provide useful context for the current benthic monitoring studies. Repeat studies would allow assessment of temporal fluctuations in epifouling communities including any important losses of species and biomass following storm events and which might represent episodic inputs of biomass to the benthos.

Additionally, development (or adoption) of an “ecosystem” or “quality” index may be useful for future monitoring purposes. For example, the index could describe the relative proportions of species exhibiting different feeding traits (i.e., filter feeders, surface deposit feeders and sub-surface deposit feeders) in each sample as a measure of the benthic quality. High numbers of sub-surface deposit feeders could, for example, be indicative of degraded conditions. Reducing the species data to this kind of index would allow for statistical significance testing of spatial and temporal changes in benthos and importantly will permit assessment of the direction of change (i.e., becoming more degraded or improving). Such an index may be useful in statutory monitoring and compliance assessment at future offshore wind facilities.

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Appendices

Appendix 1. Field Survey Records

Sample ID	X	Y	Date	Tine	Depth (m)	Grab volume	Habitat Description
T1-7_Rep1	-71.5067	41.1257	20/12/2016	09:13	27.37	1/4	Cobble, gravel, sand; Cobbles caught in jaws of grab
T1-7_Rep2	-71.5067	41.1257	20/12/2016	09:19	27.46	1/4	Cobble, gravel, sand
T1-7_Rep3	-71.5067	41.1257	20/12/2016	09:23	27.40	1/4	Cobble, gravel, sand
T1-8_Rep1	-71.5068	41.1256	20/12/2016	09:26	27.49	1/3	Cobble, gravel, sand
T1-8_Rep2	-71.5067	41.1257	20/12/2016	09:29	27.04	1/4	Cobble, gravel, sand
T1-8_Rep3	-71.5067	41.1257	20/12/2016	09:45	27.46	1/3	Cobble, gravel, sand
T1-3_Rep1	-71.5073	41.1255	20/12/2016	09:58	27.37	1/4	Cobble, gravel, sand
T1-3_Rep2	-71.5073	41.1255	20/12/2016	10:03	27.80	1/4	Cobble, gravel, sand
T1-3_Rep3	-71.5070	41.1255	20/12/2016	10:06	27.34	1/4	Cobble, gravel, sand
T1-2_Rep1	-71.5075	41.1253	20/12/2016	10:13	27.83	1/4	Cobble, gravel, sand
T1-2_Rep2	-71.5075	41.1254	20/12/2016	10:17	27.58	1/4	Cobble, gravel, sand
T1-2_Rep3	-71.5076	41.1254	20/12/2016	10:20	27.61	1/4	Cobble, gravel, sand
T1-4_Rep1	-71.5082	41.1258	20/12/2016	10:30	28.50	3/4	Gravel, sand; Go-Pro NOT on
T1-4_Rep2	-71.5083	41.1258	20/12/2016	10:35	28.19	1/4	Gravel, sand
T1-4_Rep3	-71.5083	41.1259	20/12/2016	10:38	28.38	1/4	Gravel, sand
T1-9_Rep1	-71.5084	41.1263	20/12/2016	10:41	28.32	1/2	Gravel, sand
T1-9_Rep2	-71.5083	41.1264	20/12/2016	10:48	28.56	1/4	Cobble, gravel, sand
T1-9_Rep3	-71.5083	41.1261	20/12/2016	10:52	28.50	1/2	Cobble, gravel, sand
T1-5_Rep1	-71.5077	41.1264	20/12/2016	10:56	28.29	1/2	Gravel, sand
T1-5_Rep2	-71.5077	41.1264	20/12/2016	11:06	28.25	1/4	Cobble, gravel, sand
T1-5_Rep3	-71.5079	41.1263	20/12/2016	11:10	28.04	3/4	n/a
T1-1_Rep1	-71.5071	41.1261	20/12/2016	11:14	27.68	Full	Sand; Full grab
T1-1_Rep2	-71.5074	41.1259	20/12/2016	11:18	28.13	1/8	Gravel, sand
T1-1_Rep3	-71.5071	41.1260	20/12/2016	11:21	27.92	1/4	Cobble, gravel, sand
T1-6_Rep1	-71.5071	41.1260	20/12/2016	11:27	27.77	1/2	Sand with little cobble and gravel
T1-6_Rep2	-71.5069	41.1260	20/12/2016	11:29	27.92	1/4	Sand with little cobble and gravel
T1-6_Rep3	-71.5070	41.1261	20/12/2016	11:32	27.92	1/8	Cobble, gravel, sand
T3-7_Rep1	-71.5218	41.1152	20/12/2016	11:45	26.43	1/4	Gravel, sand; Grain size tube was not flashed at Go-Pro before deployment
T3-7_Rep2	-71.5220	41.1153	20/12/2016	11:49	26.40	3/4	Gravel, sand
T3-7_Rep3	-71.5220	41.1153	20/12/2016	11:56	26.49	Full	Gravel, sand
T3-8_Rep1	-71.5223	41.1149	20/12/2016	12:11	26.27	1/2	Gravel, sand

Sample ID	X	Y	Date	Time	Depth (m)	Grab volume	Habitat Description
T3-8_Rep2	-71.5222	41.1148	20/12/2016	12:14	26.18	3/4	Gravel, sand
T3-8_Rep3	-71.5222	41.1149	20/12/2016	12:17	26.37	1/2	Gravel, sand
T3-3_Rep1	-71.5216	41.1145	20/12/2016	12:20	25.97	3/4	Gravel, sand
T3-3_Rep2	-71.5215	41.1145	20/12/2016	12:24	26.09	1/3	Gravel, sand; Mussel shell hash
T3-3_Rep3	-71.5215	41.1145	20/12/2016	12:26	26.15	1/4	Cobble, gravel, sand; Mussel shells (~1"-2")
T3-1_Rep1	-71.5214	41.1145	20/12/2016	12:31	26.21	Full	Gravel, sand; Mussel shell hash
T3-1_Rep2	-71.5216	41.1144	20/12/2016	12:36	25.79	Full	Gravel, sand; Mussel shell hash
T3-1_Rep3	-71.5215	41.1145	20/12/2016	12:39	25.91	Full	Gravel, sand; Mussel shell hash
T3-9_Rep1	-71.5213	41.1141	20/12/2016	12:50	25.36	Full	Gravel, sand
T3-9_Rep2	-71.5209	41.1141	20/12/2016	12:54	25.48	Full	Gravel, sand
T3-9_Rep3	-71.5208	41.1140	20/12/2016	12:57	26.09	Full	Gravel, sand
T3-6_Rep1	-71.5211	41.1142	20/12/2016	13:10	25.76	Full	Gravel, sand
T3-6_Rep2	-71.5212	41.1142	20/12/2016	13:13	25.51	1/2	Gravel, sand
T3-6_Rep3	-71.5211	41.1142	20/12/2016	13:15	25.97	Full	Gravel, sand
T3-4_Rep1	-71.5206	41.1147	20/12/2016	13:19	25.79	1/2	Gravel, sand
T3-4_Rep2	-71.5204	41.1147	20/12/2016	13:22	25.73	Full	Gravel, sand
T3-4_Rep3	-71.5204	41.1147	20/12/2016	13:28	25.88	1/2	Gravel, sand
T3-2_Rep1	-71.5211	41.1150	20/12/2016	13:32	26.21	Full	Sand with little gravel
T3-2_Rep2	-71.5210	41.1151	20/12/2016	13:36	26.30	Full	Sand with little gravel
T3-2_Rep3	-71.5209	41.1150	20/12/2016	13:38	26.15	Full	Sand with little gravel
T3-5_Rep1	-71.5206	41.1154	20/12/2016	13:51	26.52	1/3	n/a
T3-5_Rep2	-71.5207	41.1153	20/12/2016	13:55	26.52	1/4	Cobble, gravel, sand
T3-5_Rep3	-71.5204	41.1155	20/12/2016	13:59	26.52	Full	Sand
T5-9_Rep1	-71.5389	41.1062	20/01/2017	08:38	22.34	Full	Coarse sand
T5-9_Rep2	-71.5387	41.1063	20/01/2017	08:52	22.46	n/a	n/a
T5-9_Rep3	-71.5385	41.1063	20/01/2017	09:01	22.68	Full	Coarse sand
T5-1_Rep1	-71.5382	41.1063	20/01/2017	09:05	22.77	1/2	Coarse sand
T5-1_Rep2	-71.5380	41.1063	20/01/2017	09:08	22.83	1/3	Coarse sand
T5-1_Rep3	-71.5382	41.1063	20/01/2017	09:11	22.62	Full	Coarse sand
T5-6_Rep1	-71.5378	41.1058	20/01/2017	09:15	22.68	Full	Coarse sand
T5-6_Rep2	-71.5377	41.1058	20/01/2017	09:22	22.31	Full	n/a
T5-6_Rep3	-71.5378	41.1058	20/01/2017	09:24	22.19	Full	Coarse sand
T5-7_Rep1	-71.5375	41.1057	20/01/2017	09:29	22.04	1/4	n/a
T5-7_Rep2	-71.5377	41.1057	20/01/2017	09:36	22.16	Full	Coarse sand
T5-7_Rep3	-71.5377	41.1055	20/01/2017	09:40	22.22	1/2	Coarse sand
T5-8_Rep1	-71.5373	41.1055	20/01/2017	09:43	22.59	Full	Coarse sand
T5-8_Rep2	-71.5373	41.1055	20/01/2017	09:50	22.77	1/10	n/a
T5-8_Rep3	-71.5373	41.1055	20/01/2017	09:57	22.49	1/8	Coarse sand
T5-3_Rep1	-71.5370	41.1063	20/01/2017	10:01	23.35	1/10	n/a
T5-3_Rep2	-71.5372	41.1062	20/01/2017	10:04	23.59	1/2	Coarse sand
T5-3_Rep3	-71.5370	41.1063	20/01/2017	10:08	23.44	1/2	Gravel, coarse sand
T5-4_Rep1	-71.5368	41.1063	20/01/2017	10:15	23.93	Full	Finer sand
T5-4_Rep2	-71.5368	41.1067	20/01/2017	10:19	23.90	Full	Finer sand
T5-4_Rep3	-71.5368	41.1067	20/01/2017	10:20	24.14	Full	Medium sand

Sample ID	X	Y	Date	Time	Depth (m)	Grab volume	Habitat Description
T5-5_Rep1	-71.5372	41.1067	20/01/2017	10:30	23.90	3/4	Medium sand
T5-5_Rep2	-71.5372	41.1067	20/01/2017	10:36	23.84	3/4	Medium sand
T5-5_Rep3	-71.5370	41.1067	20/01/2017	10:40	24.14	1/3	n/a
T5-2_Rep1	-71.5373	41.1067	20/01/2017	10:45	23.59	Full	Medium sand
T5-2_Rep2	-71.5373	41.1067	20/01/2017	10:48	23.74	Full	Medium, fine sand
T5-2_Rep3	-71.5373	41.1067	20/01/2017	10:52	24.08	Full	Medium sand
CI-2_Rep1	-71.5407	41.1022	20/01/2017	11:10	21.09	1/8	Cobble, gravel sand; Gravel in jaws of grab
CI-2_Rep2	-71.5407	41.1022	20/01/2017	11:17	21.73	1/8	Cobble, gravel sand; Gravel in jaws of grab
CI-2_Rep3	-71.5407	41.1022	20/01/2017	11:27	21.70	1/10	Very little sand
C1-3_Rep1	-71.5402	41.1012	20/01/2017	11:34	21.67	Over full	Coarse sand; Shell hash
C1-3_Rep2	-71.5402	41.1012	20/01/2017	11:37	21.46	Full	Coarse sand
C1-3_Rep3	-71.5402	41.1012	20/01/2017	11:43	21.82	Full	Coarse sand; Shell hash
C1-4_Rep1	-71.5410	41.1012	20/01/2017	11:56	20.24	1/2	n/a
C1-4_Rep2	-71.5412	41.1012	20/01/2017	12:05	20.57	n/a	Sand, cobble, gravel; not much material
C1-4_Rep3	-71.5410	41.1012	20/01/2017	12:17	20.42	1/4	n/a; Rocks in jaws of grab
C1-1_Rep1	-71.5417	41.1010	20/01/2017	12:23	21.55	n/a	Sand, but mostly shell hash
C1-1_Rep2	-71.5418	41.1010	20/01/2017	12:41	22.31	1/4	Fine sand; Shell hash
C1-1_Rep3	-71.5418	41.1012	20/01/2017	12:45	22.25	1/4	Gravel, fine sand; Shell hash; Rocks in jaws of grab
C2-2_Rep1	-71.5113	41.1098	20/01/2017	12:58	27.25	3/4	Cobble, gravel, sand; Grain size tube was not flashed at Go-Pro before deployment
C2-2_Rep2	-71.5117	41.1100	20/01/2017	13:07	26.55	Full	Fine sand with gravel
C2-2_Rep3	-71.5115	41.1100	20/01/2017	13:11	26.82	1/2	Coarse sand; Rocks in jaws of grab
C2-1_Rep1	-71.5117	41.1102	20/01/2017	13:15	26.52	Full	Gravel, coarse sand; "muddy water"
C2-1_Rep2	-71.5117	41.1103	20/01/2017	13:18	26.49	1/2	Gravel, coarse sand; Rocks in jaws of grab
C2-1_Rep3	-71.5118	41.1102	20/01/2017	13:22	26.49	1/4	Gravel, sand
C2-4_Rep1	-71.5123	41.1107	20/01/2017	13:25	26.03	1/2	Gravel, coarse sand; Rocks in jaws of grab
C2-4_Rep2	-71.5125	41.1107	20/01/2017	13:35	25.97	n/a	Sand with gravel; Rocks in jaws of grab
C2-4_Rep3	-71.5123	41.1108	20/01/2017	13:38	25.63	1/8	Coarse sand with gravel
C2-3_Rep1	-71.5122	41.1108	20/01/2017	13:42	25.60	1/2	Gravel, sand; Rocks in jaws of grab
C2-3_Rep2	-71.5120	41.1108	20/01/2017	13:45	26.24	Full	Gravel, sand; Amphipods
C2-3_Rep3	-71.5122	41.1110	20/01/2017	13:48	25.88	1/4	Gravel, coarse sand; Amphipods

Sample ID	X	Y	Date	Time	Depth (m)	Grab volume	Habitat Description
C3-1_Rep1	-71.5313	41.1172	21/03/2017	08:38	27.10	1/2	Gravel, sand; Amphipods
C3-1_Rep2	-71.5318	41.1173	21/03/2017	08:48	27.01	1/2	Gravel, finer sand
C3-1_Rep3	-71.5317	41.1173	21/03/2017	08:52	26.70	1/3	Gravel, coarse sand; Rock in jaws of grab
C3-2_Rep1	-71.5303	41.1168	21/03/2017	09:02	26.91	1/4	Gravel, medium sand
C3-2_Rep2	-71.5303	41.1168	21/03/2017	09:08	26.76	1/8	Gravel, sand; Not much material
C3-2_Rep3	-71.5303	41.1168	21/03/2017	09:16	26.82	n/a	Gravel, finer sand; Not much material
C3-3_Rep1	-71.5318	41.1172	21/03/2017	09:23	27.16	1/2	Gravel, medium sand
C3-3_Rep2	-71.5318	41.1172	21/03/2017	09:27	27.01	1/2	Gravel, medium sand
C3-3_Rep3	-71.5318	41.1172	21/03/2017	09:30	27.40	1/2	Gravel, medium sand
C3-4_Rep1	-71.5322	41.1172	21/03/2017	09:33	27.25	1/2	Cobble, sand
C3-4_Rep2	-71.5323	41.1172	21/03/2017	09:39	27.43	1/4	Gravel, fine sand; Rocks in jaws of grab
C3-4_Rep3	-71.5323	41.1172	21/03/2017	09:42	27.34	1/4	Gravel, medium sand
C3-QC	-71.5310	41.1167	21/03/2017	09:50	26.82	Full	Gravel, medium sand; Go-Pro NOT on
T5-OC	-71.5368	41.1068	21/03/2017	10:00	23.53	Full	Medium sand
T3-QC	-71.5213	41.1150	21/03/2017	10:09	26.37	Full	Gravel, coarse sand
T1-QC	-71.5077	41.1252	21/03/2017	10:17	27.61	1/3	n/a; Rocks in jaws of grab

Appendix 2. Full Results of the Sediment Particle Size Distribution Analysis

Appendix 3. Results of the Seabed Video Analysis

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-1_Rep1	27.7	Homogeneous, sand waves, medium sand with little gravel. Very small amount of shell hash	
T1-1_Rep2	28.1	Homogeneous, sand waves, medium sand with little gravel. Very small amount of shell hash	
T1-1_Rep3	27.9	Homogeneous, sand waves, medium sand with some cobble and some gravel. Very small amount of shell hash	
T1-2_Rep1	27.8	Homogeneous, no visible bedform, medium sand with some cobble and some gravel. Cobbles have growth on them (appear to be barnacles). Very small amount of shell hash. Strange white thing present (biological).	

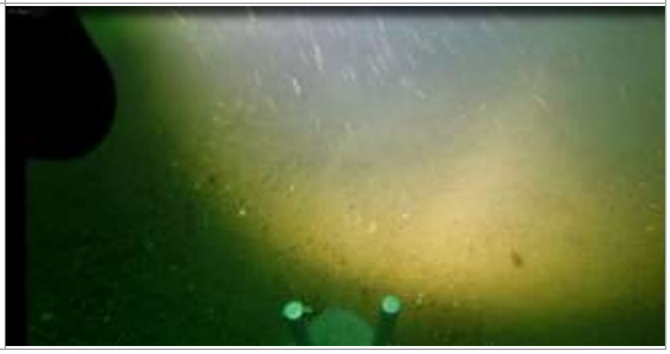
Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-2_Rep2	27.6	Homogeneous, sand waves, medium sand with little cobble and some gravel. Very small amount of shell hash	
T1-2_Rep3	27.6	Homogeneous, no visible bedform, medium sand with some cobble and some gravel. Very small amount of shell hash	
T1-3_Rep1	27.4	Homogeneous, no visible bedform, medium sand with some cobble and some gravel. No shell hash. Strange white thing present (biological).	
T1-3_Rep2	27.8	Homogeneous, no visible bedform, medium sand with some cobble and some gravel. No shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-3_Rep3	27.3	Homogeneous, sand waves, fine to medium sand with some cobble and some gravel. No shell hash	
T1-4_Rep1	28.5	N/A	N/A
T1-4_Rep2	28.2	Homogeneous, no visible bedform, medium sand with little cobble and some gravel. Very small amount of shell hash	
T1-4_Rep3	28.4	Homogeneous, no visible bedform, medium sand with some cobble and some gravel. Cobbles have growth on them (appear to be barnacles). Very small amount of shell hash	
T1-5_Rep1	28.3	Homogeneous, sand waves, medium to coarse sand with some gravel. Very small amount of shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-5_Rep2	28.2	Homogeneous, sand waves, medium sand with little cobble and some gravel. Very small amount of shell hash	
T1-5_Rep3	28.0	Homogeneous, sand waves, medium sand with some gravel. Very small amount of shell hash	
T1-6_Rep1	27.8	Homogeneous, sand waves, fine to medium sand. Very small amount of shell hash	
T1-6_Rep2	27.9	Homogeneous, sand waves, fine to medium sand. Very small amount of shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-6_Rep3	27.9	Homogeneous, sand waves, fine to medium sand. Very small amount of shell hash	
T1-7_Rep1	27.4	Homogeneous, sand waves, fine to medium sand with little gravel. Very small amount of shell hash. Strange white thing present (biological; in 2nd video from grab attempt that was not successful - "T1-7_Rep_1_Not_Kept")	
T1-7_Rep2	27.5	Homogeneous, no visible bedform, fine to medium sand with some cobble and some gravel. Very small amount of shell hash. Strange white thing present (biological).	
T1-7_Rep3	27.4	Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Very small amount of shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-8_Rep1	27.5	Homogeneous, no visible bedform, fine to medium sand with some cobble and some gravel. Very small amount of shell hash.	
T1-8_Rep2	27.0	Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Very small amount of shell hash.	
T1-8_Rep3	27.5	Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Some shell hash.	
T1-9_Rep1	28.3	Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Some shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-9_Rep2	28.6	1st drop: Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Some shell hash. 2nd drop: Homogeneous, sand waves, fine to medium sand with little cobble and lot of gravel. Quite a lot of shell hash.	 1st drop  2nd drop
T1-9_Rep3	28.5	Homogeneous, sand waves, fine to medium sand with little cobble and some gravel. Quite a lot of shell hash.	
T3-1_Rep1	26.2	Homogeneous, sand waves, medium to coarse sand with some gravel. Quite a lot of shell hash (blue mussel)	

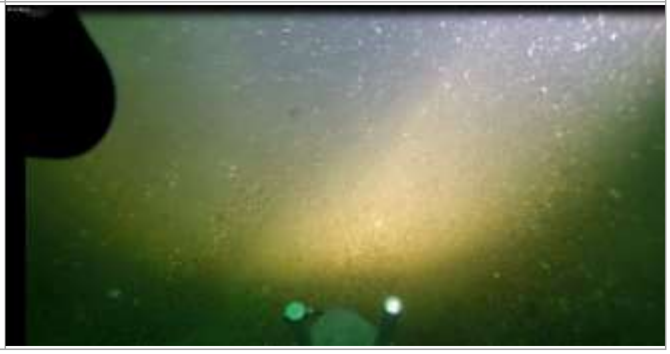
Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-1_Rep2	25.8	Homogeneous, sand waves, medium to coarse sand with some gravel. Quite a lot of shell hash (blue mussel)	
T3-1_Rep3	25.9	Homogeneous, sand waves, medium to coarse sand with some gravel and cobble. Quite a lot of shell hash (blue mussel - seemingly juvenile shells)	
T3-2_Rep1	26.2	Homogeneous, sand waves, medium sand with little gravel. No shell hash	
T3-2_Rep2	26.3	Homogeneous, sand waves, medium sand with some gravel. Very small amount of shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-2_Rep3	26.1	Homogeneous, sand waves, medium sand with little gravel. Some shell hash (blue mussel)	
T3-3_Rep1	26.0	Homogeneous, no visible bedform, coarse sand with some gravel. Some shell hash	
T3-3_Rep2	26.1	Homogeneous, sand waves, coarse sand with some gravel. Quite a lot of shell hash (blue mussel)	
T3-3_Rep3	26.1	Homogeneous, sand waves, medium to coarse sand with some gravel. A large amount of shell hash (blue mussel)	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-4_Rep1	25.8	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash	
T3-4_Rep2	25.7	Homogeneous, sand waves, medium to coarse sand with some gravel. Very small amount of shell hash	
T3-4_Rep3	25.9	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash	
T3-5_Rep1	26.5	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-5_Rep2	26.5	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash	
T3-5_Rep3	26.5	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash	
T3-6_Rep1	25.7	Homogeneous, sand waves, coarse sand with some gravel. Small amount of shell hash	
T3-6_Rep2	25.5	Homogeneous, sand waves, coarse sand with some gravel. Small amount of shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-6_Rep3	26.0	Homogeneous, sand waves, coarse sand with some gravel. Small amount of shell hash	
T3-7_Rep1	26.4	Homogeneous, sand waves, coarse sand with little gravel. Very small amount of shell hash	
T3-7_Rep2	26.4	N/A	N/A
T3-7_Rep3	26.5	Homogeneous, sand waves, coarse sand with some gravel. Very small amount of shell hash	
T3-8_Rep1	26.3	Homogeneous, sand waves, medium to coarse sand with very little gravel. Some shell hash	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-8_Rep2	26.2	Homogeneous, sand waves, medium to coarse sand with very little gravel. Some shell hash	
T3-8_Rep3	26.4	Homogeneous, sand waves, medium to coarse sand. Some shell hash	
T3-9_Rep1	25.3	Homogeneous, sand waves, medium to coarse sand with lot of gravel. Quite a lot of shell hash	
T3-9_Rep2	25.5	Homogeneous, sand waves, medium to coarse sand with some gravel. Some shell hash	

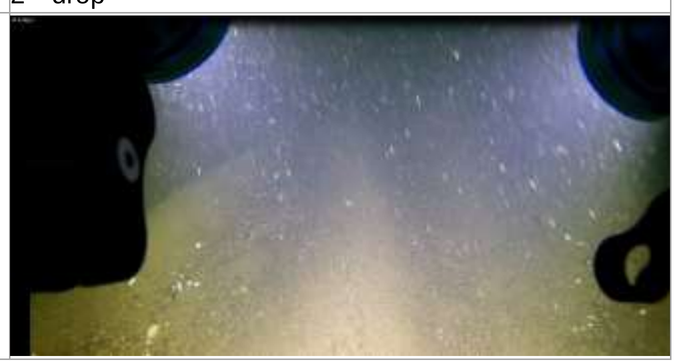
Sample ID	Depth (m)	Sediment Description	Example Photograph
T3-9_Rep3	26.1	Homogeneous, sand waves, medium to coarse sand with lot of gravel. Quite a lot of shell hash	
T5-1_Rep1	22.8	Homogeneous, sand waves, medium to coarse sand with some gravel. Some shell hash. Image "b" attempts to show sand wave features. One clam visible - believed to be *Astarte borealis* or *Astarte castanea*	 Image a  Image b

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-1_Rep2	22.8	Homogeneous, sand waves, medium to coarse sand with some gravel. Some shell hash. Image "b" attempts to show sand wave features. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	 Image a  Image b
T5-1_Rep3	22.6	Homogeneous, sand waves, medium to coarse sand with some gravel. Some shell hash. Several clams visible - believed to be Astarte borealis or Astarte castanea One starfish visible.	
T5-2_Rep1	23.6	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash. One clam visible - believed to be *Astarte borealis* or *Astarte castanea*	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-2_Rep2	23.7	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	
T5-2_Rep3	24.1	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	
T5-3_Rep1	23.3	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash.	
T5-3_Rep2	23.6	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-3_Rep3	23.4	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash.	
T5-4_Rep1	23.9	Homogeneous, sand waves, fine to medium sand. No shell hash.	
T5-4_Rep2	23.9	Homogeneous, sand waves, fine to medium sand. No shell hash. Few small blue mussel shells/fragments	
T5-4_Rep3	24.1	Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-5_Rep1	23.9	1st drop: Homogeneous, sand waves, medium to coarse sand with some gravel. Very small amount of shell hash. 2nd drop: Homogeneous, sand waves, medium to coarse sand with little gravel. Very small amount of shell hash. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	 1st drop  2nd drop
T5-5_Rep2	23.8	Homogeneous, sand waves, medium sand. No shell hash. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*.	
T5-5_Rep3	24.1	Homogeneous, sand waves, medium sand. No shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-6_Rep1	22.7	Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash.	
T5-6_Rep2	22.3	1st drop: Homogeneous, sand waves, medium to coarse sand. Few large cobbles / small boulders nearby. Very small amount of shell hash. Several crabs in surrounding area (unknown species). Several clams visible - believed to be Astarte borealis or Astarte castanea 2nd drop: Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash. Several clams visible - believed to be *Astarte borealis* or Astarte castanea	 1st drop  2nd drop
T5-6_Rep3	22.2	Homogeneous, sand waves, medium to coarse sand. Some shell hash. Several clams visible - believed to be Astarte borealis or *Astarte castanea.*	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-7_Rep1	22.0	1st drop: Homogeneous field of medium sand with small boulders and large cobbles (no gravel). Barnacle growth on cobbles and boulders (various densities). Very small amount of shell hash. 2nd drop: Homogeneous, sand waves, medium sand with small boulders and large cobbles (no gravel). Barnacle growth on cobbles and boulders (various densities). Small amount of red algae growth. Very small amount of shell hash.	 1st drop  2nd drop
T5-7_Rep2	22.1	Homogeneous, sand waves, medium sand with few large cobbles and one small boulder with barnacle and red algae growth. Very small amount of shell hash.	
T5-7_Rep3	22.2	Homogeneous, sand waves, medium sand. Some shell hash. Few large cobbles and small boulders in surrounding area / background with some barnacle and red algae growth.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-8_Rep1	22.6	Homogeneous, sand waves, medium sand. Very small amount of shell hash. Few large cobbles and small boulders in surrounding area / background with some barnacle and white algae growth. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	
T5-8_Rep2	22.8	Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash. Several large cobbles and small boulders in surrounding area and background with dense to fairly dense barnacle growth. Some red algae growth coming from seafloor.	
T5-8_Rep3	22.5	Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash. One small boulder / large cobble with dense barnacle growth. Several clams visible - believed to be *Astarte borealis* or *Astarte* castanea	
T5-9_Rep1	22.3	Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash. Several clams visible - believed to be Astarte borealis or *Astarte castanea*	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T5-9_Rep2	22.5	Homogeneous, sand waves, medium to coarse sand. Very small amount of shell hash. One small boulder / large cobble with dense barnacle growth. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	
T5-9_Rep3	22.7	Homogeneous, sand waves, medium to coarse sand. Some shell hash. Several large cobbles and small boulders in surrounding area and background with dense to fairly dense barnacle growth. Some red algae growth coming from seafloor. Several clams visible - believed to be *Astarte borealis* or *Astarte castanea*	
C1-1_Rep1	21.5	1st drop (grab not recovered): Homogeneous, dense boulder field. Boulders of various sizes (large to small). Cobbles and gravel between boulders. Dense algae (red and white) growth on boulders. Some shell hash. 2nd drop: Homogeneous, sand waves, medium sand. Some red algae growth coming from seafloor. Dense shell hash - dominating feature.	 1st drop  2nd drop

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-1_Rep2	22.3	(Have two video clips for this station…. Both are described here; believe second video is where grab was collected). 1st video: Homogeneous, dense cobble and gravel covered seafloor. Some red algae growth on cobbles and gravel. Some shell hash. 2nd video: Homogeneous, fine to medium sand with large cobbles and small boulders and some gravel. Dense shell hash. Dense algae (red and white) growth on cobbles and boulders. Some calcareous red algae present, also. Strange white thing present - quite extensive here.	 1st video  2nd video
C1-1_Rep3	22.2	Homogeneous, mix of gravel and fine to medium sand with large cobbles and small boulders. Some algae (red and white) and barnacle growth on cobbles and boulders. Some shell hash. Few starfish.	
C1-2_Rep1	21.1	Sand waves, patches of cobble and gravel (one type of patch) and medium to coarse sand (another type of patch). Few small boulders. Barnacle growth on cobbles and boulders. Small amount of red algae growth coming from seafloor. Some shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-2_Rep2	21.7	1st drop: Homogeneous, no visible bedform, dense boulder (small), cobble and gravel covered seafloor. Dense algae (red and white) growth on boulders and cobbles. Some shell hash. 2nd drop: No visible bedform, mixture of patches of boulders of various sizes (large to small), cobble, and gravel (one type of patch) and medium to coarse sand (another type of patch). Four starfish (three on cobbles, one on small boulder). Strange white thing present (biological; on large boulder). Dense barnacle growth on cobbles and boulders. Some patches on algae growth (red and white; on large boulder). Some shell hash.	 1st drop  2nd drop

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-2_Rep3	21.7	1st drop: Grab landed within what appears to be sand waves with clear distinction between trough and crest. Trough contains small cobbles, gravel, and quite a lot of shell hash. Some cobbles have barnacle growth. Crests contain medium to coarse sand with less shell hash. When grab is retrieved, it is clear grab landed just alongside an extensive area of large boulders (what image "b" is attempting to capture). 2nd drop: Homogeneous mixture of small boulders, cobbles, gravel, and medium to coarse sand. Quite a lot of shell hash. Barnacle growth on boulders and cobbles. Some red and white algae growth. One starfish (on boulder in the background) and one on sand in left side of image. 3rd drop: Homogeneous mixture of small boulders, cobbles, gravel, and medium to coarse sand. Quite a lot of shell hash. Barnacle growth on boulders and cobbles. Some red and white algae growth. One starfish in the background.	 1st drop  2nd drop  3rd drop

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-3_Rep1	21.7	1st drop (grab not recovered): Homogeneous, dense boulder area. Boulders of various sizes (large to small). Cobbles and gravel between boulders. Barnacle and algae (red and white) growth on boulders (of various densities). Very small amount of shell hash. 2nd drop: Homogeneous, sand waves, coarse sand with little gravel. Dense shell hash.	 1st drop  2nd drop
C1-3_Rep2	21.4	Homogeneous, sand waves, coarse sand with some gravel. Some shell hash. Few large cobbles with barnacle growth.	
C1-3_Rep3	21.8	Homogeneous, sand waves, medium to coarse sand with little gravel. Dense shell hash. Several large cobbles and small boulders in surrounding area and background with fairly dense barnacle growth. Some red algae growth.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-4_Rep1	20.2	1st drop: Homogeneous, mix of boulders, cobble, and gravel with fine to medium sand. No shell hash. Larger cobbles have some barnacle growth. Boulders have dense algae (red and white) growth. One starfish. 2nd drop: Appears to be homogeneous bottom of dense cobbles covered in dense algae (red and white) growth with fine to medium sand between cobbles. No shell hash. 3rd drop: Homogenous, mix of cobbles and gravel on fine to medium sand. Very small amount of shell hash. Some algae (red and white) growth. 4th drop (grab recovered): Homogeneous, sand waves, fine to medium sand (crests) with lot of gravel (troughs). Very small amount of shell hash. Boulders in distant background. One clam visible - believed to be *Astarte borealis* or *Astarte castanea*.	 1st drop  2nd drop  3rd drop  4th drop

Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-4_Rep2	20.6	1st drop: Homogeneous, mix of cobble and gravel on fine to medium sand. Very small amount of shell hash. Areas of dense algae (red and white) growth. Some barnacle growth on some cobbles. Boulders in distant background. 2nd drop: Very large boulder with dense barnacle growth, some algae (white) growth, and a few starfish. 3rd drop: Homogeneous, mix of boulders, cobble, and gravel on fine to medium sand. Some shell hash. Dense algae (red and white) growth and some barnacle growth on boulders and cobbles. Several starfish.	 1st drop  2nd drop  3rd drop

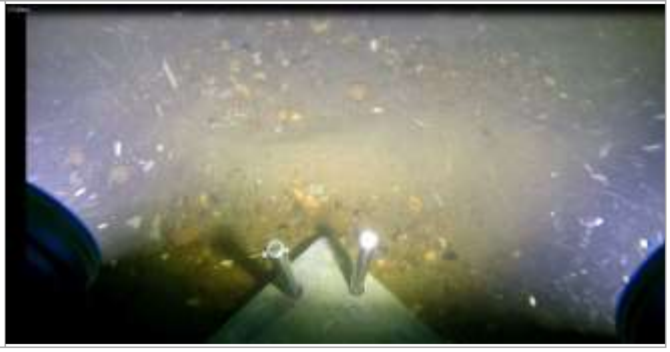
Sample ID	Depth (m)	Sediment Description	Example Photograph
C1-4_Rep3	20.4	1st drop: Homogeneous, dense mix of cobble and gravel on fine to medium sand. Very small amount of shell hash. Dense algae (red and white) growth on cobbles. Boulders in distant background. 2nd drop: Homogeneous, mix of cobble and gravel on fine to medium sand. No shell hash. Dense algae (red and white) and barnacle growth on cobbles. Few starfish.	 1st drop  2nd drop
C2-1_Rep1	26.5	Homogeneous, no visible bedform, equal mixture of fine to medium sand and gravel. No shell hash.	
C2-1_Rep2	26.5	Homogeneous, sand waves, fine to medium sand with lot of gravel. No shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C2-1_Rep3	26.5	Homogeneous, no visible bedform, equal mixture of fine to medium sand and gravel. Few small cobbles. No shell hash.	
C2-2_Rep1	27.2	Homogeneous, sand waves, fine to medium sand with some gravel and some cobbles. No shell hash. Some barnacle growth on cobbles. Small patch of red algae.	
C2-2_Rep2	26.5	1st drop: Homogeneous, sand waves, mixture of fine to medium sand and gravel. No shell hash. 2nd drop: Homogeneous, no visible bedform, dense gravel seafloor with fine to medium sand. No shell hash.	 1st drop  2nd drop

Sample ID	Depth (m)	Sediment Description	Example Photograph
C2-2_Rep3	26.8	Homogeneous, no visible bedform, medium to coarse sand with some gravel. No shell hash.	
C2-3_Rep1	25.6	Homogeneous, no visible bedform, dense gravel with small cobbles and fine to medium sand. No shell hash, but some large pieces of broken shell. Skate egg case. Appears to be calcareous growth of some sort.	
C2-3_Rep2	26.2	Homogeneous, no visible bedform, fine to medium sand with lot of gravel. No shell hash, but some large pieces of broken shell.	
C2-3_Rep3	25.9	Homogeneous, no visible bedform, fine to medium sand with lot of gravel. No shell hash, but some large pieces of broken shell.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C2-4_Rep1	26.0	Homogeneous, sand waves, medium to coarse sand with some gravel. Very small amount of shell hash	
C2-4_Rep2	26.0	1st drop: Homogeneous, sand waves, medium to coarse sand with some cobbles and a lot of gravel. Dense barnacle growth on cobbles. No shell hash. 2nd drop: Homogeneous, no visible bedform, fine to medium sand with some gravel and little cobble. No shell hash. Skate egg case. 3rd drop: Homogeneous, no visible bedform, medium to coarse sand with some gravel. Few cobbles. Very small amount of shell hash.	 1st drop  2nd drop
C2-4_Rep3	25.6	Homogeneous, sand waves, medium to coarse sand with some gravel. Very small amount of shell hash.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C3-1_Rep1	27.1	Homogeneous, sand waves, dense gravel with fine to medium sand and some cobble. Very small amount of shell hash.	
C3-1_Rep2	27.0	Homogeneous, sand waves, fine to medium sand with lot of gravel and some cobble. No shell hash. Some barnacle growth. Few starfish.	
C3-1_Rep3	26.7	Homogeneous, sand waves, fine to medium sand with lot of gravel and some cobble. No shell hash. Some barnacle growth. Few starfish.	
C3-2_Rep1	26.9	Homogeneous, sand waves, fine to medium sand with lot of gravel and some cobble. No shell hash. Some barnacle growth.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C3-2_Rep2	26.8	Homogeneous, sand waves, fine to medium sand with some gravel and little cobble. No shell hash.	
C3-2_Rep3	26.8	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	
C3-3_Rep1	27.1	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	
C3-3_Rep2	27.0	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
C3-3_Rep3	27.4	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	
C3-4_Rep1	27.2	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash.	
C3-4_Rep2	27.4	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	
C3-4_Rep3	27.3	Homogeneous, sand waves, fine to medium sand with a lot of gravel and little cobble. No shell hash. Some barnacle growth.	

Sample ID	Depth (m)	Sediment Description	Example Photograph
T1-QC	27.6	Homogeneous, sand waves, fine to medium sand with some gravel and little cobble. No shell hash. Some barnacle growth.	
T3-QC	26.4	Homogeneous, sand waves, fine to medium sand with little gravel. No shell hash.	
T5-QC	23.5	Homogeneous, sand waves, fine to medium sand with little gravel and little cobble. Dense barnacle growth on cobbles. No shell hash.	
C3-QC	26.8	N/A	N/A

Appendix 4. Camera Field Notes

				Plot Label	Data Directory	# Images	Note
Day 1 – Control Areas 6/28/17							
2nd drop	41 06 9.4256 N	071 32 25.5741 W	10:30:50	D1-2	stereo_surv_1419	BW 334	
2nd recover	41 06 9.4306 N	071 32 47.2654 W	11:00:24			Color 334	
3rd drop	41 06 4.3487 N	071 32 21.2024 W	11:24:54	D1-3	stereo_surv_1519	BW 573	
3rd recover	41 06 1.8616 N	071 33 0.7179 W	12:09:27			Color 571	
4th drop	41 07 0.4035 N	071 31 46.4251 W	12:33:44	D1-4	stereo_surv_1627	BW 625	
4th recover	41 06 58.2207 N	071 31 59.061 W	13:06:26			Color 625	
5t drop	41 07 2.2434 N	071 31 43.0546 W	13:24:59	D1-5	stereo_surv_1716	BW 896	
5th recover	41 06 56.7147 N	071 31 49.3558 W	14:07:22			Color 847	
6th drop	41 06 39.4243 N	071 30 42.5795 W	14:31:01	D1-6	stereo_surv_1824	BW 1023	
6th recover	41 06 33.0584 N	071 30 38.9662 W	15:18:57			Color 1023	
Day 2 – Turbine Areas 8/9/17							
drop 1	41 06 55.4611 N	071 31 16.9588 W	8:53:46	D2-1	stereo_surv_1251	BW 673	
recover 1	41 06 52.3003 N	071 31 30.807 W	9:25:59			Color 675	
drop2	41 06 51.018 N	071 31 13.4758 W	9:41:59	D2-2	stereo_surv_1337	BW 639	
recover2	41 06 47.4895 N	071 31 26.7836 W	10:13:50			Color 639	
drop3	41 07 34.4225 N	071 30 25.8154 W	10:31:17	D2-3	stereo_surv_1426	BW 585	
recover3	41 07 30.9421 N	071 30 38.9035 W	11:03:24			Color 601	
drop4	41 07 31.1076 N	071 30 26.2505 W	11:39:21	D2-4	stereo_surv_1529	BW 453	8-bit
recover4	41 07 27.7819 N	071 30 35.8594 W	12:11:19			Color 0	
drop5	41 06 24.4283 N	071 32 15.5297 W	12:31:01	D2-5	stereo_surv_1627	BW 96	8-bit
recover5	41 06 23.0000 N	071 32 16.1562 W	12:47:01			Color 0	
drop6	41 06 22.0583 N	071 32 16.6649 W	12:52:15	D2-6	stereo_surv_1646	BW 424	8-bit
recover6	41 06 12.3688 N	071 32 17.7263 W	13:24:10			Color 0	
drop7	41 06 22.1883 N	071 32 14.7691 W	13:43:23	D2-7	stereo_surv_1735	BW 140	Dying strobe
recover7	41 06 10.3441 N	071 32 15.2148 W	14:15:14			Color 311	Dying strobe
drop8	41 06 22.1547 N	071 32 17.4531 W	14:29:54	D2-8	stereo_surv_1824	BW 79	Dying strobe
recover8	41 06 15.0901 N	071 32 18.5089 W	14:49:47			Color 149	Dying strobe
drop9	41 06 52.3902 N	071 31 17.2978 W	15:03:19	D2-9	stereo_surv_1859	BW 67	Dying strobe
recover9	41 06 44.5542 N	071 31 17.0274 W	15:23:12			Color 142	Dying strobe
drop10	41 07 31.9203 N	071 30 28.5224 W	15:35:48	D2-10	stereo_surv_1932	BW 64	Dying strobe
recover10	41 07 27.4791 N	071 30 28.9664 W	15:55:27			Color 116	Dying strobe

Appendix 5. Results of the Sediment Organic Analysis

Sample ID	DATE	Total Organic (%)	Organic Carbon (%)
T1-1_1	12/20/2016	0.52	0.23
T1-1_2	12/20/2016	0.42	0.18
T1-1_3	12/20/2016	0.31	0.14
T1-2_1	12/20/2016	0.21	0.09
T1-2_2	12/20/2016	0.12	0.05
T1-2_3	12/20/2016	0.19	0.08
T1-3_1	12/20/2016	0.37	0.16
T1-3_2	12/20/2016	0.41	0.18
T1-3_3	12/20/2016	0.27	0.12
T1-4_1	12/20/2016	0.45	0.20
T1-4_2	12/20/2016	0.60	0.26
T1-4_3	12/20/2016	0.37	0.16
T1-5_1	12/20/2016	0.36	0.15
T1-5_2	12/20/2016	0.32	0.14
T1-5_3	12/20/2016	0.44	0.19
T1-6_1	12/20/2016	0.07	0.03
T1-6_2	12/20/2016	0.49	0.21
T1-6_3	12/20/2016	0.50	0.21
T1-7_1	12/20/2016	0.13	0.06
T1-7_2	12/20/2016	0.27	0.12
T1-7_3	12/20/2016	0.34	0.15
T1-8_1	12/20/2016	0.37	0.16
T1-8_2	12/20/2016	0.24	0.10
T1-8_3	12/20/2016	0.13	0.06
T1-9_1	12/20/2016	0.41	0.18
T1-9_2	12/20/2016	0.25	0.11
T1-9_3	12/20/2016	0.32	0.14
T3-1_1	12/20/2016	0.34	0.15
T3-1_2	12/20/2016	0.25	0.11
T3-1_3	12/20/2016	0.52	0.22
T3-2_1	12/20/2016	0.06	0.03
T3-2_2	12/20/2016	0.45	0.19
T3-2_3	12/20/2016	0.39	0.17
T3-3_1	12/20/2016	1.00	0.43
T3-3_2	12/20/2016	0.22	0.10
T3-3_3	12/20/2016	0.42	0.18
T3-4_1	12/20/2016	0.38	0.16
T3-4_2	12/20/2016	0.52	0.23
T3-4_3	12/20/2016	0.82	0.35
T3-5_1	12/20/2016	0.71	0.31
T3-5_2	12/20/2016	0.19	0.08
T3-5_3	12/20/2016	0.69	0.30
T3-6_1	12/20/2016	0.32	0.14
T3-6_3	12/20/2016	0.42	0.18
T3-6_2	12/20/2016	0.53	0.23

Sample ID	DATE	Total Organic (%)	Organic Carbon (%)
T3-7_1	12/20/2016	0.06	0.03
T3-7_2	12/20/2016	0.31	0.13
T3-7_3	12/20/2016	0.44	0.19
T3-8_1	12/20/2016	0.53	0.23
T3-8_2	12/20/2016	0.38	0.16
T3-8_3	12/20/2016	0.49	0.21
T3-9_1	12/20/2016	0.31	0.14
T3-9_2	12/20/2016	0.47	0.20
T3-9_3	1/20/2017	0.39	0.17
T5-1_1	1/20/2017	0.70	0.30
T5-1_2	1/20/2017	0.64	0.27
T5-1_3	1/20/2017	0.66	0.29
T5-2_1	1/20/2017	0.38	0.17
T5-2_2	1/20/2017	0.35	0.15
T5-2_3	1/20/2017	0.31	0.13
T5-3_1	1/20/2017	0.21	0.09
T5-3_2	1/20/2017	0.42	0.18
T5-3_3	1/20/2017	0.66	0.29
T5-4_1	1/20/2017	0.38	0.17
T5-4_2	1/20/2017	0.29	0.13
T5-4_3	1/20/2017	0.33	0.14
T5-5_1	1/20/2017	0.52	0.23
T5-5_2	1/20/2017	0.33	0.14
T5-5_3	1/20/2017	0.28	0.12
T5-6_1	1/20/2017	0.13	0.06
T5-6_2	1/20/2017	0.41	0.18
T5-6_3	12/20/2016	0.49	0.21
T5-7_1	1/20/2017	0.71	0.31
T5-7_2	1/20/2017	0.91	0.39
T5-7_3	1/20/2017	0.40	0.17
T5-8_1	1/20/2017	0.36	0.16
T5-8_2	1/20/2017	0.30	0.13
T5-8_3	1/20/2017	0.61	0.26
T5-9_1	1/20/2017	0.41	0.18
T5-9_2	1/20/2017	0.87	0.37
T5-9_3	1/20/2017	0.60	0.26
C1-1_1	1/20/2017	1.04	0.45
C1-1_2	1/20/2017	0.47	0.20
C1-1_3	1/20/2017	0.61	0.26
C1-2_1	1/20/2017	0.46	0.20
C1-2_2	1/20/2017	0.35	0.15
C1-2_3	1/20/2017	0.40	0.17
C1-3_1	1/20/2017	0.00	0.00
C1-3_2	1/20/2017	0.37	0.16
C1-3_3	1/20/2017	0.36	0.16
C1-4_1	1/20/2017	0.40	0.17
C1-4_2	1/20/2017	0.65	0.28

Sample ID	DATE	Total Organic (%)	Organic Carbon (%)
C1-4_3	1/20/2017	0.59	0.25
C2-1_1	1/20/2017	0.24	0.10
C2-1_2	12/20/2017	0.29	0.13
C2-1_3	1/20/2017	0.33	0.14
C2-2_1	1/20/2017	0.35	0.15
C2-2_2	1/20/2017	0.35	0.15
C2-2_3	1/20/2017	0.48	0.21
C2-3_1	1/20/2017	0.74	0.32
C2-3_2	1/20/2017	0.47	0.20
C2-3_3	1/20/2017	0.74	0.32
C2-4_1	1/20/2017	0.39	0.17
C2-4_2	1/20/2017	0.26	0.11
C2-4_3	1/20/2017	0.16	0.07
C3-1_1	3/21/2017	0.29	0.12
C3-1_2	3/21/2017	0.85	0.37
C3-1_3	3/21/2017	0.46	0.20
C3-2_1	3/21/2017	0.69	0.30
C3-2_2	3/21/2017	0.42	0.18
C3-2_3	3/21/2017	0.28	0.12
C3-3_1	3/21/2017	0.54	0.23
C3-3_2	3/21/2017	0.44	0.19
C3-3_3	3/21/2017	0.32	0.14
C3-4_1	3/21/2017	0.32	0.14
C3-4_2	3/21/2017	0.33	0.14
C3-4_3	3/21/2017	0.46	0.20
T1-QC	3/21/2017	0.58	0.25
T3-QC	3/21/2017	0.46	0.20
T5-QC	3/21/2017	0.64	0.28
C3-QC	3/21/2017	0.35	0.15

Appendix 6. BIWF Macrofaunal Abundance Species List (Winter 2016-2017)

Appendix 7. Summary Macrofaunal Species Statistics

Sample ID	No. Species (S)	No. individuals (N)	Richness (d)	Eveness (J')	Diversity (H'(loge))	Dominance (1-λ)'
T1-1_1	25	96	5.258	0.698	2.247	0.790
T1-1_2	6	7	2.569	0.976	1.748	0.952
T1-1_3	15	45	3.678	0.767	2.078	0.812
T1-2_1	18	40	4.608	0.870	2.516	0.910
T1-2_2	14	53	3.274	0.777	2.051	0.804
T1-2_3	23	122	4.579	0.734	2.303	0.860
T1-3_1	8	31	2.038	0.879	1.829	0.839
T1-3_2	16	74	3.485	0.801	2.220	0.864
T1-3_3	24	398	3.842	0.489	1.554	0.634
T1-4_1	26	128	5.152	0.831	2.706	0.913
T1-4_2	17	56	3.975	0.818	2.318	0.876
T1-4_3	11	44	2.643	0.847	2.030	0.845
T1-5_1	29	117	5.880	0.863	2.905	0.935
T1-5_2	16	54	3.760	0.783	2.171	0.845
T1-5_3	19	88	4.020	0.744	2.191	0.840
T1-6_1	27	45	6.830	0.929	3.063	0.958
T1-6_2	15	26	4.297	0.924	2.502	0.935
T1-6_3	9	14	3.031	0.931	2.045	0.912
T1-7_1	12	22	3.559	0.874	2.172	0.883
T1-7_2	6	14	1.895	0.754	1.352	0.681
T1-7_3	8	47	1.818	0.705	1.467	0.690
T1-8_1	13	44	3.171	0.833	2.136	0.867
T1-8_2	5	13	1.559	0.919	1.479	0.808
T1-8_3	17	64	3.847	0.863	2.444	0.904
T1-9_1	23	100	4.777	0.840	2.634	0.908
T1-9_2	25	106	5.146	0.788	2.536	0.882
T1-9_3	22	91	4.655	0.753	2.328	0.843
T3-1_1	22	172	4.080	0.776	2.398	0.873
T3-1_2	24	204	4.325	0.665	2.113	0.777
T3-1_3	19	274	3.207	0.625	1.841	0.756
T3-2_1	19	187	3.441	0.707	2.083	0.803
T3-2_2	23	224	4.065	0.804	2.522	0.885
T3-2_3	22	198	3.971	0.753	2.328	0.860
T3-3_1	23	212	4.107	0.669	2.098	0.810
T3-3_2	23	327	3.800	0.642	2.012	0.753
T3-3_3	19	139	3.648	0.782	2.303	0.861
T3-4_1	17	131	3.282	0.810	2.296	0.860
T3-4_2	16	110	3.191	0.787	2.181	0.849
T3-4_3	16	108	3.204	0.852	2.363	0.890
T3-5_1	20	120	3.969	0.655	1.963	0.745
T3-5_2	21	62	4.846	0.855	2.604	0.900
T3-5_3	19	147	3.607	0.795	2.342	0.877
T3-6_1	19	107	3.852	0.793	2.336	0.863
T3-6_2	28	271	4.820	0.808	2.693	0.901
T3-6_3	26	348	4.272	0.661	2.153	0.820
T3-7_1	14	192	2.473	0.456	1.203	0.462

Sample ID	No. Species (S)	No. individuals (N)	Richness (d)	Eveness (J')	Diversity (H'(loge))	Dominance (1-λ)'
T3-7_2	24	278	4.087	0.681	2.163	0.804
T3-7_3	25	221	4.446	0.781	2.514	0.894
T3-8_1	22	208	3.934	0.666	2.058	0.777
T3-8_2	23	361	3.736	0.682	2.137	0.820
T3-8_3	24	233	4.219	0.762	2.421	0.877
T3-9_1	12	86	2.469	0.868	2.156	0.872
T3-9_2	20	151	3.787	0.751	2.249	0.828
T3-9_3	18	111	3.610	0.765	2.211	0.841
T5-1_1	19	122	3.747	0.762	2.244	0.865
T5-1_2	17	213	2.984	0.614	1.741	0.715
T5-1_3	19	384	3.025	0.275	0.810	0.328
T5-2_1	18	161	3.346	0.703	2.032	0.805
T5-2_2	20	243	3.459	0.530	1.587	0.641
T5-2_3	15	159	2.762	0.583	1.578	0.664
T5-3_1	12	35	3.094	0.883	2.193	0.892
T5-3_2	12	102	2.378	0.721	1.793	0.783
T5-3_3	19	362	3.055	0.758	2.233	0.854
T5-4_1	26	177	4.830	0.601	1.957	0.689
T5-4_2	19	129	3.704	0.540	1.590	0.600
T5-4_3	13	61	2.919	0.799	2.050	0.846
T5-5_1	22	126	4.342	0.588	1.819	0.661
T5-5_2	21	67	4.757	0.659	2.006	0.707
T5-5_3	17	86	3.592	0.493	1.395	0.511
T5-6_1	16	234	2.750	0.690	1.914	0.817
T5-6_2	23	247	3.993	0.629	1.972	0.788
T5-6_3	16	250	2.717	0.656	1.817	0.787
T5-7_1	22	137	4.268	0.775	2.394	0.869
T5-7_2	17	227	2.949	0.712	2.016	0.818
T5-7_3	13	109	2.558	0.612	1.569	0.684
T5-8_1	17	215	2.979	0.675	1.913	0.800
T5-8_2	8	77	1.611	0.738	1.534	0.721
T5-8_3	9	56	1.987	0.787	1.730	0.785
T5-9_1	15	224	2.587	0.737	1.997	0.820
T5-9_2	23	411	3.655	0.621	1.948	0.794
T5-9_3	19	311	3.136	0.647	1.905	0.787
C1-1_1	28	143	5.440	0.773	2.575	0.887
C1-1_2	28	787	4.049	0.261	0.870	0.312
C1-1_3	26	112	5.298	0.790	2.574	0.889
C1-2_1	15	50	3.579	0.663	1.796	0.697
C1-2_2	5	38	1.100	0.478	0.770	0.371
C1-2_3	12	80	2.510	0.568	1.413	0.588
C1-3_1	13	122	2.498	0.698	1.791	0.770
C1-3_2	13	116	2.524	0.782	2.006	0.839
C1-3_3	17	118	3.354	0.721	2.042	0.808
C1-4_1	34	106	7.076	0.923	3.256	0.961
C1-4_2	31	230	5.517	0.757	2.600	0.870
C1-4_3	37	311	6.272	0.814	2.938	0.925
C2-1_1	34	399	5.510	0.727	2.563	0.863
C2-1_2	28	261	4.852	0.730	2.433	0.846

Sample ID	No. Species (S)	No. individuals (N)	Richness (d)	Eveness (J')	Diversity (H'(loge))	Dominance (1-λ)'
C2-1_3	19	107	3.852	0.872	2.567	0.908
C2-2_1	35	195	6.448	0.710	2.525	0.836
C2-2_2	27	343	4.454	0.714	2.354	0.827
C2-2_3	21	145	4.019	0.801	2.440	0.883
C2-3_1	34	180	6.355	0.769	2.712	0.886
C2-3_2	21	200	3.775	0.632	1.923	0.722
C2-3_3	18	119	3.557	0.777	2.245	0.826
C2-4_1	18	72	3.975	0.868	2.509	0.908
C2-4_2	14	30	3.822	0.818	2.159	0.834
C2-4_3	19	41	4.847	0.855	2.518	0.901
C3-1_1	27	163	5.104	0.779	2.568	0.883
C3-1_2	30	189	5.533	0.759	2.581	0.886
C3-1_3	25	103	5.178	0.821	2.642	0.903
C3-2_1	17	63	3.862	0.796	2.256	0.854
C3-2_2	11	36	2.791	0.875	2.099	0.871
C3-2_3	5	5	2.485	1.000	1.609	1.000
C3-3_1	31	135	6.116	0.819	2.813	0.915
C3-3_2	28	184	5.177	0.669	2.229	0.818
C3-3_3	20	117	3.990	0.705	2.112	0.803
C3-4_1	24	146	4.615	0.708	2.251	0.832
C3-4_2	25	232	4.406	0.639	2.055	0.769
C3-4_3	24	81	5.234	0.819	2.603	0.903
T1-QC	14	77	2.993	0.741	1.955	0.785
T3-QC	21	230	3.678	0.808	2.460	0.890
T5-QC	24	143	4.634	0.777	2.470	0.878
C3-QC	16	60	3.664	0.718	1.990	0.790

The Department of the Interior Mission

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy primary responsibilities are to manage the mineral resources located on the nation's Outer Continental Shelf in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.