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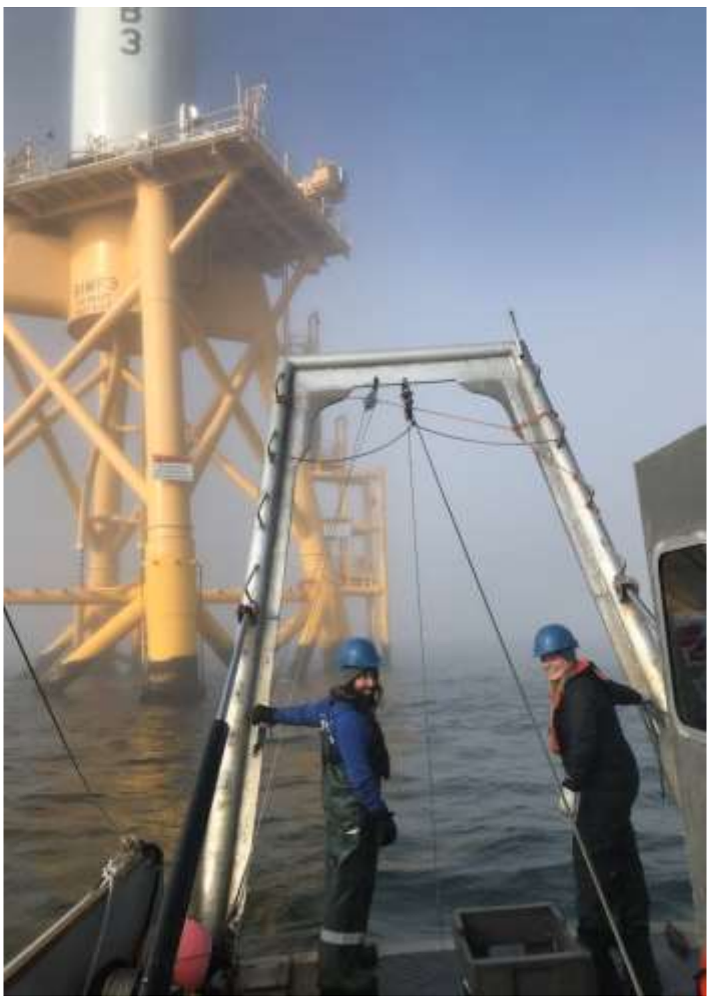
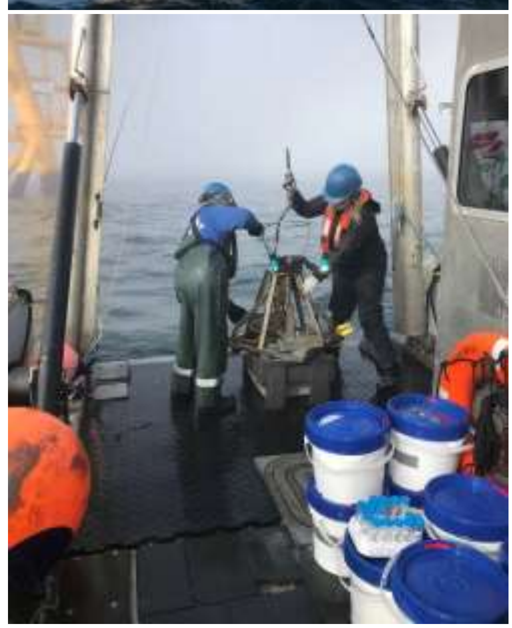
BOEM 2020-044

Benthic and Epifaunal Monitoring During Wind Turbine Installation and Operation at the Block Island Wind Farm, Rhode Island – Project Report





US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

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26 September 2020

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ABOUT THE COVER

Cover Photographs: HDR Team members collecting sediment samples at the BIWF site. Courtesy of the HDR RODEO Team. Used with permission.

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List of Abbreviations and Acronyms

°C	degrees Celsius
ANOSIM	analysis of similarity
ANOVA	analysis of variance
BIWF	Block Island Wind Farm
BOEM	Bureau of Ocean Energy Management
cm	centimeter(s)
CMECS	Coastal and Marine Ecological Classification Standard
FGDC	Federal Geographic Data Committee
HSD	Honestly Significant Difference
kg	kilogram(s)
L	liter(s)
LOI	Loss-On-Ignition
m	meter(s)
m^2	square meter(s)
m/s	meters per second
MDS	multi-dimensional scaling
NACCS	North Atlantic Coast Comprehensive Study
nMDS	non-metric multi-dimensional scaling
OSAMP	Ocean Special Area Management Plan
OWF	offshore wind farm
PRIMER	Plymouth Routines in Multivariate Ecological Research
QC	quality control
RODEO	Real-Time Opportunity for Development of Environmental Observations
ROV	remotely operated vehicle
SIMPER	similarity percentages
TOC	total organic carbon
TOM	total organic matter
UTM	Universal Transverse Mercator projection
U.S.	United States

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 results and recommendations from a three-year benthic habitat and turbine structure epifauna monitoring study that was conducted at the Block Island Wind Farm (BIWF) Project Area are presented in this report. The overarching goals of the multi-year monitoring study were to gather and analyze data to improve understanding of the following:

- The nature, as well as potential spatial and temporal scales, of anticipated alterations in benthic habitats, including macrofaunal community characteristics (e.g., species abundance, richness, diversity, assemblage structure, and biomass), surficial sediment characteristics (e.g., particle size distribution, organic content), and relationship dynamics between macrofaunal communities and their associated environments at the BIWF facility.
- Characteristics of the epifaunal communities colonizing the turbine foundations (e.g., species assemblages, percent cover, biomass, growth thickness).
- Potential physical effects of the epifaunal growth (e.g., total added weight, change in surface area and drag forces) on turbine structures.

The following types of data were collected and analyzed:

- Benthic grab samples collected at randomly selected locations within three distance bands around three of the five BIWF turbines (30 to 90 meters [m] from the turbine center point) and three control areas (three years). These samples were collected using a Smith McIntyre grab sampler that was deployed from a vessel.
- Manual benthic grab samples collected at three of the five BIWF turbines at randomly selected locations (15 to 30 m from turbine center point; very near-field area [one year], and at defined locations along a transect underneath the turbine structures [i.e., within the footprint, two years]). These samples were collected by divers using SCUBA by manually excavating sediment into fine mesh bags.
- All benthic grab samples were analyzed in the laboratory for macrofaunal community characteristics, sediment grain size distribution, total organic matter, and total organic content.
- Seabed video accompanying each round of vessel-based grab sampling (three years).
- Visual observations from seabed photography transects around three of the five turbines and three control areas obtained by camera float missions (three years) and diver-towed missions from under the turbines (two years).
- Visual observations from video data of epifauna on turbine foundation structures (two years).
- Epifauna biota scrape samples collected from selected locations on one turbine (two years).

Important results and key observations:

- Within four years of initial installation, significant modification of the seabed has occurred within the footprint of the turbine foundations, with the area underneath Turbine 1 exhibiting the fastest rate of change.
- The transition of the area underneath the turbines to a dense mussel and fine, organic rich sediment dominated habitat appears to be occurring along a gradient across the BIWF, with area underneath Turbine 1 exhibiting the greatest degree and fastest rate of change, and Turbine 5 the least change within the study period.
- The transition that has occurred under the Turbines is from a clean coarse sandy/polychaete association to a fine grained, organically enriched sediment supporting dense mussel aggregations.

- Diver sampling in Year 3 suggests that patches of seabed sediment beyond the footprint of Turbine 1, within 30 m of the center point of the foundation, is similarly transistioning with respect to organic content.
- The greatest rate of transition is occurring below Turbine 1, which may be due to the apparent seabed stability at this location compared to the other turbines studied. This underscores the highly localized (turbine specific) nature of benthic responses that can occur within offshore wind farms in this region.
- There has been a large increase in the incidence and abundance of juvenile mussels settling on the seafloor beyond the foundation footprints of Turbine 1 and up to distances of 90 m away. Mussel presence and abundance was comparably much lower within Control sites. Patches of adult mussel dominance were also observed up to 42 m from the center of foundation structure of Turbine 1 and are associated with highly modified seabed conditions and macrofauna in Year 3.
- Four years post installation, the foundations support dense mussel populations which colonize the structures between the intertidal and seabed. Several epifaunal species are becoming more common on structures including: anemones, sponges, and the invasive tunicate *Didemnun vexillium.* The coral *Astrangia poculata* has appeared near the base of the foundations.
- Changes in the mobile epifaunal community are evident. For example, sea stars were present but not common in Year 2; in Year 3, they have become more abundant at the base and on the bottom of foundations.
- Abundance of black sea bass (*Centropristis stiata*) around the foundations increased dramatically between Years 2 and 3.
- Epifaunal growth on the turbine foundations was estimated to add approximately 1,025 kilograms of weight to each turbine jacket leg at the BIWF and more importantly to increase the mean drag force (per unit length) on the leg from approximately 2543 N (no growth) to 4313 N during an extreme current event (velocity of 2 meters per second). This represents a maximum of 75 to 85% increase in drag force (per unit length) due to epifaunal growth on the leg structure.
- The total drag force on the simplified BIWF jacket structures in an extreme current event was estimated to be 483,056 N, whereas it was considerably higher 1,347,360 N for the larger and deeper monopile structures, such as those being considered for future offshore wind projects.

The footprint of each turbine jacket foundation measures approximately 576 square meters. The study only investigated alterations in the seabed underneath and in the vicinity of Turbines 1, 3, and 5. Assuming that similar changes have either already taken place or are starting to occur underneath all five turbines, the total extent of the benthic habitat altered due to the presence of the turbines is about 2,880 square meters (0.003 square-kilometers). This area represents between 25 and 42% of the area impacted by two BIWF construction phases. It was therefore concluded that while the effects of the turbines on the benthic habitat are localized, they are profound given the strong change from a sand habitat to a habitat characterized by mussel aggregations with associated organic matter, sediment fines and macrofaunal communities. Also, the Year 3 data indicate that the effects observed within the turbine footprint seem to be expanding beyond the turbines. Lastly, the foundations provide suitable surfaces for colonization by epifauna, and may facilitate range expansion of these species. Larval dispersion from BIWF and connectivity between future offshore wind projects, for mussel populations but also for the associated native and non-native species, indicate clear potential for larger scale changes in the longer term.

Based on the results of the three-year study, the following management recommendations are offered for the BIWF:

- Ongoing monitoring is recommended because seabed effects appear to be expanding and not enough time has elapsed since the construction of the facility to fully understand the spatial scale and magnitude of potential benthic effects and resulting changes in ecological function attributed to an offshore wind farm in the New England region. Repeat monitoring studies should continue to employ the same sampling methods to ensure data consistency for comparison. Ideally, subsequent surveys should continue to be undertaken at the same time of year to minimize variability in measurements due to seasonal variation, which has become important now that a mussel population has established.

- Monitoring should be expanded to include all five turbines allowing assessment of gradients, similarities and differences between turbines to be determined, either confirming or refuting the idea of a gradient of change occurring across the wind farm area.
- Both the near- and far-field areas should be monitored because the *Balanus*/*Mytilus* biotope seems likely to spread beyond the 90 m area monitored as part of this study. Extending monitoring beyond 90 m will record if changes occurring further away from the turbines over a longer temporal scale.
- Monitoring should include dedicated investigation of the colonization (or lack of) of the concrete mattresses use for scour protection over portions of the cable. This should be performed in order to determine potential contribution to, or prevention of, the artificial reef effect on these mattresses, the use of which may become widespread in future offshore wind projects.
- For longer-term studies, it also would be beneficial to sample across seasons to investigate any seasonality that may be present now that ecological changes have been observed. 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).
- Biennial monitoring is probably adequate to track long-term spatial and temporal changes. An alternate approach to consider would be to conduct “detailed” surveys every other year and “rapid” (camera) surveys in alternate years. Most of the changes are expected to be visual and could be detected and monitored using cameras as a cost-effective option.
- Given the short amount of time that the foundations have been in the water, associated epifaunal communities are unlikely to be in a mature or ‘climax’ state. Continued monitoring of the epifauna is thus recommended to document future community dynamics and confirm whether offshore wind farms in the New England region will act as long-term biodiversity and biomass hotspots.
- Epifaunal surveys of the turbine foundations should continue to be conducted in parallel with benthic habitat characterization studies to provide context and collect quantitative information on community succession on and around the foundations.
- Detailed quantitative analysis of the seabed imagery acquired by the Lagrangian float camera collected under this program, and development, or adoption, of standard analysis methods should be considered.
- Fish surveys also are recommended within the entire project area to better understand which species are responding to the changes in the benthic habitat and how they are using the structures and/or associated epifaunal communities.

The results of this study summarized above may be used to guide development of monitoring protocols for similar studies to be conducted at future other offshore wind farms. Recommendations that also could be incorporated into future planning are as follows:

- Benthic responses at BIWF have been shown to be turbine specific. In heterogeneous habitats, and where localized seabed processes occur, monitoring plans should ensure that all local benthic conditions and seabed types are covered. Results from the initial Environmental Assessment and geophysical survey data should be used to identify the different geographical levels or strata within which samples will be collected to ensure all benthic conditions are adequately represented.

- The purpose-driven monitoring has been useful to provide a framework for survey and analysis design and should be considered in future monitoring programs at other offshore wind farms.
- The vessel-based benthic grab study design employed at BIWF, including the use of randomized sampling positions within the distance bands each year is highly recommended, rather than repeat visits to fixed positions along fixed transects or at remote locations. Use of random stratified sampling at BIWF has removed any potential bias that might otherwise be inadvertently introduced into the sampling and it improved the probability of unanticipated events being detected and described, while still addressing the test hypotheses.
- Monitoring of epifaunal growth should commence as soon as is practicable after foundation installation to capture the characteristics of the initial colonizing communities and any apparent interaction within higher trophic levels such as fish and marine mammals.
- The use of remote video and cameras and retrievable settlement plates deployed nearby should be considered for future epifaunal monitoring and associated studies on potential ecosystem interactions.
- The use of remotely operated vehicles and cameras to investigate epifaunal colonization of foundation structures may be considered in order to alleviate health and safety concerns associated with using divers.
- To assess longer-term effects, far-field monitoring in the surrounding area (up to 200 m from the foundation) at a lower frequency also should be incorporated into the study design.
- The monitoring performed to date at BIWF can help inform future wind farm monitoring programs and the establishment of effective baseline studies.

This BIWF benthic habitat monitoring and turbine biofouling study was conducted for BOEM by the HDR RODEO Team under Contract M15PC00002, Task Orders M17PD00015 and 140M0119F0025.

1 Introduction

This Project Report presents results and recommendations from a three-year benthic habitat and wind turbine epifaunal monitoring study conducted at the Block Island Wind Farm (BIWF) Project Area (**Figure 1**). The monitoring was initiated soon after the wind farm became operational in December 2016 and it continued through 2019. Key results from Year 1 and Year 2 monitoring were previously presented in separate reports (HDR 2018a and HDR 2019). This project report consolidates three years of monitoring data and presents cumulative results and overall management recommendations to guide 1) future benthic habitat and turbine epifaunal growth monitoring at BIWF and 2) planning for similar studies to be conducted at other offshore wind farms that are planned for the eastern seaboard of the United States (U.S.).

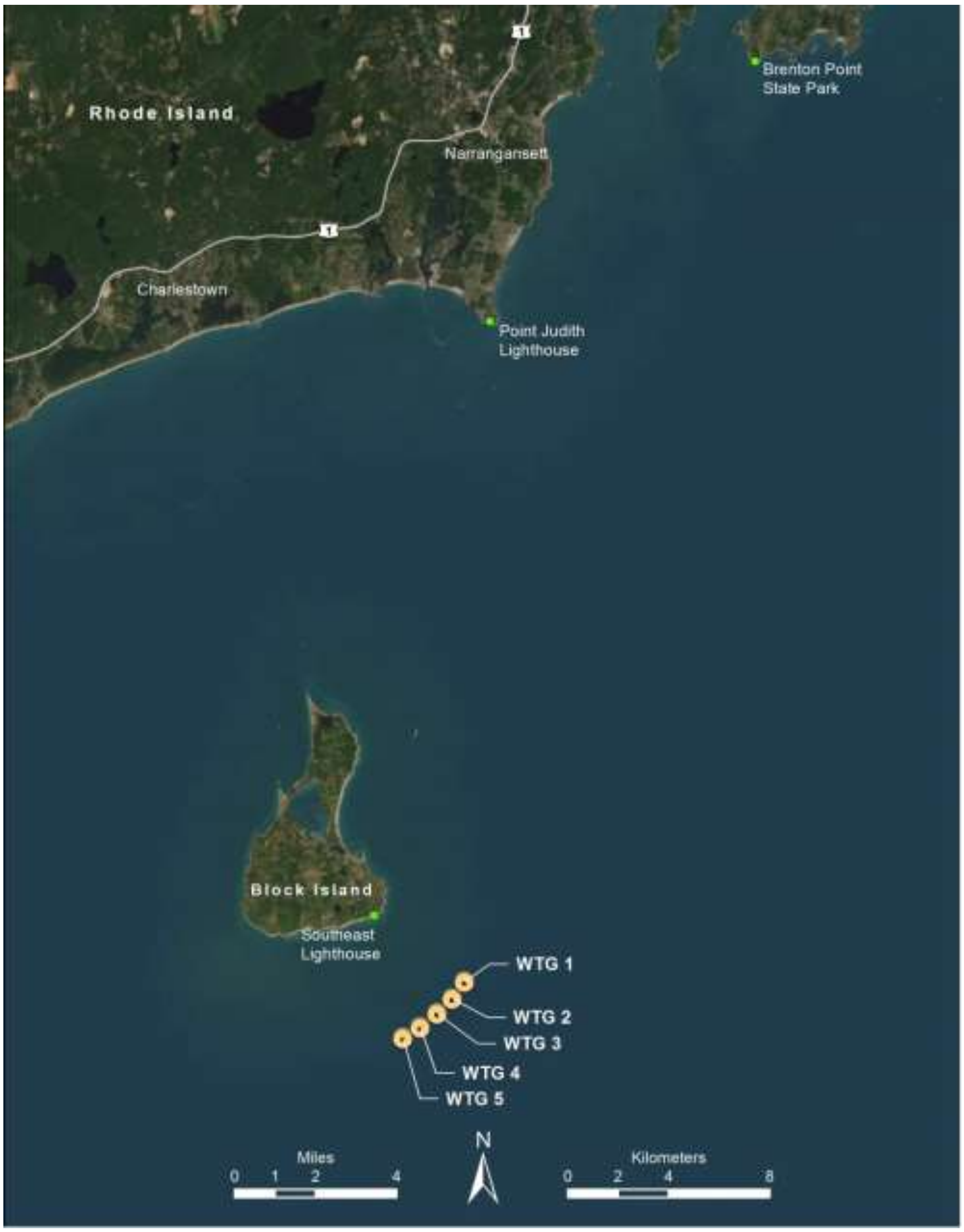

Figure 1. Location of Block Island Wind Farm

1.1 Block Island Wind Farm

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 data were collected over three sampling periods, referred to as "Year 1," "Year 2" and "Year 3." Year 1 data were collected between December 2016 and August 2017. Year 2 data were collected between November 2017 and June 2018. Year 3 data were collected between August 2018 and November 2019. Data collected in both years include grab samples, seabed video, and still imagery.

Each of the five turbines at the Block Island Wind Farm consists of a 6-megawatt GE Haliade 150 three-bladed turbine with a rotor diameter of 150 meters (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, monitoring data for these foundation types and impacts on benthic ecology are minimal. Therefore, this study contributes to filling knowledge gaps about the effects of offshore renewables and, in particular, the specific construction and operational effects of jacket structures on seabed sediment communities.

1.2 The RODEO Program

The monitoring reported in this document was conducted under the U.S Department of the Interior's Bureau of Ocean Energy Management's (BOEM) Real-Time Opportunity for Development Environmental Observations (RODEO) Program. The purpose of the RODEO Program is to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and 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.

BOEM conducts environmental reviews, including National Environmental Policy Act analyses and compliance documents for each major stage of energy development planning which includes leasing, site assessment, construction, operations, and decommissioning. These analyses include 1) identification of impact producing factors (stressors) and receptors such as marine mammals and seafloor (benthic) habitats, and 2) evaluation of potential environmental impacts from the proposed offshore wind development activities on human, coastal, and marine environments. The analyses require estimations of impact-producing factors such as noise and the effects from the stressor on the ecosystem or receptors. Describing the impact-producing factors requires knowledge or estimates of the duration, nature, and extent of the impact-generating activity. Because there have been no offshore facilities constructed in the United States prior to BIWF, model predictions will be used primarily to forecast likely impacts from future projects.

The RODEO Program data may be used by BOEM as inputs to analyses or models that evaluate the effects or impacts from future offshore wind turbine construction and operations, as well as facilitate operational planning that would reduce potential impacts to the greatest extent possible. The understanding and insights gained from the BIWF monitoring program data analyses will help BOEM to identify, reduce, and mitigate environmental risks in the future, and significantly increase the efficiency and efficacy of BOEM's regulatory review process for offshore wind development in the United States. Finally, data collected by the BIWF monitoring program will support prioritization of future monitoring efforts and risk retirement. For example, if the BIWF monitoring data indicate that likelihood of impacts from a particular project development phase is low or inconsequential, then such phases may not be monitored during future projects.

It is important to note that the RODEO 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. Therefore, RODEO monitoring was limited to selected parameters only. 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. All monitoring surveys were implemented in accordance with a pre-approved Field Sampling Plan (**Appendix A**), which included a project-specific Health and Safety Plan.

1.3 Study Goals and Objectives

The overall goal of this multi-year monitoring study was 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. The timeframe over which any such alterations may occur is similarly unclear for this area.

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 underwater structures also provide substrate for the growth of epifaunal marine organisms (biofouling). Benthic habitat and biota in the immediate vicinity of offshore turbines could also be meaningfully influenced by the epifaunal communities developing on the structures. Over time, these communities can provide continuous organic input to the surrounding seafloor in the form of biomass that is dislodged from the structures due to predator activity, storms, senescence and feces. As it accumulates at the base of the foundation, this organic enrichment could influence sediment characteristics, which in turn may lead to changes in benthic macrofaunal community diversity and abundance. 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.

The following three hypotheses were tested over the three-year study period, with respect to sediment composition, organic enrichment and macrofaunal communities:

- $H_0 1$ – There are no differences between turbine areas.
- $H_0 2$ – There are no differences between control areas and turbine areas.
- $H_0 3$ – There are no effects of distance from the wind farm foundations.

Study results were used to evaluate spatial and temporal scales of changes in benthic macrofaunal community characteristics around the turbines and improve understanding of ecosystem-level alterations that may result from these changes.

1.4 Study Challenges

1.4.1 Natural Variations

The data presented in this and the Year 1 and 2 reports represent a snapshot of benthic ecological conditions in and around the BIWF Project Area. They do 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 to compare for operational effects during future assessments.

1.4.2 Sampling Timeframe

Monitoring was initiated soon after the wind farm became operational in December 2016. In Year 1, sediment samples were collected for laboratory analyses using a Smith McIntyre grab sampler over three days throughout the winter season (December 20, 2016; January 20, 2017; and March 21, 2017). Collecting all testing samples as close to each other as practicable is preferable because this ensures that the samples are collected under similar environmental conditions. However, sampling at BIWF could not be completed on consecutive days because of inclement weather.[1] The four-month sampling timeframe was considered adequate because sampling was completed within the winter season (i.e., conditions were consistent).

Prior to the development of the BIWF, research has indicated that the benthic macrofaunal communities within Rhode Island Sound and Block Island Sound show minimal natural variation, both seasonally and over longer periods of time (LaFrance et al. 2014; Steimle 1982; Savard 1966; S. 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) also were recovered in samples collected in the mid-to-late 1940s in studies by Smith (1950) and Deevey (1952). Further, Savard (1966) 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) also were identified by Steimle (1982), although the abundances at which they were recovered were not compared. This comparability indicates the composition of macrofaunal communities has persisted in this area for over six decades.

Similar to the macrofaunal communities, the geological environments in and around the BIWF study area show patterns of stability over time. Previous data collected within Rhode Island and Block Island Sounds over the past decade have 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 be identified easily in the side-scan sonar data collected in December 2016 for this study (**Figure 2**).

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[1] Collecting all test samples as close to each other as practicable is preferable because this ensures that the samples are collected under similar environmental conditions. For the BIWF Project, collecting samples over a four-month period was not a limiting factor because the collection was completed within the winter season (i.e., metocean conditions were generally consistent across the sample collection dates).

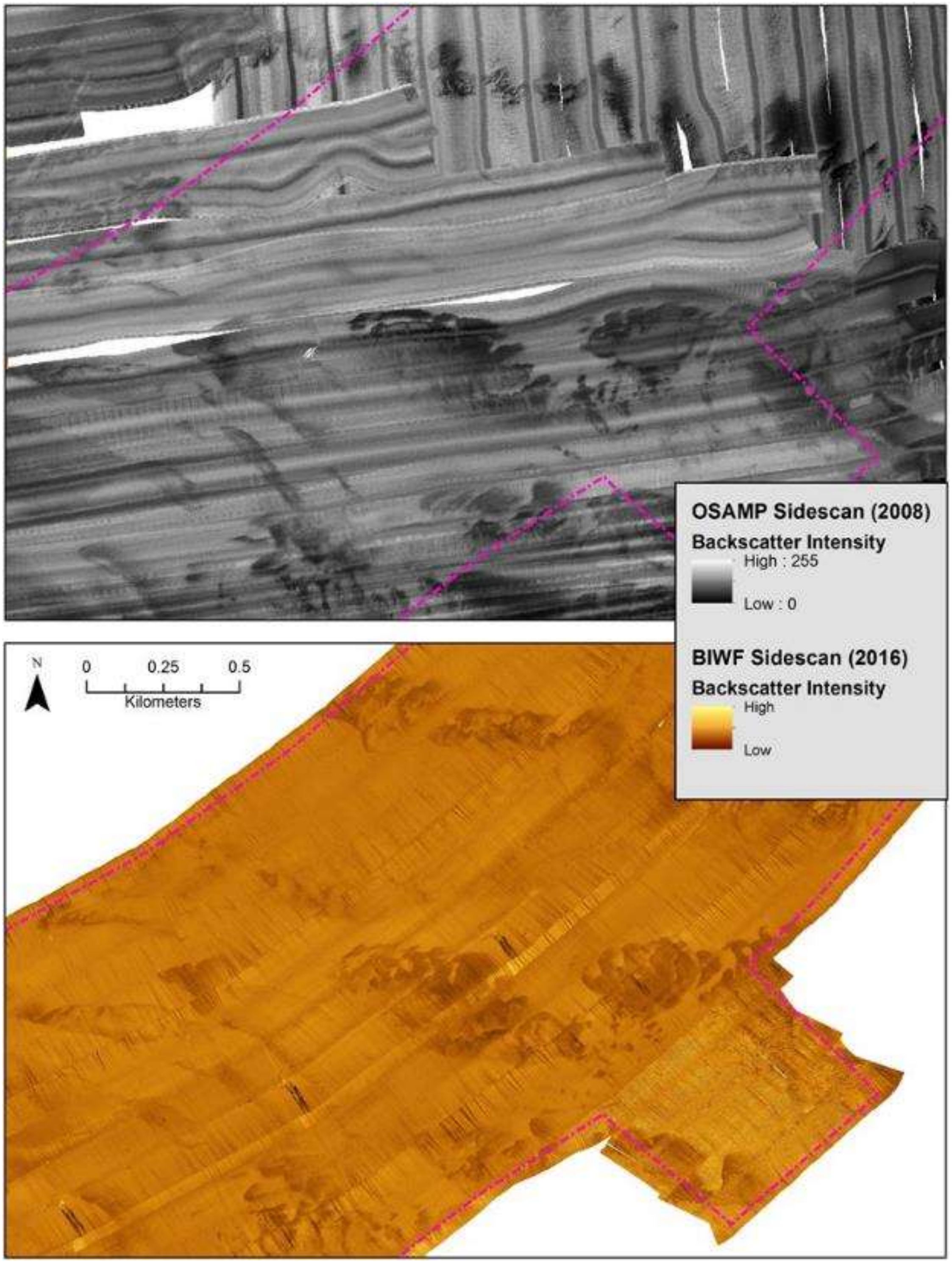


Figure 2. Comparison of 2008 and 2016 side-scan mosaics showing minor changes to geological environment.

Note**:** Specific examples are highlighted in colored circles, although such similarities are visible throughout the two mosaics.

Any remaining concerns regarding time between sampling days were abated in Year 2, as all quantitative grab samples were collected in two consecutive days (November 30 and December 1, 2017). The collection of quantitative diver samples from below the turbine foundations in Year 2, as recommended during the Year 1 monitoring, was completed during May and June 2018. The Year 2 remote video surveillance data were also collected between May and June 2018.

Two different sediment collection techniques were employed in Year 2. Samples were collected at all monitoring locations farther away from the turbines using a grab sampler over a two-day period, November 30 and December 1, 2017. Manual collection of sediment samples by divers using SCUBA in the vicinity of the turbine foundations could not be conducted during the extremely cold winter season. These samples were therefore collected during May and June 2018.

Year 3 monitoring could not be initiated during November and December 2018 (as was planned) due to persistent inclement weather conditions. Sampling was initiated in February 2019 and it continued through fall 2019.

1.4.3 Sampling Coarse Seabed Deposits

From the literature and previous data collection, it was expected that areas of coarse seabed deposits, including boulders, cobble, and gravel, would be present within the study area. Observations during monitoring generally confirmed this, although most sample areas were dominated by coarse-medium sand. Experience shows that such coarse seabed deposits (boulders, cobble, and gravel) 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 the most reliable grab sampler for use in open sea conditions when sampling from small vessels (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 was collected with a volume of $1/8^{th}$ or greater of the sampler. It was evident that $1/8^{th}$ was the largest volume recoverable in areas with dense boulder, cobble, and/or gravel concentrations. However, this volume was enough to capture the surficial material of the seafloor within which the benthic biological community resides (Mackie et al. 2007).

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 allows for more robust statistical analyses of the biological communities, as well as the assessment of small-scale spatial variability.

Examination of 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 volume; and yet, at other stations, cluster samples of the same volume exhibited substantial variations in species richness and abundance. This inconsistency prevented use of a multiplier to standardize the volumes across all the samples in the BIWF study area. As such, samples were analyzed using unadjusted species richness and abundance counts. This approach was favored over attempting to standardize the samples, which would have knowingly introduced error. As detailed above, volume inconsistencies were limited by ensuring that a reasonable sample volume was obtained while in the field (i.e., $1/8^{th}$ of bucket) and if not, the sample was repeated. The same Smith McIntyre grab sampler was used throughout the three year study. The grab sampler had surface area of 0.06 square meters (m^2) and therefore provides a standardized sample area. The area sampled is more informative than the volume of a grab sample, because the macrofauna targeted by this sampling method typically live in the top 5 to 10 centimeters (cm) of sediment (Mackie et al. 2007).

1.4.4 Comparison of Smith McIntyre and Diver Grab Samples

Two sediment grab sample collection methods were used during this study: 1) a Smith McIntyre grab sampler was deployed from a vessel at monitoring stations located farther away from the turbines, and 2) monitoring locations very close to the turbine could not be sampled with a grab sampler due to potential for damage to the structure, therefore manual sample collection by divers using SCUBA was conducted. Since the data from samples collected using two different methods were combined into a single dataset for analyses, it was important to ensure that the two methods yielded comparable samples.

To test the comparability of the two grab sample techniques, a parallel study was therefore conducted in which both methods were employed side-by-side at an offsite location (Narragansett Bay). Diver collected grab samples that were designed to be similar in size, volume and surface area were collected alongside samples collected with Smith McIntyre grab sampler used in the vessel-based sampling. All grab samples were subjected to the same sediment grain size, organic content and macrofaunal analyses (see **Section 3.3.2**.). The two methods were considered comparable with regard to sediment grain size and macrofaunal metrics (mean species richness, mean abundance, mean biomass and species composition) but were different in organic content due to wash out.

1.5 Study Context

1.5.1 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. Under a parallel BOEM-funded study, which investigated scour around the turbine foundations using installed scour monitors, Fugro, Inc. also deployed an acoustic wave and currents sensor on the seabed at the BIWF site for the measurement of local hydrodynamic conditions. Two scour monitors also were 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 m. 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 acoustic wave and current 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 (HDR 2018b).

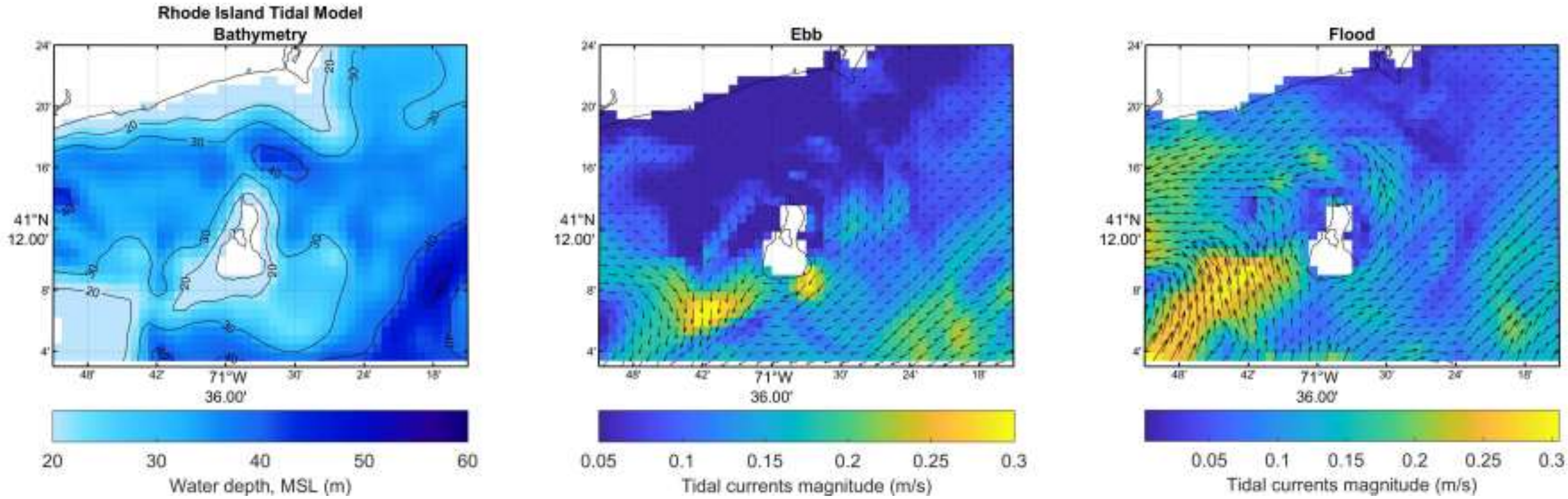


Figure 3. Tidal current movements around Block Island, RI. The baseline tidal model bathymetry is shown in the left panel. The magnitude of the tidal currents is shown for the ebb (middle panel) and flood (right panel).

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 characterized primarily by sand of medium, coarse, and/or very coarse grain size.

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 *Polymastia* 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; and dominated by the bivalve, *Nucula* sp. (Steimle 1982). Elsewhere in Block Island Sound, finer grained silty sand sediments persist and support the 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).

1.5.2 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**). The sidescan, bathymetry, and geology maps reveal the types and overall complexity of the seafloor environments present within the OSAMP study area.

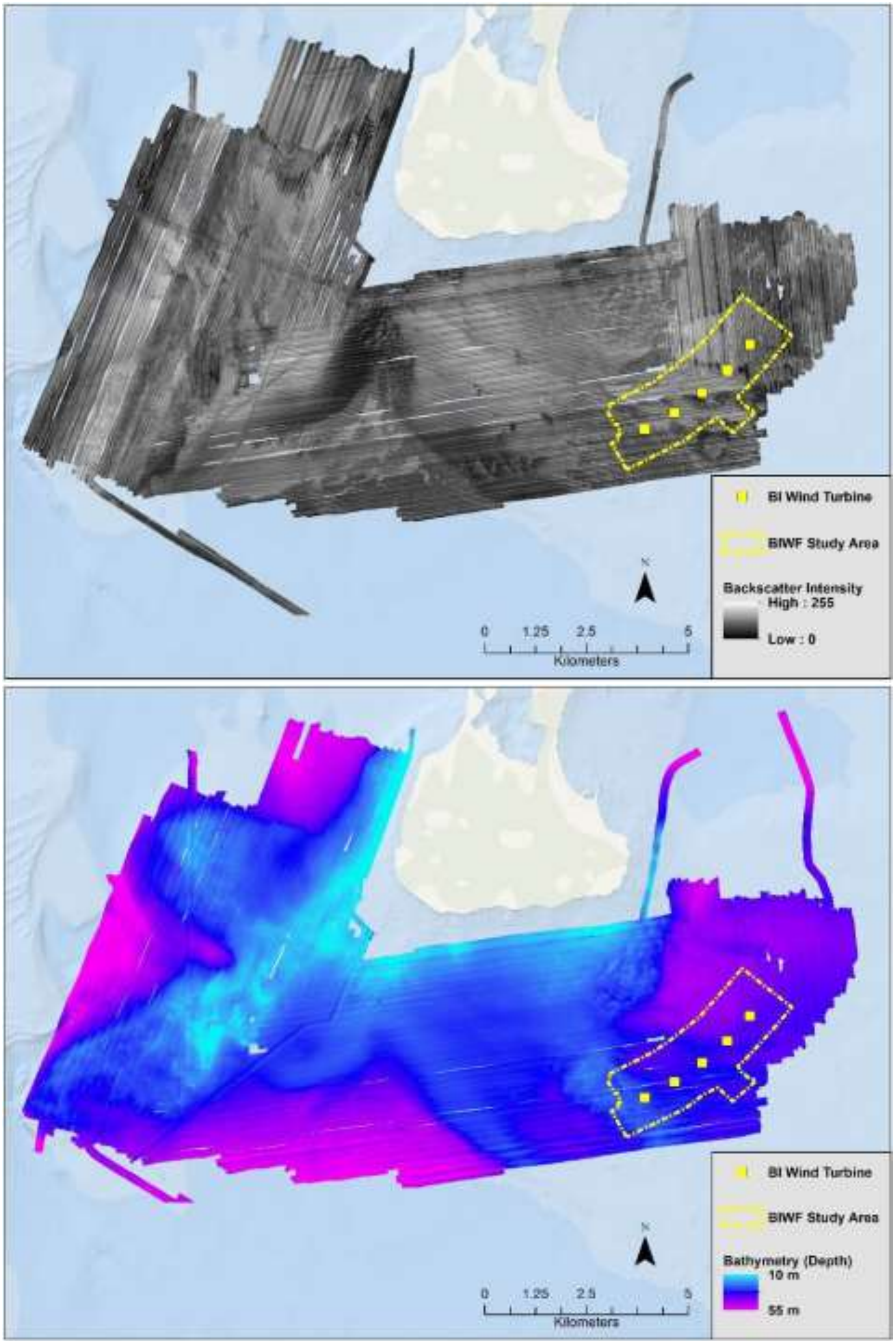


Figure 4. Acoustic datasets (sidescan and bathymetry) collected within the OSAMP study area illustrating the complexity of the area.

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

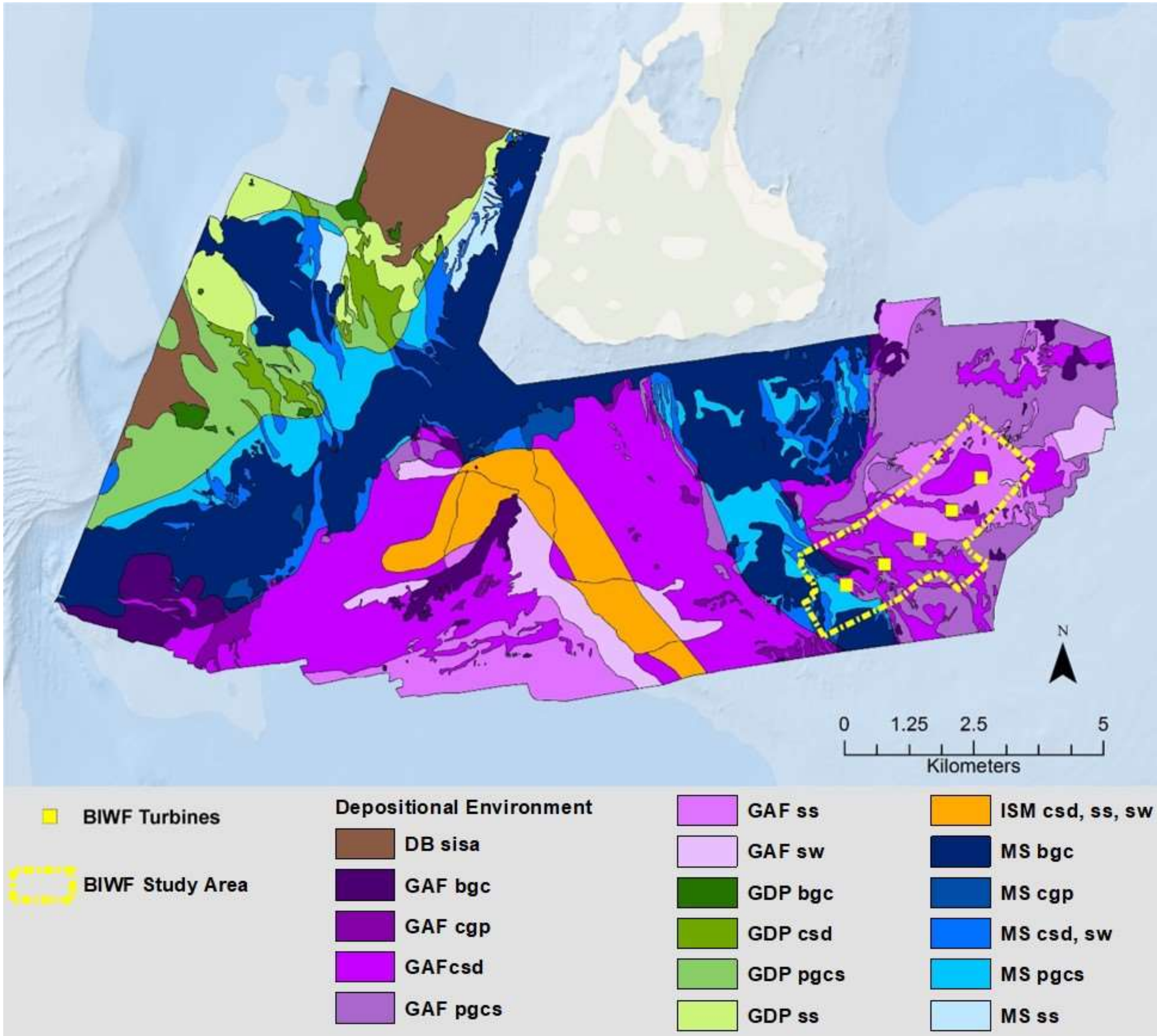


Figure 5. Benthic geologic depositional environments of the OSAMP study area.

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.

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[2] 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). Within the BIWF study area itself, the surficial depositional environments 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-gravel concentrations and boulder-gravel concentrations.

Regarding biological data, a total of 48 benthic grab samples were collected throughout the OSAMP 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 was used to develop a habitat classification (i.e., biotope) map of the study area (**Figure 6**).

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 1**).

Table 1. 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] A bedform is a feature that develops at the interface of fluid and a moveable bed, the result of bed material being moved by fluid flow. Examples include ripples and dunes on the seafloor.

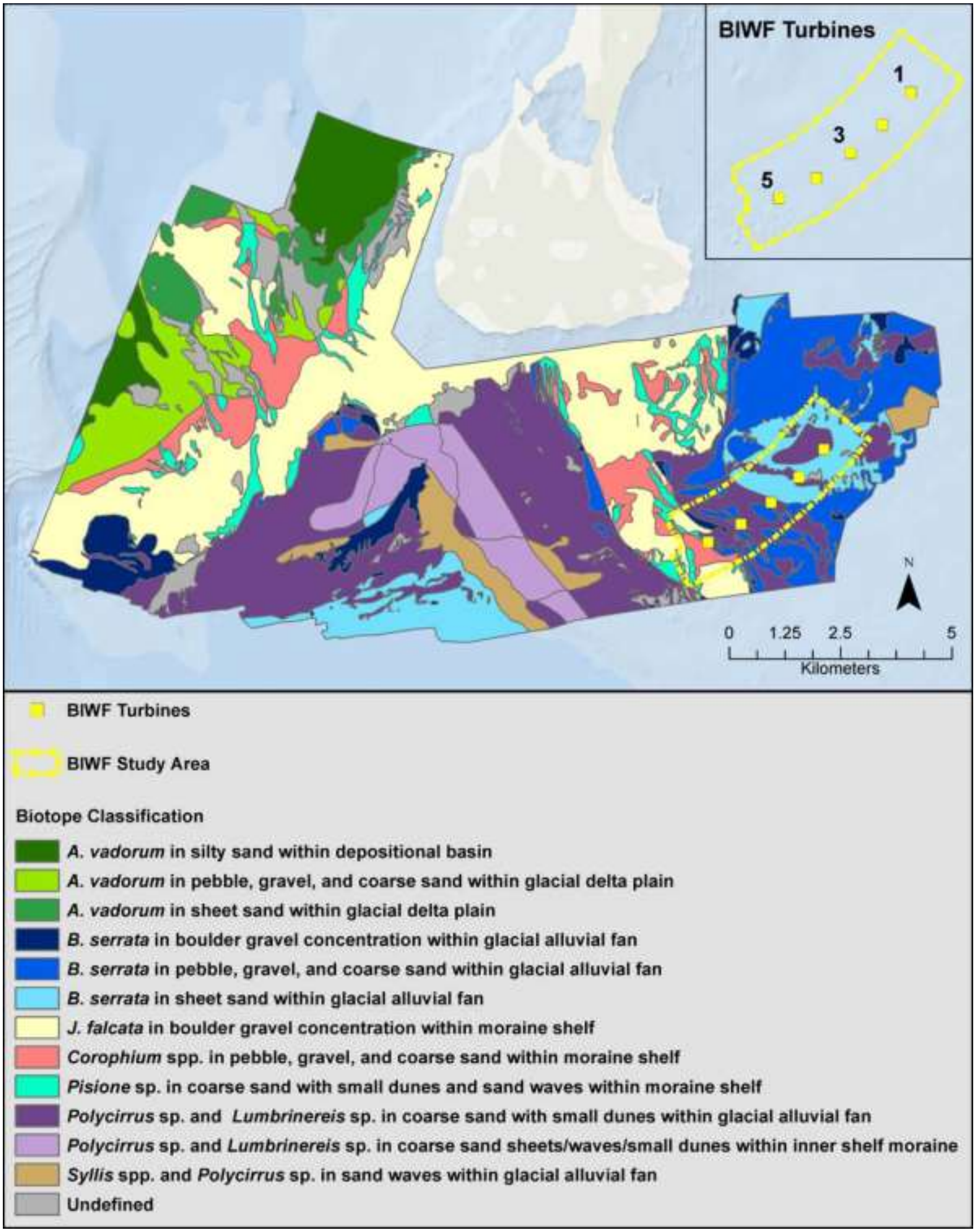


Figure 6. Biotope map of BIWF study area and surrounding area.

Note: Biotope map units are classified according to 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.

1.5.3 Ecosystem considerations

Benthic systems provide food, refuge and critical spawning and nursery habitat for a wide range of teleost fish, elasmobranchs, and invertebrates. Benthic communities also provide ecosystem services such as nutrient recycling, regulation of water quality, and are critical in the exchange of mass, energy and nutrients between pelagic and benthic habitats. Loss or change to benthos may have far-reaching ecological consequences in the marine environment. Offshore wind farms have the potential to change benthic ecosystem functioning by re-structuring the biological communities at and around their foundations (Slavik et al. 2017).

Invertebrates typically form fouling communities that colonize turbines, turbine foundations, and scour protection structures. These communities increase system biomass, serve as food for fish predators, and in this way may benefit predators at higher trophic levels, such as marine mammals (Raoux et al. 2017). The potential ecosystem benefits of artificial structures in the water column are relatively well studied (Smith et al. 2016; Ajemian et al. 2015), as is the role of offshore wind farm (OWF) structures serving as artificial reefs (Ashley et al. 2014; Degraer et al. 2019).

However, the longer-term ecological consequences of wind farm construction, operation, and decommissioning remain unknown. Offshore wind farm leases may be held for upwards of 25 years, and modifications of seabed habitat, changes in benthic communities, maturation of fouling communities, and wider benthic linked ecosystem functions over these time scales are not well understood. Environmental monitoring programs of offshore wind farms to date have focused on species groups, such as fish, birds, and marine mammals, with little attention given to the relationships between these groups.

Data collected as part of the BIWF monitoring study will improve our understanding of the potential ecosystem impacts of anticipated alterations in the benthic macrofaunal community incurred by the placement of turbine foundations on the seafloor. Multi-year sampling sites at turbines and control areas can be used to characterize natural regional fluctuations in benthic communities over time and correct for operational effects during future assessments. Key benthic monitoring techniques employed in this study include vessel- and diver-based seabed sampling; visual assessments of epifaunal communities on turbines and turbine foundations; turbine platform scour monitoring; assessment of organic compounds in marine sediments adjacent to turbine foundations, and post-construction seafloor recovery through bathymetry surveys. This monitoring approach allows evaluation of key community characteristics including species abundance, richness, and assemblage structure, along with relationship dynamics between macrofaunal communities and their associated environments.

The BIWF monitoring study uses the Coastal and Marine Ecological Classification System (CMECS) (FGDC 2012), which is the U.S. national standard adopted by the Federal Geographic Data Committee (FGDC) for habitat classification. CMECS provides a useful framework for monitoring changes in habitat characteristics over time and space, as well as whether these changes indicate positive, negative, or neutral impacts to the environment. CMECS analyses produce biotope maps, which integrate both physical and biological characteristics of a study area and can be used to derive useful management metrics, e.g., the area of sea floor with changed biotope and the qualitative impact of that change.

Wind farm development may incur localized and short-term changes in seafloor sediment composition and invertebrate communities, but these changes may or may not cause lasting impacts to the marine ecosystem. The BIWF monitoring study is, therefore, designed to capture benthic changes on multiple temporal and spatial scales, provide information on interactions between marine species and biotopes, and contribute to our understanding of whether these alterations have any significant and lasting impacts on the marine environment.

2 Methods

The approach adopted in this study consists of a benthic sampling strategy and an epifaunal sampling strategy which were both applied on and/or around specific turbines at BIWF, over three sampling periods. The monitoring survey design incorporating the turbine selection and an overview of the sampling strategy is presented in **Section 2.1** and the sampling effort is explained in **Section 2.2**. The benthic sample collection (vessel and diver-based methods) and subsequent processing is described in **Section 2.3**, and the epifaunal sample collection and processing is described in **Section 2.4**. The data analyses applied are detailed in **Section 2.5**.

2.1 Monitoring Survey Design

The monitoring survey design was iterative in that each year, the survey design was revised to reflect lessons learned in the previous year. The original design focused on the areas 30 to 90 m from the turbine center using vessel-based benthic sampling techniques. Benthic samples were collected within pre-determined distance bands around three of the five turbine foundations and the turbines were selected relative to the location of biotopes previously defined by LaFrance et al. (2014). 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**). Benthic samples were also collected within three control areas characterized by comparable biotopes outside of the wind farm construction area (**Figure 7**).

As the monitoring project progressed, it became apparent that benthic sampling closer to the turbine structures (<30 m) was required to understand the near-field effects and so a diver-based benthic sampling technique was employed around the same turbines. To understand the near-field effects and, in particular, explore the artificial reef effects, epifaunal sampling from the turbine structures was introduced.

This benthic grab sampling strategy and epifaunal sampling strategy allows for temporal and spatial comparisons to be made among sampling sites, post-construction. The benthic grab sampling strategy also allows fine-scale biotope classification to be completed at BIWF, and using the regional study completed prior to construction (LaFrance et al. 2010), allows for pre- and post-construction comparisons to be made. This monitoring approach is valuable for understanding the responses of benthic macrofaunal communities to potential changes with respect 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 hosted the scour monitoring equipment,[3] may, in time, allow opportunity for correlations between measured physical seabed changes with observed habitat and biological community effects, associated with scour protection.

In **Section 2.2** the sampling strategy is explained for both the benthic sampling (**Section 2.2.1**) and epifaunal sampling (**Section 2.2.2**) completed over the three sampling Years. The sampling effort for each year is then presented in **Section 2.3**.

[3] Real-time scour monitoring at Turbine 3 was conducted as part of the BIWF Seafloor Disturbance and Recovery Assessment task.

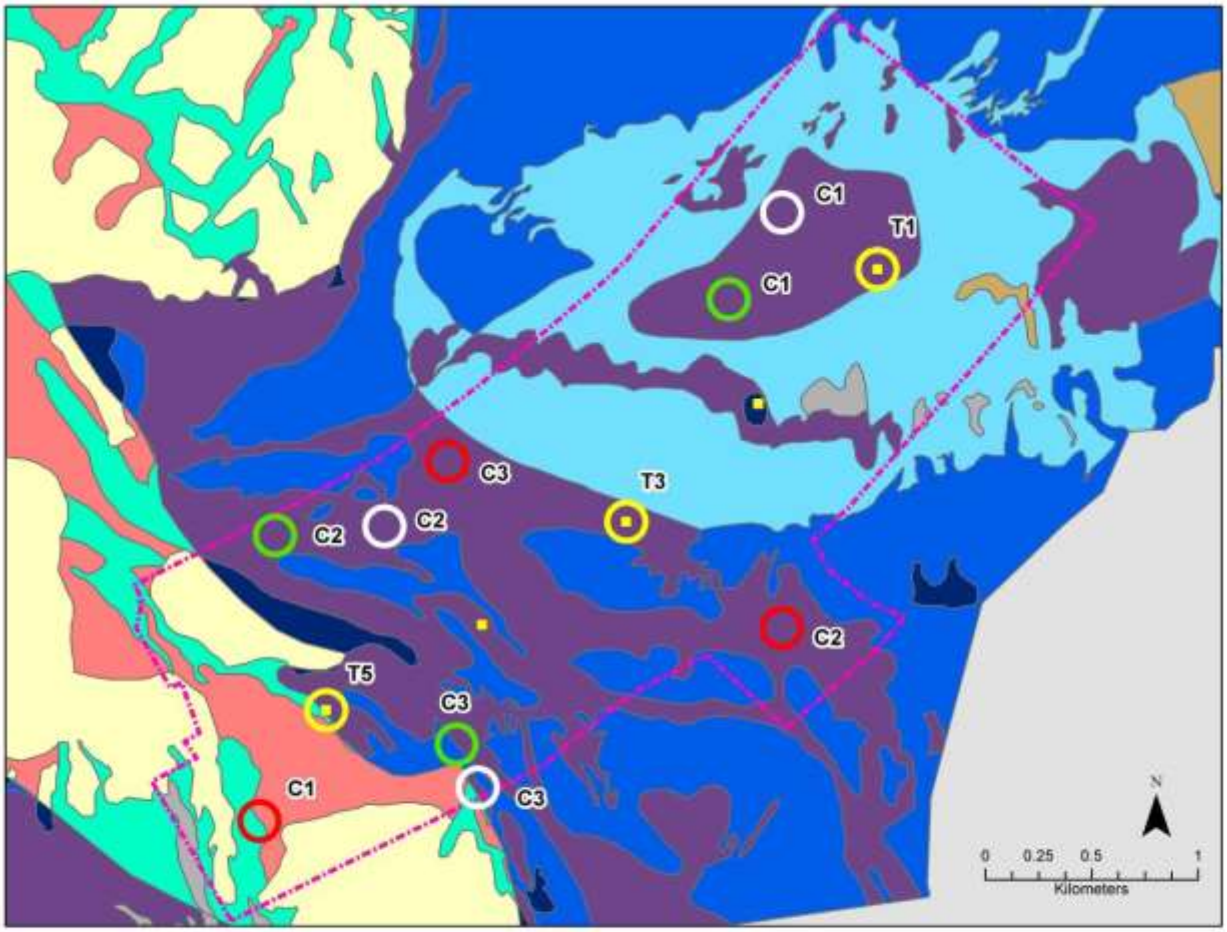


Figure 7. Distribution and extents of classified seabed biotopes in relation to BIWF.

2.1.1 Benthic Sampling Strategy

During this study, benthic samples were collected over three sampling periods, referred to as “Year 1” (2016–2017), “Year 2” (2017–2018) and “Year 3” (2019). In each sampling period, hereafter ‘Year,’ samples were collected using the same base methods to allow for direct spatial and temporal comparisons. The Year 2 and 3 methods were enhanced to expand the sampling effort (described below). This report compares data derived from the Year 3 sampling with data from Year 2 and Year 1, in efforts to detect any significant temporal differences. In addition, data from each year (1, 2, and 3) were analyzed to investigate if any significant spatial differences in benthic macrofaunal communities and/or sediment properties, have occurred between the turbine and control areas, within each sampling period.

Sample stations were planned at three of the five turbines (T1, T3, and T5) and within three control areas (C1, C2, C3) (**Figure 7**). A new array of stations was planned within the turbine areas in each year, i.e., Year 1 stations were not resampled in Year 2 and Year 3, to avoid sampling previously disturbed areas. Similarly, entirely new control areas were chosen each year because in Year 1 one of the control areas (C1) was characterized by coarse sediment and boulders and was thus unrepresentative of the turbine areas.

Vessel-based sampling targeted the area 30 to 90 m from the center of the turbines. A Smith McIntyre grab sampler was paired with seabed video to provide broader contextual information of the surrounding area. Nine sample stations were randomly positioned within each sampled turbine area (T1, T3, T5), and using a cluster sample strategy, resulted in 27 samples per turbine (81 samples total), per year (Years 1–3). These cluster samples are not considered true replicates due to the difficulties of collecting three co-located samples in offshore conditions in water depths averaging 30 m. However, the collection of three cluster samples (rather than single 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.

Furthermore, within each turbine area, the random sampling process was stratified to position three of the sampling stations within three pre-determined distance bands (near, intermediate and far) so that samples were collected at increasing distances from the turbine foundation. This strategy was intended to provide adequate coverage, to investigate potential benthic modification with distance from the turbine foundations (Schröder 2006; Coates et al. 2012 and 2014). From the center point under the foundation structure, these distance bands were equal to 30 to 49 m (near), 50 to 69 m (intermediate), and 70 to 90 m (far). 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 perimeter of the 'near' distance band (30 m, **Figure 8**) is located 15 m from each leg and 20 m from the sides of the foundation structure itself.

When pre-defining the sample stations, 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 4) scour protection material (concrete mats) placed over portions of the cable.

Within each control area, cluster samples were collected at randomly positioned sampling stations (without the use of distance bands). In each of the three control areas, three cluster samples were collected, resulting in nine samples per year (Years 1–3). The control areas were selected at locations outside of the predicted influences of the construction and operation of the BIWF (**Figure 7**). The areas also were 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 the natural variation.

In Year 2 and 3, an additional diver-based benthic sampling effort was undertaken to assess the near-field effects of the turbines. The samples were added in recognition that the sampling design in Year 1 was not adequate to detect changes that may be occurring at small distances, i.e., in the order of meters, from the turbine structure because samples were collected at a minimum distance of 15 m and maximum of 20 m from the outer perimeter of the structure, and 30 m from the center point under the structure (**Figure 8**). Further, the Year 1 sampling strategy was not designed to consider changes that could be occurring within the footprint of the jacket structures, despite this being a sizable area of approximately 625 square meters (i.e., 25 m per side).

This additional diver-based sampling effort focused on distance banding 0 to 30 m from the turbine center, i.e., within the footprint of the turbine, directly under the turbine structure (Years 2 and 3) and the area immediately surrounding the turbine (Year 3 only). For sampling in such proximity to the turbines, benthic grab samples could not be taken following the same vessel-based protocol using the Smith McIntyre grab sampler. Therefore, for this near-field sampling effort (0 to 30 m), a diver-based data collection method was developed to mimic the grab sampler. The samples from within the turbine footprint, were collected by divers on a diagonal transect between two turbine legs (south leg to north leg). In Years 2 and 3, five samples were collected within the footprint of each of the three turbines (T1, T3, T5). In Year 3 the sampling protocol was further expanded to incorporate the area outside of the structure but immediately surrounding the turbine, hereafter 'very near-field.' Again, excluding any construction-related disturbance features identified. For each turbine (T1, T3, T5), three randomized sample stations were pre-determined within the 30 m radius but outside of the turbine footprint. From that randomized predetermined location, samples were taken at 1 m distance from each other moving closer to the structure thereby providing a mini transect of distance from structure. A total of three stations, each with three replicates were collected at each turbine resulting in a total of 27 samples, collected in Year 3 only.

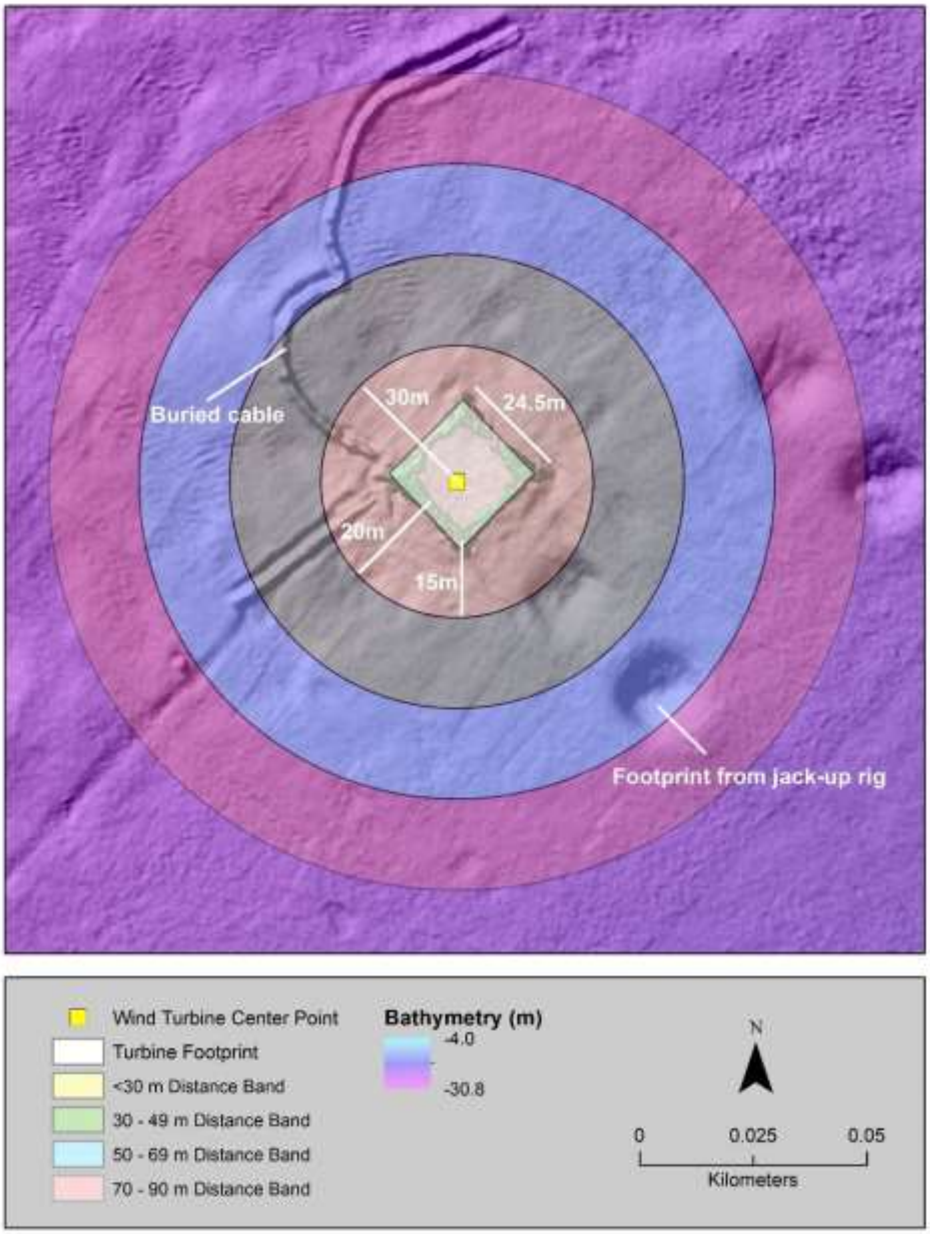


Figure 8. Example of the relationship between distance bands and the center of the turbine foundation structure (Turbine 1 shown here).

Note: Distance bands include the 'footprint' (under the structure), the 'very near-field' (<30 m from but outside of the structure), 'near' (30 to 49 m), 'intermediate' (50 to 69 m) and 'far' (70 to 90 m).

Diver collected samples and vessel collected grab samples using the Smith McIntyre grab sampler were designed to collect samples of similar dimensions (e.g., surface area and volume) and therefore be comparable. To assess the comparability of these two methods, three samples using each method were collected in a soft sediment environment and subjected to the same biological analysis to determine if they were comparable or not.

Additional benthic data was obtained using a Lagrangian floating imaging platform to collect high-resolution, high-frequency, photographs of the seabed (see **Section 2.3.1.3.**). Seabed photography was undertaken to obtain a clear interpretation of the seabed, including geological (e.g., sand, gravel, boulders) and biological characteristics (e.g., organisms, shell hash), as well as any artificial features (e.g., concrete mats overlaid on portions of the buried cable). This was completed each year (Years 1–3) by allowing the floating imaging platform to drift collecting images in transects at each of the turbine and control study areas. Divers also used the imaging platform to collect high-resolution images within the footprint of the turbines in Years 2 and 3. These images were used to provide a qualitative account of the changes occurring underneath the turbine structures over the sample two-year period.

2.1.2 Epifauna Sampling Strategy

Over time it is expected that epifaunal communities will develop on the structures with consequences for the surrounding area. The epifaunal communities may attract other species to the structures, for example, due to the provision of food and shelter; the artificial reef effect (Langhamer 2012; Coolen et al. 2018). It is also likely that as the epifaunal communities develop, the surrounding benthic area becomes enriched with organic matter. As a first step to understanding the epifaunal processes at BIWF, a sampling strategy was introduced with the intention of repeating the Year 2 sampling in Year 3 to establish temporal and spatial changes in epifaunal communities. This helps provide insight into the overall ecological processes occurring at BIWF.

Epifauna sampling (i.e., video footage, scrape samples) and biological analyses were designed to determine percent cover, species composition, density and biomass of organisms colonizing the turbine structures (Years 2 and 3). The video sampling strategy facilitated temporal and spatial assessments of the epifaunal community developing on the vertical turbine structures, the turbine bases and concrete mattresses. Additionally, video footage was intended to be used to assess for opportunistic observations of squid eggs, fish presence, alterations to concrete mats, snagged fishing gear and where possible comparisons between turbines. The video sampling strategy was further supported by epifaunal scrape samples from the southern leg of BIWF Turbine 1, which allowed a preliminary assessment of the biomass of the early successional epifaunal community on the turbine structures. Turbine 1 was selected for this sampling strategy because it presented the deepest profile to investigate epifaunal changes and had shown the greatest record of changes in the previous year's sampling effort. The primary objective of the epifaunal scrape sampling strategy was to provide a more complete analysis of the epifaunal communities on the BIWF turbine structures and alterations of the marine environment due to the presence of the structures. An additional objective was to determine the increased mass and surface area resulting from the epifaunal community and the subsequent influence of drag forces on the structure from an engineering perspective.

Video data were collected in Year 2 and Year 3, from the leeward and current side of southern leg of Turbines 1, 3 and 5 covering the area between the water line and the base of the structure, i.e., the full vertical extent (approximately 30 m). From the video footage of each side of the turbine leg, 50 photoquadrats were extracted at random intervals, resulting in 100 samples per turbine, per year (Years 2 and 3).

Epifaunal scrape samples (0.1 m^2) were taken along the leeward side (only) of the southern leg of Turbine 1. In Year 2, scrapings were collected from eight positions on the leg, the leg base and the grate base areas of the foundation leg (total of 10 samples). In Year 3, again focusing on the southern leg of turbine 1, epifaunal scrape samples (0.01 m^2) were taken at approximately 1 m intervals from the base of the leg up to the intertidal mark, repeated on both the leeward and current side of turbine leg. Because of the tidal level, this provided a total of 27 samples on the leeward side and 27 samples on the current side of the turbine leg, collected in Year 3 only.

All Year 2 scrape samples from the leeward side (10 samples total) and 15 of Year 3 samples from the leeward and 15 from the current side of the leg (Year 3, 30 samples total) were biologically analysed (**Section 2.5.2**). All scrape samples from Year 3 were used to determine the influence of the epifaunal organisms on the turbine structure (e.g., weight, surface area, drag forces), from an engineering perspective (**Section 2.5.3**).

2.2 Sampling Effort

2.2.1 Benthic Sampling Effort

In Year 1, a total of 121 benthic grab samples were planned within the turbine and control areas (**Figure 9**). These samples include 27 samples collected at nine stations across the three distance bands within each of the three turbine areas (81 samples total); 12 samples collected at four stations within each of the three control areas (36 samples total); and four samples collected for independent quality control (QC). All samples collected in Year 1 were collected using vessel-based techniques.

The QC 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. The sampling strategy in Year 2 was updated based on experiences from Year 1. For the benthic sampling, the number of sample stations within the control areas was reduced to three (9 samples at each station; a total of 27 samples) because the Year 1 design was determined to be unbalanced to which significance testing procedures can be sensitive. In Year 1, the total sample size for the control areas (combined) was 36, whereas the sample size for each of the turbines was 27. Removing one control sample station allowed the total sample size from the control areas to be 27; equal to the sample size for each turbine area. Further, the QC samples were removed from the sampling plan, as they were considered unnecessary in Year 2.

The Year 2 benthic sampling effort was also modified to include the collection of five grab samples located within the footprint of each of the three turbine structures, i.e., underneath the turbine structure. These samples were collected by divers as single samples (not in clusters of three).

In Year 2, a total of 123 benthic grab samples were planned within the turbine and control areas (**Figure 10**). These samples include 27 samples collected at nine stations across the three distance bands within each of the three turbine areas (81 samples total), nine samples collected at three stations within each of the three control areas (27 samples total), and five samples collected within the footprint of each turbine structure (15 samples total). Samples collected in Year 2 were collected using a combination of vessel- and diver-based techniques (**Figure 15**).

The sampling strategy in Year 3 was updated based on experiences from Year 2. Additional benthic samples were added to sample the very near-field area, i.e., outside of the structure's footprint but within 30 m from the structures center point. These very near-field samples were collected at three stations in replicates of three by divers. The number of samples taken within the footprint of the turbine structures was maintained, the same as Year 2 (five per turbine footprint), to assess changes occurring within the footprint of the jacket structure (an approximate 625 m^2 area). Furthermore, for the purposes of comparison between the vessel-based grab sample methods and the diver-based grab sample collection methods, three samples from each method were collected from a new control site with environmentally suitable conditions.

In Year 3, a total of 186 benthic grab samples were planned within the turbine and control areas (**Figure 11**). These samples include 36 samples collected at twelve stations across the four distance bands within each of the three turbine areas (108 samples total); nine samples collected at three stations within each of the three control areas (27 samples total); five samples collected within the footprint of each turbine structure (45 samples total); and three samples from each method for comparison, i.e., diver- verses vessel-based grab samples collection (6 samples total). Samples collected in Year 3 were collected using a combination of vessel- and diver-based techniques (**Figure 15** and **Figure 16**).

2.2.2 Epifaunal Sampling Effort

Epifaunal sampling was introduced in Year 2 and enhanced in Year 3. In Year 2, a total of 310 epifaunal samples were collected from the Turbine structures (**Table 3**). This included video footage of the southern leg of each turbine collected in a vertical transect on the current and leeward side, from which 50 samples were extracted (300 samples total); and 10 epifauna scrape samples collected from the southern leg of Turbine 1 on the leeward side (10 samples total).

Epifaunal sampling was enhanced in Year 3 to assess the extent of the colonization by epifauna on the structures. In Year 3, additional epifaunal samples were added, comprising of more frequent scrape samples over the vertical extent of the structure and further video footage of the structure. This was added in order to gain a better understanding of how the epifaunal communities varied over the vertical extent of the turbine structure, on the base and on the supporting infrastructure, such as cables and concrete mattresses used as cable protection. There was also interest in determining if squid eggs had populated the structure and in documenting the fish now surrounding the structure, as well as if any debris or fishing gear had become snagged on the turbine structures. In addition, the biomass of the epifauna was to be assessed to understand if the weight was of importance from a structural perspective.

In Year 3, a total of 354 epifaunal samples were collected from the turbine structures (**Table 3**). This included video footage of the southern leg of each turbine, collected in a vertical transect on the current and leeward side, from which 50 samples were extracted (100 samples total per turbine); and 27 epifauna scrape samples collected from the southern leg of Turbine 1 on the leeward side and 27 samples from the current side (54 samples total).

Table 2. Summary of benthic survey sampling effort for Year 1, 2 and 3.

		Sample collection type	Number of samples						
			Turbine 1	Turbine 3	Turbine 5	Control 1	Control 2	Control 3	Method Comp.
Year 1	30–49 m	Vessel	9	9	9	--	--	--	--
	50–69 m	Vessel	9	9	9	--	--	--	--
	70–90 m	Vessel	9	9	9	--	--	--	--
	Control Areas	Vessel	--	--	--	12	12	12	--
	Independent QC samples	Vessel	1	1	1	--	--	1	--
	Total No. of Samples		**121**						

Table 2. Summary of benthic survey sampling effort for Year 1, 2 and 3.

		Sample collection type	Number of samples						
			Turbine 1	Turbine 3	Turbine 5	Control 1	Control 2	Control 3	Method Comp.
Year 2	30–49 m	Vessel	9	9	9	--	--	--	--
	50–69 m	Vessel	9	9	9	--	--	--	--
	70–90 m	Vessel	9	9	9	--	--	--	--
	Control Areas	Vessel	--	--	--	9	9	9	--
	Within footprint of turbine structure	Diver	5	5	5	--	--	--	--
	Total No. of Samples		**123**						
Year 3	<30 m	Diver	9	9	9	--	--	--	--
	30–49 m	Vessel	9	9	9	--	--	--	--
	50–69 m	Vessel	9	9	9	--	--	--	--
	70–90 m	Vessel	9	9	9	--	--	--	--
	Control Areas	Vessel	--	--	--	9	9	9	--
	Within footprint of turbine structure	Diver	5	5	5	--	--	--	--
	Method Comparison	Diver Vessel	--	--	--	--	--	--	3 3
	Total No. of Samples		**186**						

Table 3. Summary of epifauna survey sampling effort for Year 2.

		Sample collection type	Number of samples		
			Turbine 1	Turbine 3	Turbine 5
Year 2	Leeward	Video	50	50	50
	Current	Video	50	50	50
	Leeward	Scrape	--	--	--
	Current	Scrape	10	--	--
	Total No. of Samples		**310**		
Year 3	Leeward	Video	50	50	50
	Current	Video	50	50	50
	Leeward	Scrape	27	--	--
	Current	Scrape	27	--	--
	Total No. of Samples		**354**		

2.3 Benthic Sampling Methods

2.3.1 Vessel-Based Benthic Data Collection

2.3.1.1 Benthic Grab Samples (vessel)

A Smith McIntyre grab sampler (approximately 620-square centimeter sample area) was used to collect the grab samples within the turbine and control areas. An overview of the locations of the vessel-based Smith McIntyre grab deployments for Year 1, 2 and 3 samples are presented in **Figure 9, Figure 10,** and **Figure 11**, respectively. Samples are named according to turbine (T) or control (C) area, followed by station number (1 to 9) and sample number (1 to 3). As examples, the name T1-1_1 represents the first cluster sample taken at Station 1 from Turbine 1, and C2-3_2 names the second cluster sample taken at Station 3 within Control 2. Note that diver-based grab sample locations are described in **Section 2.3.2**.

Upon recovery of the grab sample, the sediment within the grab bucket was inspected to assess whether the sample was acceptable (i.e., had not been subject to partial washout during retrieval, and was of sufficient volume relating to depth of bite). If the sample was not acceptable, the vessel was repositioned, and the sample was attempted again until an acceptable sample was obtained. The approximate volume of each grab sample, accompanied by a visual description, including conspicuous sediment features and obvious fauna, was recorded in the field. Field survey records are presented in **Appendix B**. In Year 2 and Year 3, photographs of each sample were also taken upon recovery in the field and retained for future reference.

A sediment sub-sample (25–50 milliliters) was collected from the grab sample, for analysis of sediment grain size (**Section 2.3.4.1**) and organic content (**Section 2.3.4.2**). The remaining material was transferred to a bucket for macrofaunal analysis (**Section 2.3.4.3**). All samples were stored in pre-labeled containers with locking lids to ensure no loss of material and brought back to the lab. Upon arrival to the lab, all samples were stored at 4 degrees Celsius (°C) until processed to reduce deterioration.

2.3.1.2 Seabed Video

A GoPro video camera outfitted with lights was attached to the frame of the Smith McIntyre grab sampler, allowing for video and grab sample datasets with identical spatial and temporal attributes to be collected. Such co-located datasets reduce uncertainties associated with returning to an area for sampling. Seabed video footage was collected to complement the grab sample data and provide contextual information on the degree of spatial heterogeneity of the environment and associated benthic biological communities. Additional qualitative information provided by the video footage included the identification of bedforms, coarse surficial material concentrations (e.g., boulders, cobble, gravel), and species that are more mobile or present at low densities (e.g., crabs, starfish, sponges, algae) which tend not to be captured by the grab sampler.

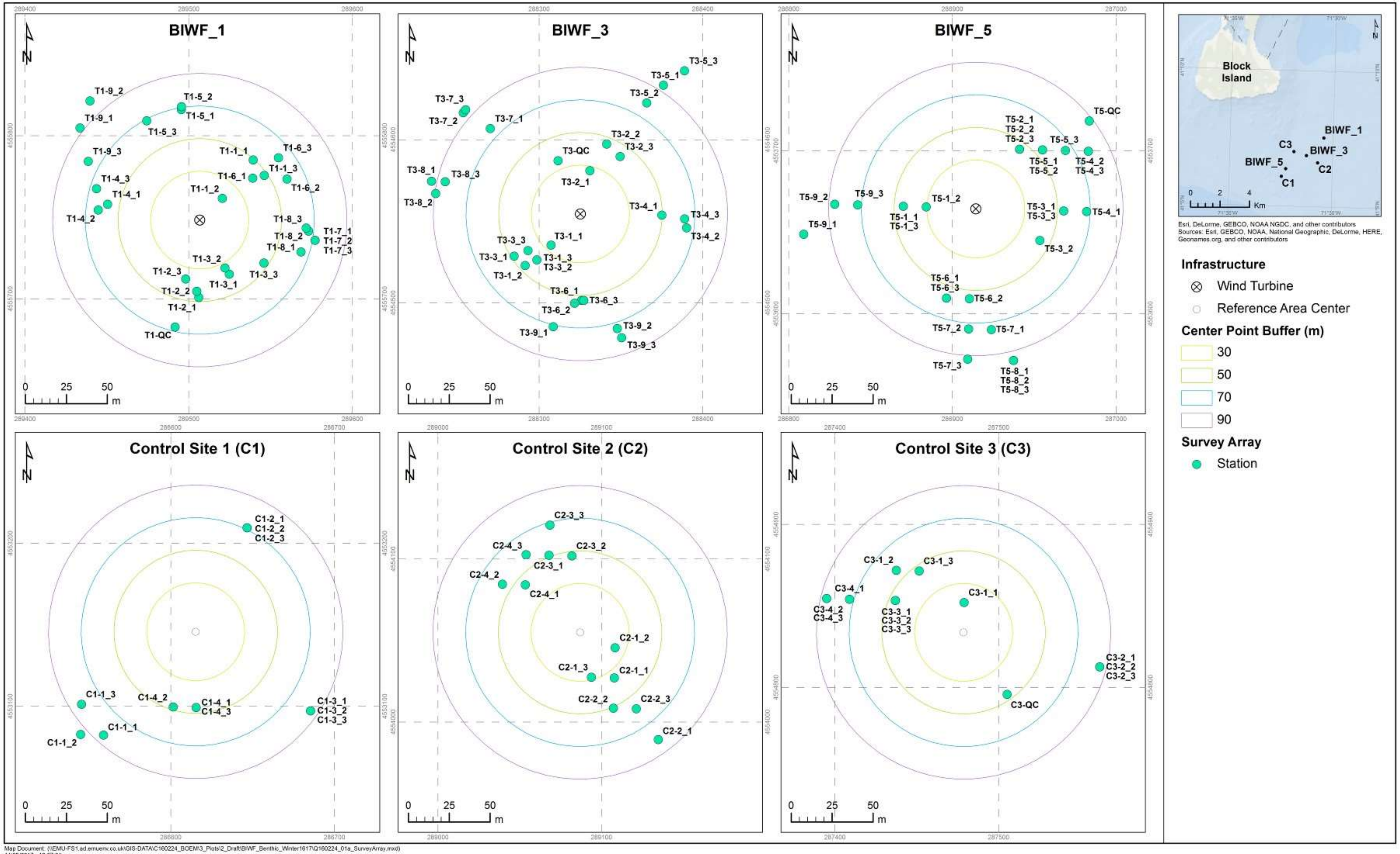


Figure 9. Location of the vessel-based grab samples and seabed video collected within the BIWF study area for Year 1.

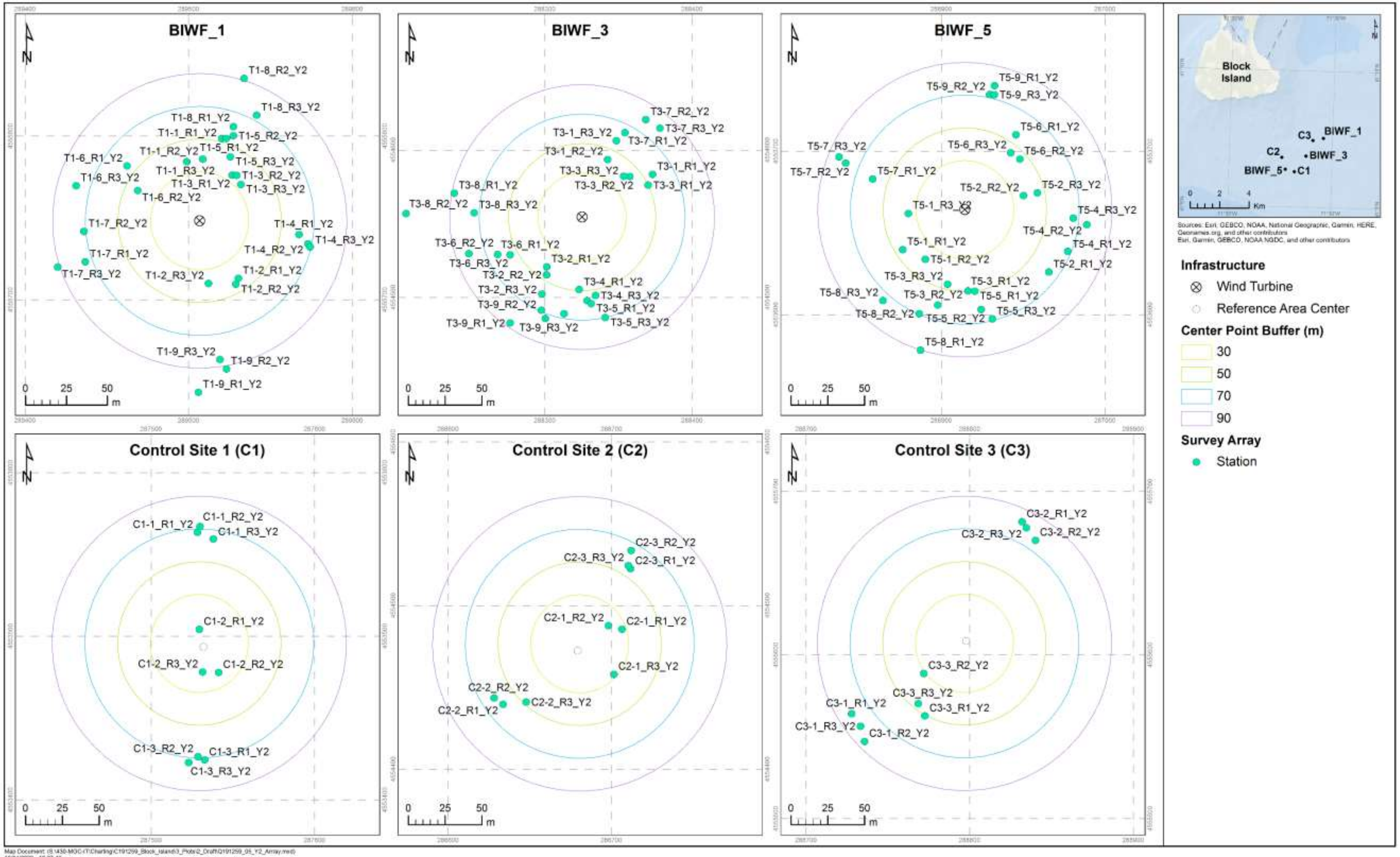


Figure 10. Location of the vessel-based grab samples and seabed video collected within the BIWF study area for Year 2.

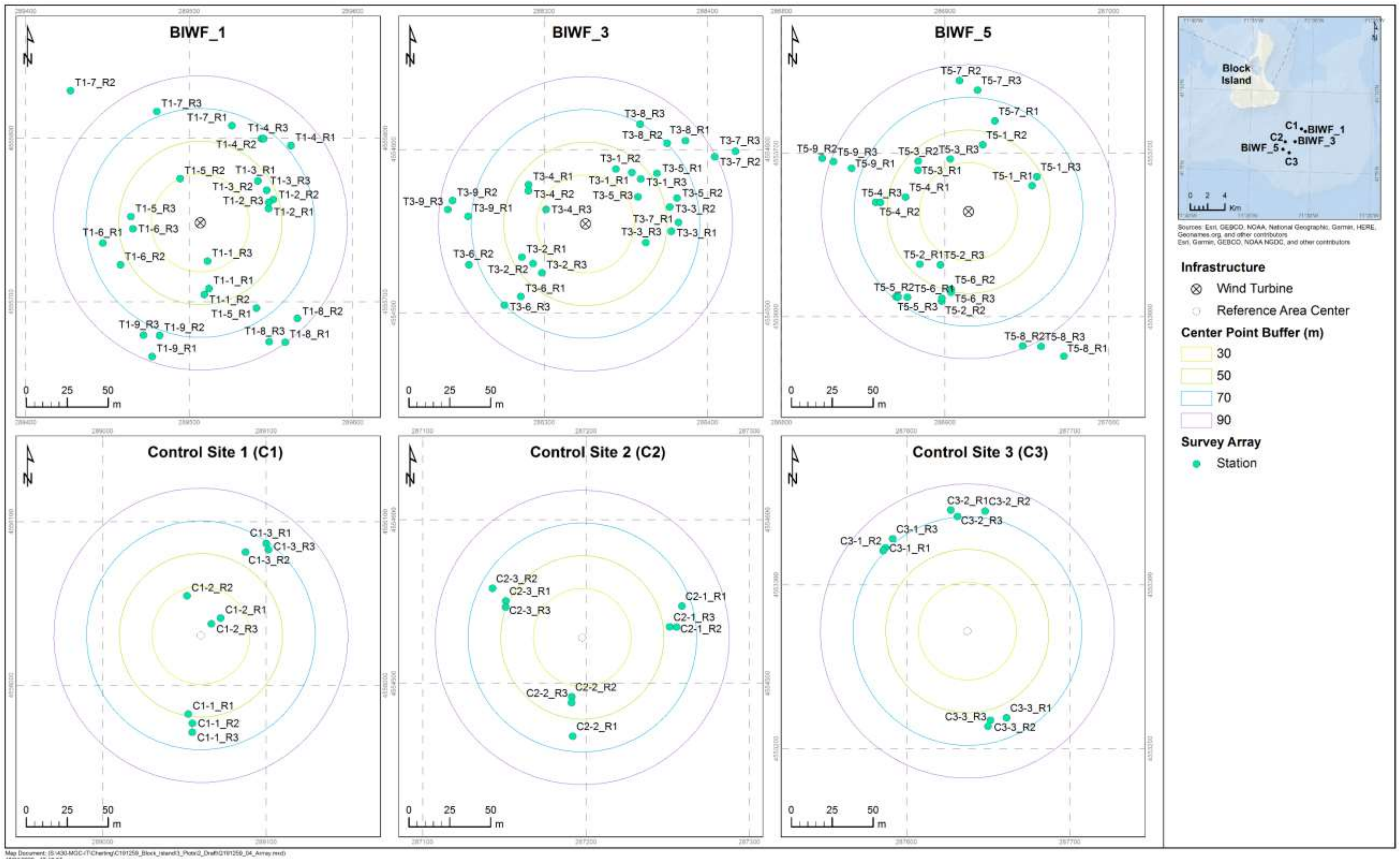


Figure 11. Location of the vessel-based grab samples and seabed video collected within the BIWF study area for Year 3.

2.3.1.3 Seabed Photography (float)

High-resolution, high-frequency, still images of the seabed were collected, using a Lagrangian floating imaging platform, equipped with a remote digital camera with strobes (Roman et al. 2011). The platform is free-floating by design, i.e., its trajectory is determined by bottom currents. The system was tethered to a surface buoy, which provided a visual aid of the drift track and allowed easier recovery. Using active buoyancy control to move up and down the water column, the platform followed the seabed at a pre-programmed constant altitude of approximately 1.7 to 2.2 m. This ensured that high resolution images of the seabed were obtained while maintaining a safe distance from the seabed, avoiding any raised objects (e.g., boulders). The time and location of deployment and recovery were recorded from the vessel GPS and provide an approximate transect, although the exact drift track was not recorded. The duration of each deployment was between 15 and 30 minutes. The imaging platform was redeployed where necessary to obtain a successful photography transect, thus ensuring that all features can be confidently described.

Seabed photography transects were completed at each sampled turbine (T1, T3 and T5) and each of three control areas, over the three-year study period (i.e., six study areas per year). In Year 1, sampling was variable with between one and four photography transects collected at each study area (three turbines and three controls), a total of 15 transects. In Year 2, two photography transects were collected at each study area, a total of 12 transects. In Year 3, two photography transects were completed at each turbine and each control area, a total of 12 transects. The transect locations for Years 1, 2 and 3 are presented in **Figure 12, Figure 13,** and **Figure 14**, respectively. Records of the float missions are detailed in **Appendix C**.

Note that divers also used this floating imaging platform to collect photography transects within the turbine footprint in Year 2 and 3 (**Section 2.3.2.2**).

2.3.2 Diver-Based Benthic Data Collection

2.3.2.1 Benthic Grab Samples (diver)

Where Smith McIntyre grab samples from the vessel (**Section 2.3.1**) were not possible because of proximity to the turbine, divers collected comparable grab samples. Diver-collected grab samples were collected in Year 2 and Year 3 only, and methods in Year 3 were updated based on lessons learned in Year 2.

The diver grab samples were collected by using an ice scoop to transfer a sample into a pre-labelled bag. In Year 2, the divers were instructed to extract a sample 5 inches deep (marked on the scoop) and transfer material to a 2-gallon bag with a 1-gallon (3.79 L) marker line as a maximum fill indicator. This technique was successful in that suitable material was recovered for organic and particle size distribution analysis. However, it should be noted that while the volume of samples from within the turbine footprint are comparable, the sample volume across turbines varies based on the diver responsible for the collection. As such, the descriptions and comparisons of macrofaunal data between turbines in Year 2 should be considered relative, rather than direct. In Year 3, the method was updated, and divers were provided with a PVC quadrat designed to match the dimensions of the Smith McIntyre sampler (35 × 16 cm) to assist in collecting a 5-inch (12.7 cm) deep sample. The use of the quadrat allowed divers to sample a similar surface area as the Smith McIntyre grab sampler (0.06 m^2).

Divers collected samples from within the turbine footprint in Year 2 and Year 3. At each turbine, the divers descended the southern leg and worked from the inside of the southern leg on a diagonal transect to the inside of the northern leg; a transect of approximately 30 m. Divers collected samples at approximately equal spacing along the 30 m transect, i.e., 0, 7.5, 15.0, 22.5 and 30 m; a total of five samples. In both Year 2 and Year 3, the five samples at each turbine were collected as single samples (**Figure 15**).

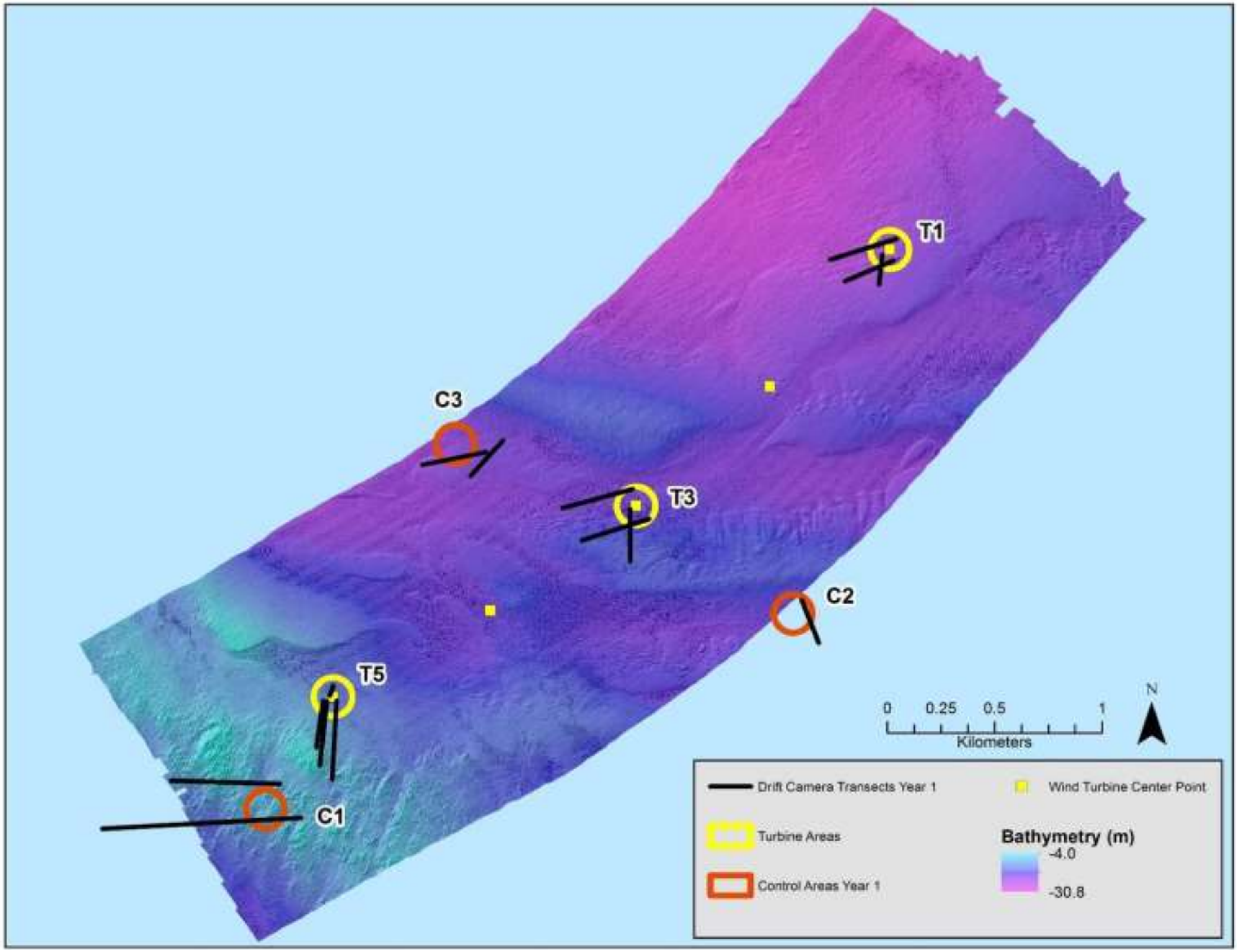


Figure 12. Locations of seabed photography transects collected using a Lagrangian floating imaging platform in Year 1.

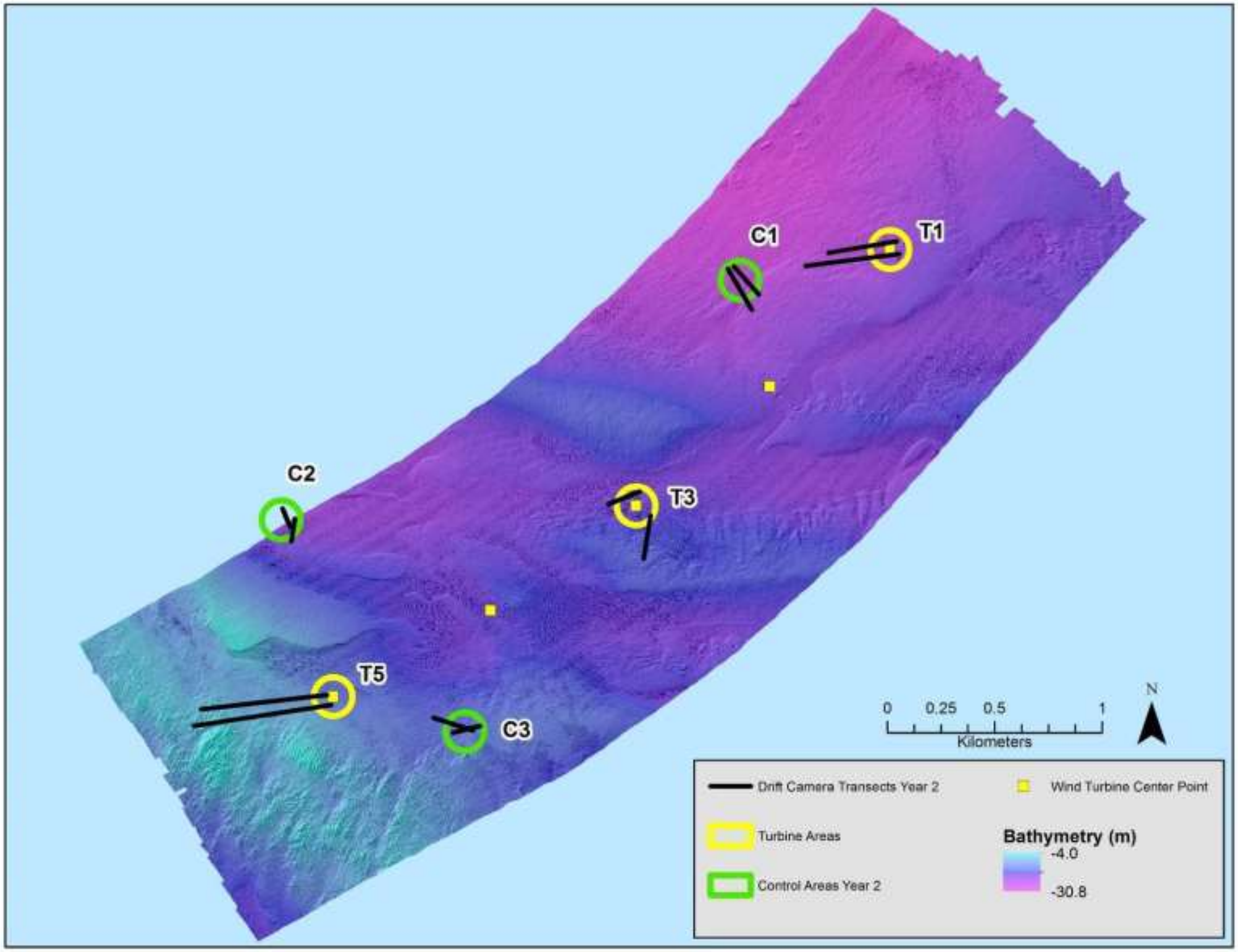


Figure 13. Locations of seabed photography transects collected using a Lagrangian floating imaging platform for Year 2.

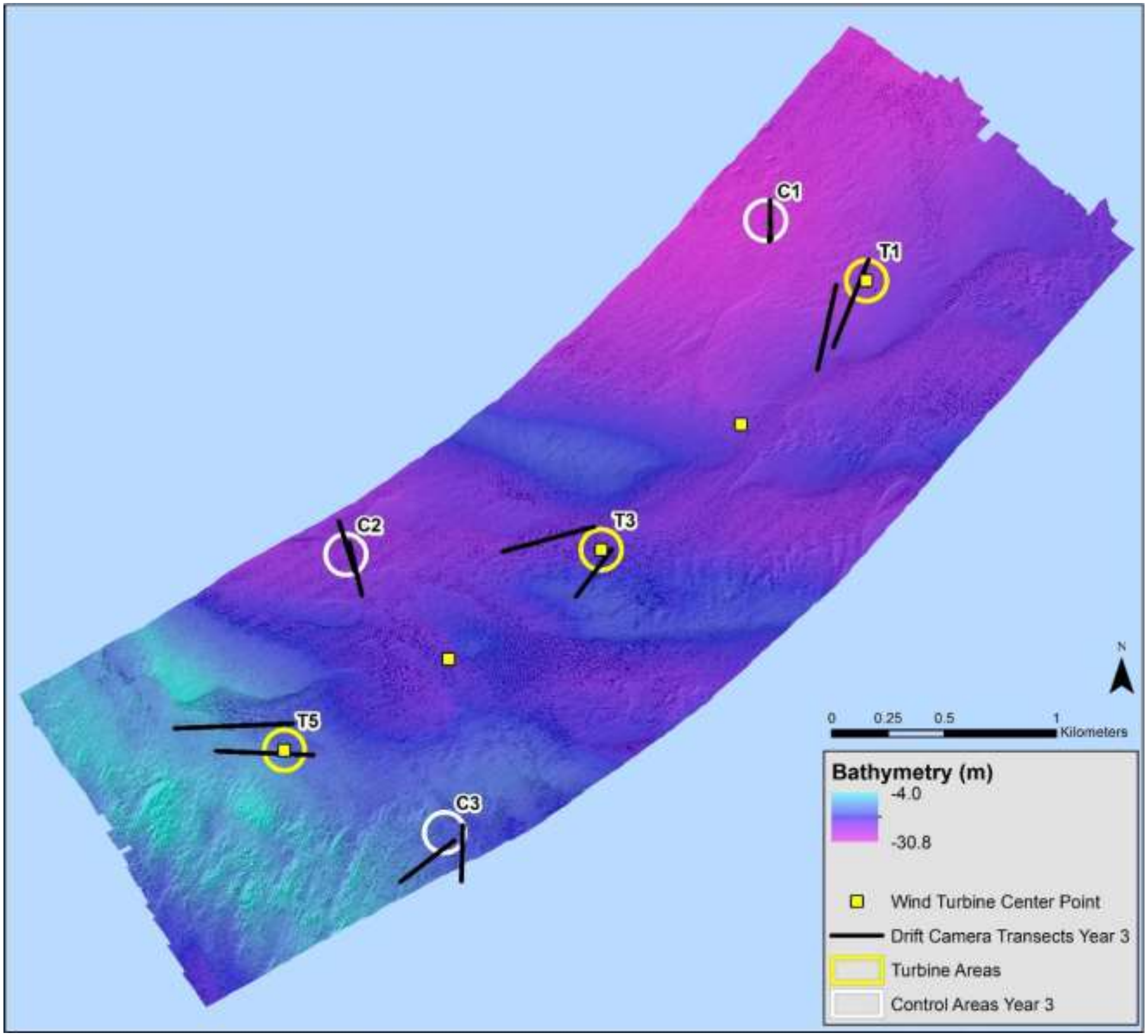


Figure 14. Locations of seabed photography transects collected using a Lagrangian floating imaging platform for Year 3.

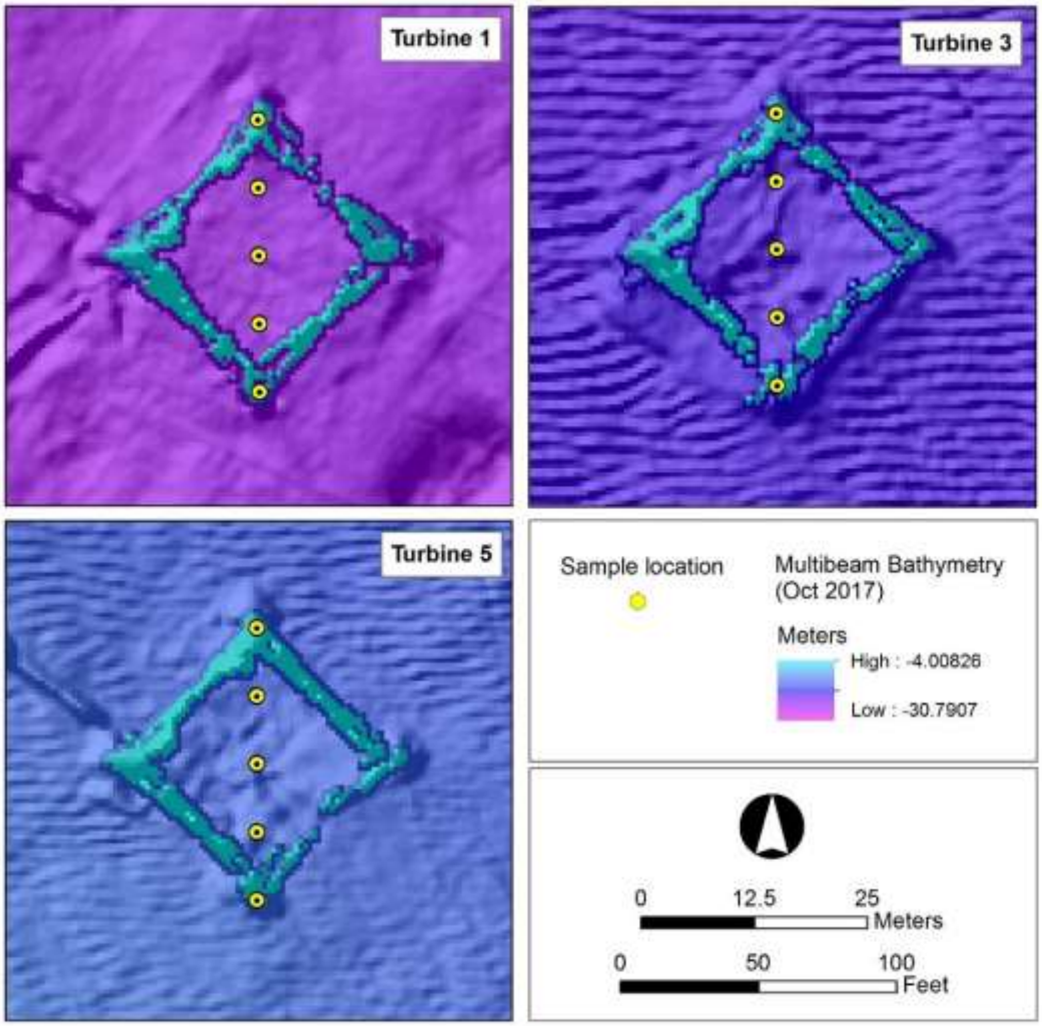


Figure 15. Location of the diver-based grab samples collected within the turbine footprint at the BIWF study area for Year 2 and Year 3.

Divers collected near-field samples, i.e., outside of the structure but within 30 m of turbine central point (**Figure 8**) using the same quadrat sample collection technique, in Year 3 only. Divers were provided with a bearing and a distance from a designated turbine leg to locate a predetermined randomized sample location and a second bearing dictating the orientation of the second and third replicate samples which were taken in the direction of the turbine structure. Divers descended the turbine leg, swam along a tape measure reel, on the given bearing and took the first sample. Divers then turned back toward the structure, informed by the second bearing, and took the replicate samples. At each of the three turbines, within the 30 m radius, nine samples were collected at three stations; a total of 27 samples in the near-field zone (**Figure 16**).

All samples were collected in pre-labeled bags and where necessary, double-bagged upon recovery to ensure no loss of material. Upon arrival to the lab, all samples were stored at 4°C until processed to reduce deterioration. The sediment grain size, organic content, and macrofaunal analyses of the diver-collected grab samples followed the same protocols as those from the vessel-based grab samples, as outlined in **Section 2.3.3**.

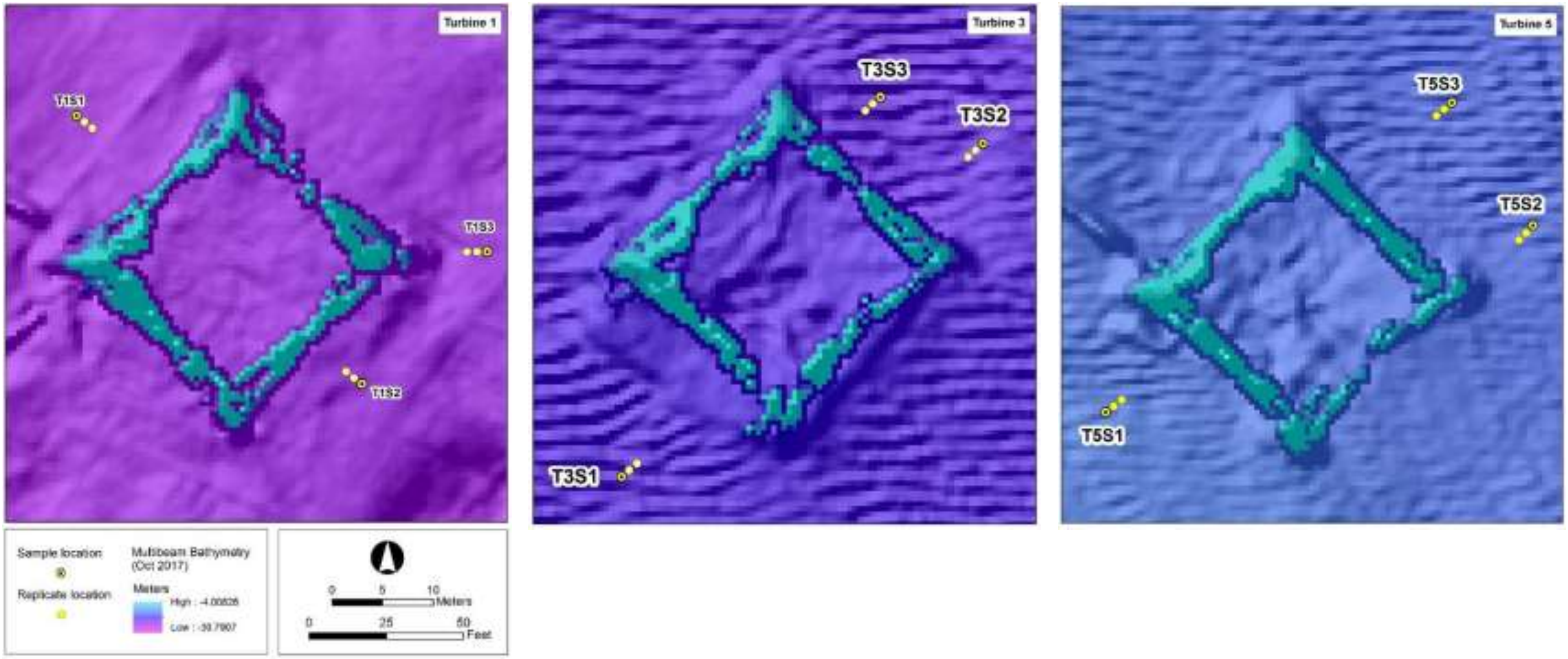


Figure 16. Location of the diver-based grab samples collected in the very near-field area surrounding the turbines at the BIWF study area for Year 3 (i.e., <30 m from the center of the turbine but outside of the structure).

2.3.2.2 Seabed Photography (towed)

The Lagrangian floating imaging platform (described in **Section 2.3.1.3**) was used (with modification) to collect high-resolution photographs of the seabed within the footprint of the three sampled turbines in Year 2 and Year 3. The system was modified to be towed by a diver, rather than programmed for free-floating drift tracks. In general, divers towed the imaging platform by mimicking the north-south transect along which the diver grab samples were collected (**Section 2.3.2.1**), and then continued beyond the structure, up to 90 m to ensure imagery was captured across each of the distance bands. The extension distance and direction of travel varied (north-south or south-north) depending on sea conditions. The floating imaging platform was still able to maintain its position, 1.7 to 2.2 m from the seabed and the high resolution, high frequency images were taken at the same rate (2 to 5 seconds) when the free-floating drift tracks took place.

In Year 2, one diver-towed photography transect was completed at each sampled turbine. At Turbines 1 and 5, divers towed along a south-north transect and extended the transect out to the 90 m distance. At Turbine 3, divers towed in the north-south direction and extended out to 80 m.

In Year 3, the diver towed photography transects were completed at each of the three sampled turbines (T1, T3, T5). Transects at these turbines were completed in the south-north direction and extended out to approximately 80 to 90 m.

Records of the diver-towed missions completed in Year 2 and Year 3 are detailed in **Appendix C**.

2.3.3 Benthic Sampling Method Evaluation

The original benthic sampling strategy adopted in Years 1 through 3 was to use a Smith McIntyre grab sampler deployed from a vessel as detailed in **Section 2.3.1**, and the Year 1 data were used to assess the performance of this sampler in different sediment types **(Section 2.3.3.1)**. In Years 2 and 3, a diver-based collection method for benthic grab sampling in proximity to the turbine was developed **(Section 2.3.2**); therefore, a comparison of the two methods was made **(Section 2.3.3.2)**.

2.3.3.1 Smith McIntyre Grab Sample Performance

It was observed that the performance of the Smith McIntyre grab sampler differed depending on substrate type as indicated in the field survey records (**Appendix B**). In general, the grab returned smaller samples from coarser sediments compared to finer grained deposits. To qualitatively assess this relationship, data were extracted from the visual descriptions of the sediment type and volume of the grab sample from the Year 1 field notes.

2.3.3.2 Grab sample method comparison: vessel-based versus diver-based collection

Diver-collected grab samples (**Section 2.3.2.1**) were designed to be similar in size, volume and surface area, as the Smith McIntyre grab sampler deployed from the vessel (**Section 2.3.1.1**). To test the comparability of the two grab sample techniques, three samples were collected using each method, in a soft bottom environment in Narragansett Bay, Rhode Island (total six samples). At this location, the sediment type was considered comparable to that of BIWF, and the shallow depth (3–6 m) allowed for a controlled comparison to be completed. The Smith McIntyre sample was taken after which the divers took a grab sample such that the samples were side by side, within 10 cm of each other. Note that any sediment disturbance in the water column had cleared by the time the divers entered the water so there was no influence on the second grab samples taken by the divers. All grab samples were subjected to the same sediment grain size, organic content and macrofaunal analyses, as described in **Section 2.3.4**.

2.3.4 Benthic Sample Processing

Grab samples were collected, predominantly by vessel-based deployment of a Smith McIntyre grab sampler (**Section 2.3.1.1**) and where this was not possible, because of proximity to the turbine structures, diver-based grab samples were collected (**Section 2.3.2.1**). From each grab sample, regardless of the method of collection, a sub-sample was taken (approximately 25 to 50 milliliters) and used for an assessment of the sediment grain size (**Section 2.3.4.1**) and organic content (**Section 2.3.4.2**). The grab sample was then processed to be assessed for macrofaunal analyses (**Section 2.3.4.3**).

2.3.4.1 Sediment Grain Size

Sediment properties of the sub-samples from all grab samples, were characterized using a particle size analyzer (Malvern Mastersizer 2000G). This generated the percentage weight of each particle size fraction (e.g., silt, fine sand, coarse sand, etc.) according to the Wentworth classification system (Wentworth 1922). Therefore, sediment analyses were performed on grain sizes ranging from 0 to 2,000 µm (i.e., clay to very coarse sand). While sediment larger than 2,000 µm (e.g., gravel, cobble, and boulder) were not quantitatively assessed, qualitative data of such material was collected. Within the grab samples, the presence of gravel and cobbles was noted for all samples. Furthermore, in Years 2 and 3, gravel and cobbles were removed from each sample during sieving, photographed and retained for future reference.

2.3.4.2 Organic Content

A portion of each sub-sample from the grab samples, also was 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 (LOI) method, adapted from Dean (1974). In brief, the weight of the sample was measured after drying for 24 hours (100°C) and after ignition (550°C). The percentage of combustible material was determined after the LOI and the percentage organic carbon was determined by multiplying the value by 0.432.

2.3.4.3 Macrofaunal Analyses

Prior to biological analysis, the volume and weight of each sample was recorded. The samples were then sieved through a 1-millimeter aperture mesh sieve. At the time of sieving, photographs were taken of each grab sample, and a visual description was recorded. The description included general sediment grain size, any conspicuous sediment features, and visible fauna. Habitat description records of benthic grab samples are presented in **Appendix B.** In addition, all gravel and cobbles were removed from each sample, retained and photographed for future reference.

The contents of the sieve were transferred into a pre-labeled bucket and fixed on-site using 4% buffered saline formalin solution with Rose-Bengal stain added. The samples were transported to the designated lab where all macrofaunal individuals recovered were counted and identified to the species level or lowest possible taxonomic group.

The macrofaunal analyses of all samples (Year 1, 2 and 3) were consistently conducted by taxonomic specialists at the Ecological Consulting Organization (Long Island, New York). The number of individuals counted remained unadjusted with respect to sample size (i.e., volume), as there was no apparent correlation between these two factors for the samples collected within the BIWF survey area. As an initial quality check, the Year 1 macrofauna identification spreadsheet was reviewed by Sheldon Pratt, a local expert at the University of Rhode Island, to ensure consistency with regards to nomenclature and to confirm species identified could be reasonably expected within the study area based on historical accounts.

In Year 3, macrofaunal biomass of the samples was measured and collated by phylum for the vessel-based sampling (30 to 90 m area) and the diver-based sampling (turbine footprints and very near-field area). All phyla were measured by dry weight, with the exception of Mollusca, which were measured by wet weight. This was because of the shell weight and because some bivalves remained closed during the drying process. In addition, the biomass of conspicuous species, namely the bivalve, *Mytilus edulis*, the barnacle *Balanus* sp., and crab *Cancer borealis* were measured independently from the phyla.

2.3.4.4 Seabed Video Processing

Seabed videos were collected when the Smith McIntyre grab sampler was being deployed and the videos were watched in real time to record seabed properties. From each video, the sediment type, presence of gravel, cobbles and/or boulders, the bed form (e.g., sand waves), and any macrofauna that could be identified, were recorded. These were considered as categorical variables in analyses as described in **Section 2.6.1.2**. Particular attention was given to larger and/or mobile macrofauna which would not be captured in grab sampling techniques.

2.3.4.5 Seabed Photography Processing

The images were collected at a rapid rate (2 to 5 seconds), allowing for a continuous series of overlapping images of the seabed. The camera has an inbuilt compass, allowing the images to be orientated consistently to the north (Roman et al. 2011). Using the known deployment and recovery locations, the images were spaced out over the transect providing an estimate location for each image. The raw images were color corrected to account for lighting artifacts and small variations in altitude. Images were processed individually and, where of interest, merged into single strip mosaics. Images and mosaics were reviewed, and qualitative records of interesting features noted. No statistical analysis was conducted. Similar to the seabed video, the images and mosaics complement the grab samples by providing contextual information of the geological environments and local heterogeneity, as well as capturing conspicuous species present throughout the camera deployment. The images also provided information on the presence and distribution of larger mobile epibenthos in relation to the installed wind farm infrastructure which are not typically captured by grab techniques.

2.4 Epifaunal Biota Sampling Methods

2.4.1 Video Data Collection

Divers used a GoPro Hero 4 camera to collect video footage of the southern leg of each of the three sampled turbines (T1, T3, T5) in Year 2 and Year 3. Video footage was collected with the camera positioned approximately 0.2 m from the structure. Divers collected video footage of both the leeward and current side of southern leg of each turbine, between the waterline and the base of the structure, representing an approximately 30 m vertical transect on each side (total of two vertical transects per turbine). Photoquadrats were extracted from each of the videos at 50 random intervals (stops) along the 15- to 16-minute videos collected for each turbine. Video transects were collected from each turbine in Year 2 (June 2018) and Year 3 (July 2019) providing a total of six video transects per year, a total of 300 photoquadrats per year.

2.4.2 Epifaunal Specimen Sample Collection

Divers collected scrape samples in Year 2 and Year 3. The methods in Year 3 were updated based on lessons learned in Year 2.

In Year 2, divers collected approximately 0.01 m^2 scrape samples from the southern leg of Turbine 1, on the leeward side (only). Samples were collected using a plastic scraper and placed in a bag. Samples were collected at the intertidal water mark, and below the water, at depths of 3, 8, 13, 18, 23, and 28 m, as well as on the leg base and grate base areas of the foundation (**Figure 17**).

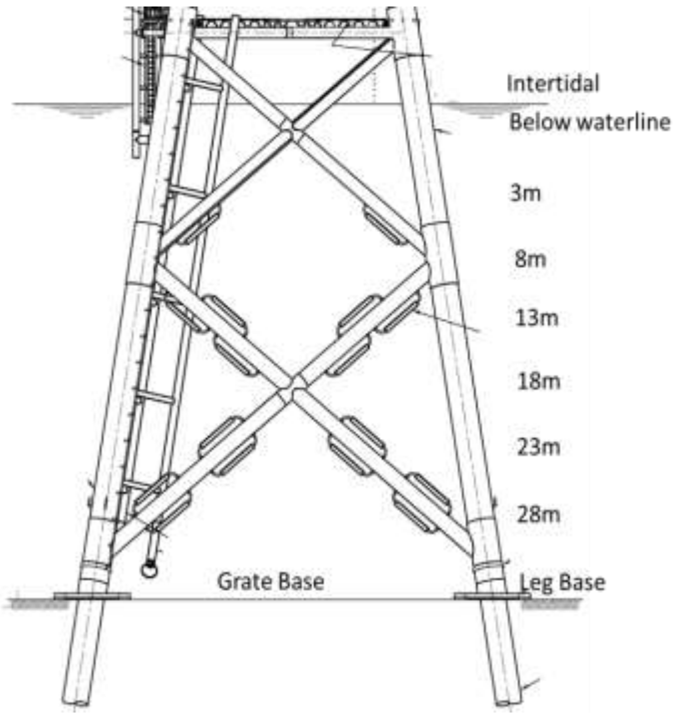


Figure 17. Block Island Wind Farm turbine leg structure (subsea) showing depth increments for epifaunal specimen scrape collections taken by divers, from Turbine 1, in Year 2. In Year 3, divers took scrape samples from Turbine 1 at 1 m intervals.

In Year 3, the epifaunal scrape sample collection at Turbine 1 (only) was extended to include both the leeward and current side of the southern leg. Samples were collected on each side of the leg, at approximately 1 m intervals starting at the base of the turbine and working up to the surface. At measured intervals, the divers used a PVC quadrat (0.1×0.1 m) as a guide to scrape 0.01 m^2 samples into a bag. Prior to scraping the sample, the thickness of the epifaunal cover was measured (i.e., from the base of the structure to the top of the epifauna, in cm). The quadrat had a string which the divers used as a 1 m measure between samples. Due to the tidal cycle, the depth of the deepest sample on the leeward side was 28.7 m and on the current side was 28.0 m. From each side of the turbine leg, 27 scrape samples were collected; a total of 54 scrape samples.

All scrape samples were collected in a cloth bag, zip tied shut. Once at the surface, samples were stored on ice, in a cooler until returned to the lab where they were stored at 4°C until processed.

For the Year 3 epifaunal scrape samples, all samples (27 per side of leg, total of 54 samples) were processed for the physical analyses (**Section 2.5.3**) and 15 of the 27 samples per side of leg (total of 30 samples) were processed for biological analyses (**Section 2.5.2**). Therefore, in Year 3, epifaunal scrape samples which were subjected to biological analyses were collected at the following approximate depths from both sides of the leg; at the waterline and then depths of 1, 2, 5.5, 8, 10, 12, 15, 17, 19, 20, 22, 25, 27 and 28 m.

2.4.3 Epifaunal Sample Processing

2.4.3.1 Turbine Epifaunal Video processing

For the image analysis, individual video frames were displayed on a high-resolution monitor in the laboratory and using ImagePlus 10, random dots were overlaid and all sessile organisms underlying the dots were recorded (Sebens and Johnson 1991; Aronson et al. 1994). This approach was repeated for each image, comprising 50 random stops and images taken per video transect. Care was taken that no overlap of stops/photographs occurred.

In addition, to properly document rare species and abundance of fish present in the video, data were gathered by viewing the entire video record (Chiappone and Sullivan 1991) and noting presence. Image analysis was conducted with the program Image-Pro Plus.

2.4.3.2 Turbine Epifaunal Scrape Sample Processing

Epifaunal scrape samples were subjected to two types of processing: 1) macrofaunal analysis and 2) physical analysis. In Years 2 and 3, macrofaunal analyses were completed, but the physical analysis was added in Year 3.

In Years 2 and 3, samples were transferred into a pre-labeled bucket and fixed using 4% buffered saline formalin solution with Rose-Bengal stain added and later transferred to alcohol solution for long term storage. All Year 2 samples (10 total) and 15 of 27 samples from either side of the leg in Year 3 (30 samples total) were processed for macrofaunal analysis. The samples were transported to the designated lab where the mass of each sample was determined using an OHAUS scale, and the macrofaunal individuals recovered were counted and identified to the species level or lowest possible taxonomic group. All samples were carefully examined for rarer species. Since there was a high density of mussels in each sample, all mussels were measured with digital callipers (to the nearest mm). The macrofaunal analyses of all samples were consistently conducted by the same taxonomic specialist (Southern Connecticut State University).

In Year 3, prior to being fixed, all 27 samples from each side of the turbine leg (a total of 54 samples) were subjected to physical analysis. On return to the lab, the buoyant weight of the samples (in its bag) was determined. These wet weights were use in calculations described in **Section 2.5.3**.

2.5 Data Analyses

2.5.1 Benthic Data Analyses

A range of univariate and multivariate analyses were employed to describe aspects of the faunal communities found in each year of sampling at turbine sites and control sites and to statistically compare community parameters to address the hypotheses relating to significant spatial and temporal differences. The descriptive univariate measures used in each year include number of species (S), number of individuals (A), Shannon Weiner diversity (H'), Margalef's Richness (d), Pielou's Eveness index (J') and Simpson's Dominance (λ) and are discussed in **Section 2.5.1.1.** Analysis of Variance (ANOVA) was used to detect significant differences between multiple (three or more) groups of samples as explained in **Section 2.5.1.2**. A series of Student *t* tests also were performed to test for significant differences in organic content, grain size and mass between diver and vessel collected samples and assess compatibility between the two techniques. The multivariate analysis techniques employed include multi-dimensional scaling (MDS), similarity percentages (SIMPER), and analysis of similarity (ANOSIM) as discussed in **Section 2.5.1.3**. To assess gross changes in benthos over time, local biotopes have been classified and described. The biotope classification system used is presented in **Section 2.5.1.4.**

2.5.1.1 Univariate Analyses

The following univariate measures were calculated using PRIMER (Plymouth Routines in Multivariate Ecological Research) v6.0 and v7.0.13 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). The indices used are useful for reducing community data to a single value for comparison and are typically reported in benthic studies to express important aspects of a species assemblage. **Table 4** summarizes univariate measures calculated for each year of sampling.

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 ith 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 (N) (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 ith 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).

2.5.1.2 Significance Testing

In Year 1, SigmaPlot 12.5 was used to conduct significance testing on selected abiotic and biotic variables using two-way 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 an F ratio, which is the ratio of the variability between the groups relative to the variability within the groups. Where the "within" and "between" variability is the same, the F ratio will be 1. However, as the 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 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 not 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. Noting that some sample sizes are small, a value of Cohen's d was calculated for all one-way ANOVAs and was used to assist interpretation of significance. Cohen's d is a measure of the effect size between two sample means with large effects generally indicated by values of $d > 0.8$ (Cohen 1977). Further to this, ANOVAs are accompanied by box and whisker plots to compare sample means and sample variances and which similarly assist the interpretation and validation of the ANOVA outcomes.

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.

Data which did not fulfil the variance and normality assumptions were analyzed using the non-parametric Kruskal-Wallis method followed by Tukey Kramer pair-wise tests for significant interactions. The Kruskal-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.

Year 2 and Year 3 abiotic and biotic data were analyzed using the same ANOVA techniques as those employed in Year 1, although the SigmaPlot package was replaced by the Microsoft Excel Real Statistics Tool Pack. Also, Welch's ANOVA was used in place of the non-parametric Kruskal-Wallis test in instances where the usual data assumptions were not met or where the design was unbalanced. On detection of statistical differences, post-hoc comparison between pairs of groups was undertaken using a Tukey Honestly Significant Difference (HSD) test to identify where the significant difference lies.

One final slight deviation from the Year 1 methodologies, in Year 2 and 3, was the use of Levene tests to confirm variance assumptions in addition to the Shapiro-Wilks test to indicate data normality. Data not passing initial variance and normality assumptions, as indicated by the results of the Shapiro-Wilks and Levene tests, were transformed as necessary (sqrt or ln), as per previous occasions.

Note that for Year 1, the use of four sample stations at each of the three control areas led to an unbalanced design for the ANOVA (i.e., 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). 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. The sampling strategies in Year 2 and Year 3 were revised to achieve a balanced design, i.e., there is a sample size of 27 for each turbine area and the control areas.

Differences between sample groups were tested using ANOSIM and Permanova[4]+ 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 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 and Walsh 2013). The PermDisp function was performed in parallel with the Permanova+. The results from this analysis express observed

[4] Permutational multivariate analysis of variance

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 and between sampling occasions.

2.5.1.3 Multivariate Analyses

Multivariate analyses were carried out using the statistical software package, PRIMER v6.0 and v7.0.13 (Plymouth Routines in Multivariate Ecological Research) with the Permanova+ add-on software (Clarke and Gorley 2006; Anderson et al. 2008). The PRIMER suite of statistical routines is frequently used in monitoring and research and is recommended in relevant guidance for the conduct of benthic ecology studies. Current versions run on the MS Windows platform, which makes PRIMER a particularly convenient tool for analyzing spreadsheet data. The range of different statistical tools available within PRIMER allow the relative strengths of relationships between samples and groups of samples to be investigated within multivariate space, highlighting those that are similar and those that are dissimilar while identifying the key biotic and abiotic factors most responsible for observed group (dis)similarities.

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.

Abiotic variables extracted from the grab samples and seabed video data were also imported into PRIMER and used to investigate potential relationships with observed macrofaunal patterns. Abiotic 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 were used as factors in PRIMER to investigate potential relationships with observed macrofaunal patterns, including study area (i.e., Turbines 1, 3, 5; Controls 1, 2, 3), sampling period (i.e., Year 1, Year 2, Year 3), and the distance from turbine (i.e., near, mid, far). Abiotic variables extracted from the grab samples and seabed video data were also used as categorical factors, such as 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), and the geologic depositional environment types, as defined by LaFrance et al. (2010). Note these factors were considered for Year 1, 2 and/or 3, and not all results are included in this report.

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 farther apart. The representativeness of this two-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 compare macrofaunal community composition within and across study areas and sampling periods, as well as to assess the cohesiveness of the cluster samples at each sample station. The plots were also used to investigate patterns in benthic community composition in relation to sediment characteristics and geologic depositional environment, and distance from turbine.

SIMPER 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 study area and the level of dissimilarity between each study area. Sample groups can also be defined according to sampling period, cluster station, etc. As such, SIMPER can assist the assessment of the distinctiveness of each sample group and the identification of the characterizing taxa.

The ANOSIM routine was used to test the null hypothesis that there are no differences between biological communities among different user-defined groups (e.g., study area, sampling period, 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.

2.5.1.4 CMECS Biotope Classification and Analyses

2.5.1.4.1 Rationale for Use of CMECS in this Study

The Coastal and Marine Ecological Classification System (CMECS) (FGDC 2012) is the U.S. national standard adopted by the FGDC for habitat classification. CMECS is used in this study because it can provide a useful and sensitive lens for monitoring changes in habitat characteristics over time and space, as well as whether these changes indicate positive, negative, or neutral impacts to the environment. In fact, a biotope map (see description below) integrates both physical and biological characteristics of a study area and can be used to derive useful management metrics, e.g., area of sea floor with changed biotope and the qualitative impact of that change.

2.5.1.4.2 Description of CMECS

The CMECS framework 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 18**).

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 a wide and multidisciplinary user base.

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 1996). The marine and coastal environments are described in terms of two settings, Biogeographic and Aquatic. The Biogeographic Setting identifies ecological units based on species aggregations and features influencing the distribution of organisms, following that of Spalding et al. (2007) in Marine Ecosystems of the World. As such, coastal and marine waters are organized according to realm, province, and ecoregion. For the Aquatic Setting, System is the primary component and follows that described in the Classification of Wetlands and Deepwater Habitats in the United States (FGDC 1996). The Aquatic Setting is further divided into Subsystem and Tidal Zone.

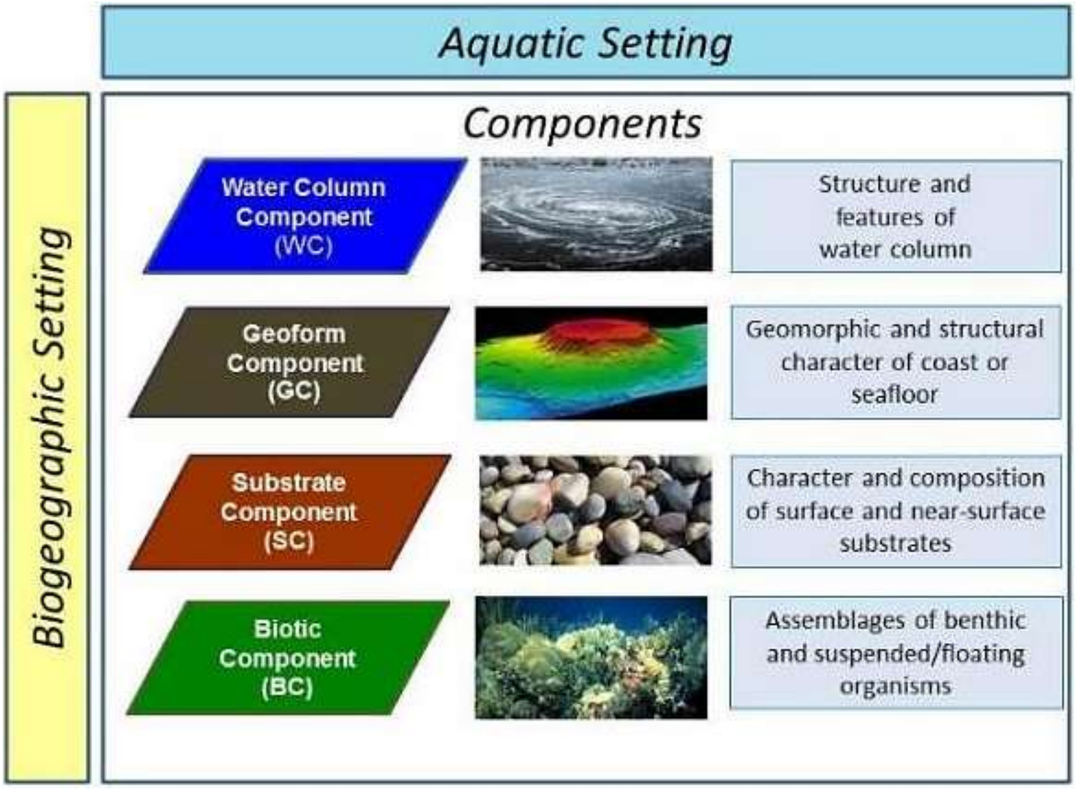


Figure 18. CMECS settings and components (from FGDC 2012).

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 1996). 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 1996). 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).

2.5.1.4.3 CMECS Biotope Classification

The term "biotope" is specific in that it integrates biotic-abiotic data within a given area to offer information that is more ecologically meaningful. In this study, the Geoform, Substrate, and Biotic Components 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 at this spatial 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. Statistical analyses can then be used to assess this presumption and gain further understanding of the biotopes.

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 **Figure 5 through Figure 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 using the Year 1, Year 2 and Year 3 data. 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 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.

2.5.2 Epifaunal Data Analyses

2.5.2.1 Video Analyses

Species identified were organised by taxa. For sessile species, the total percentage cover is reported, and counts are reported for mobile species identified. Additionally, because the video included both leeward and current sides of the structure, t-tests were used (SigmaPlot 13.0) to compare species density between the leeward and current side in each year (Year 2 and 3).

Using the Year 3 data, the percent cover of common species on and between turbines was compared on arcsine square root transformed data with a two-way ANOVA (SYSTAS 13.0) with the dependent variable species percent cover ((i)Mytilus/Epibionts and (ii) Others) and the independent factors, turbine number (1, 3 or 5) and transect location (leeward, current). A Tukey's post hoc multiple comparisons test was used when significance existed between turbines.

2.5.2.2 Epifaunal Specimen Analyses

In both Year 2 and Year 3, the scrape samples were dominated by mussels. The biomass of mussels and epibionts is reported and plotted with depth on the turbine leg, however the analysis focused on the mussel cover. The variation in size frequency for mussels with depth, is reported. To examine the effect of depth on mussel shell length and density, data collected from all samples per depth were compared with a One-Factor ANOVA using SigmaPlot 13.0.

In Year 3, a two factor ANOVA was used to examine the effects on location (leeward and current) and depth on the density of the mussel/epibiont complex. A paired t-test was used to compare the total biomass of samples collected on the leeward and current sides of Turbine 1. Differences in epifaunal thickness were also examined with a paired t-test.

Lastly, the percent cover of (i) mussel/epibiont complex and (ii) other species present in the turbine leg epifaunal community were compared between Year 2 and Year 3. Statistical analyses were not applied due to the unbalanced sampling that occurred each year.

2.5.3 Physical Analyses of Epifouling

2.5.3.1 Estimation of Total Mass

To calculate the total weight imposed by epifouling on the support structure, a simple approach using the mean values of epifouling samples was implemented. The total mass (per unit length, L) contributed by epifouling (m_b) on a circular cross section can be calculated from

$$m_b = \rho_b V_b; \qquad V_b = A_b dL$$

$$A_b = \pi \left[\left(\frac{D + t_b}{2} \right)^2 - \left(\frac{D}{2} \right)^2 \right]$$

where $\rho_b$is the density (g/cm^3), $t_b$is the thickness (cm) and V_b is the total volume of epifouling (cm^3). In this study, the mean density ($\overline{\rho_b}$) and thickness ($\overline{t_b}$) of epifouling were derived from the samples and used in the estimates of total additional mass. For simplicity, a uniform distribution for each region (outside and inside leg) were assumed.

2.5.3.2 Estimation of the Change in Surface Area and the Possible Effect of Drag on the Support Structure

The epifouling samples collected were also used to estimate the change in pile surface area due to presence of epifauna and the possible added drag force on the support structure. For a cylindrical pile, the total forces (dF) per unit length-L, exerted by a fluid flow is described by the Morison equation as

$$dF = F_{Inertia} dz + F_{drag} dz$$

$$dF = \rho C_m \left(\frac{\pi D^2}{4}\right) \frac{dU}{dt} dz + \frac{1}{2} \rho C_d D |U| U dz$$

where ρ is density of the fluid, D is the diameter of cylindrical body, and U is the flow velocity. The inertial and drag coefficients, C_m and C_d, are derived from experiments, and are known to be a function of the Keulegan-Carpenter number ($KC = U_m T/D$), Reynolds number ($Re = U_m D/\upsilon$) and the relative roughness (k/D), where U_m is the maximum flow velocity of $U(t)$, T is the period of flow oscillation, k is the mean roughness height, and υ is the fluid kinematic viscosity.

Engineering standards (e.g., API, DNV codes) have also suggested a set of guidelines to determine C_m and C_d coefficients under steady-state flow assumptions. For instance, C_d for steady-state flow can be estimated as

$$C_d = C_{ds} . \psi(C_{ds}, KC)$$

where

$$C_{ds} = \begin{cases} 0.65 & for \dfrac{k}{D} < 10^{-4} (smooth) \\ [29 + 4\, log_{10}(k/D)]/20 & for\ 10^4 < k/D < 10^{-2} \\ 1.05 & for \dfrac{k}{D} > 10^{-2} (rough) \end{cases}$$

and the wake amplification factor (ψ) can be estimated using the relationship shown in **Figure 19**. Typically, new uncoated and/or painted steel can be assumed [2] to be smooth, and the presence of marine growth can be represented by k=0.005 to 0.05 m (DNV JS101). For C_m, the value can be estimated by

$$C_m = \begin{cases} 2.0 & for\ KC < 3 \\ max \begin{cases} 2.0 - 0.044(KC - 3) \\ 1.6 - (C_{ds} - 0.65) \end{cases} & for\ KC > 3 \end{cases}$$

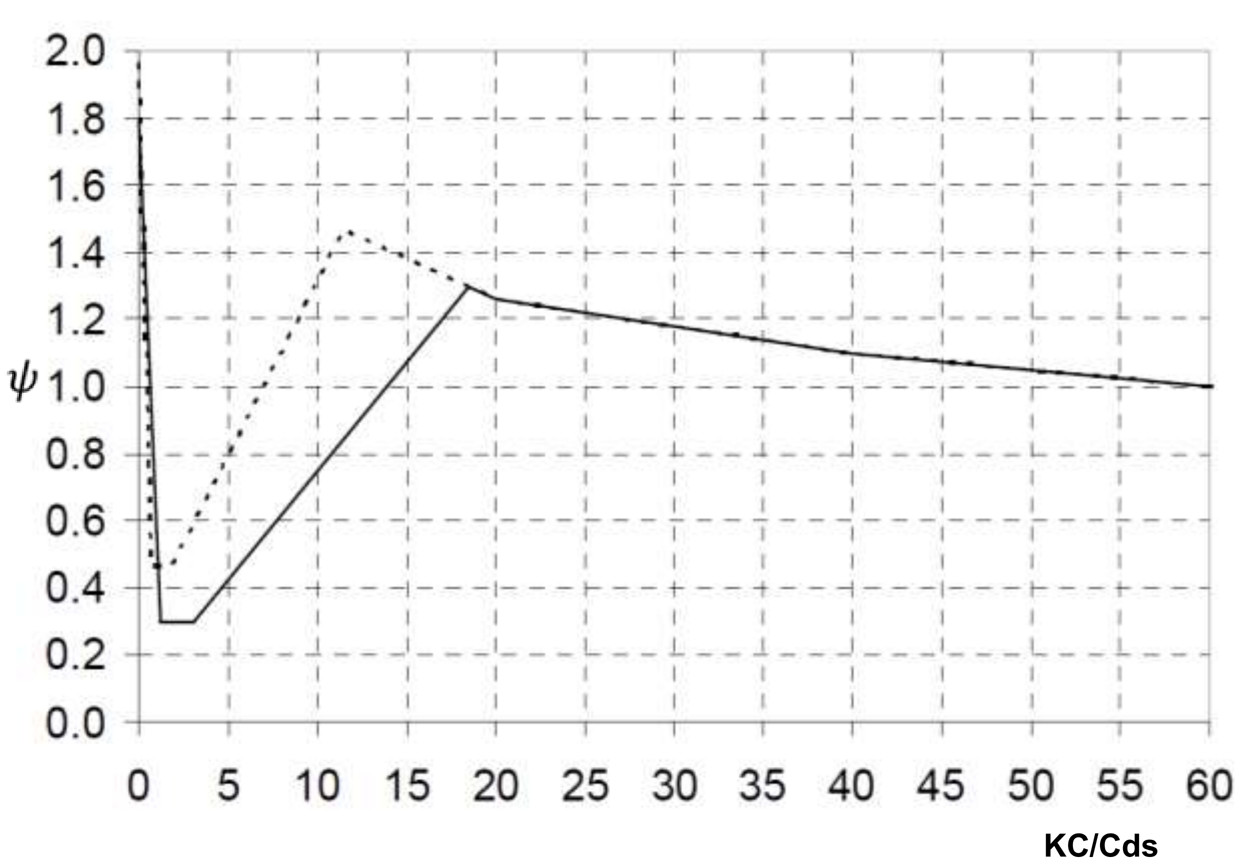


Figure 19. Wake amplification factor as a function of KC number. Values for smooth and rough surfaces are represented by solid and dotted lines (from Cialone et al. 2015).

For this calculation, an idealized case with $U_{max} = 2\ m/s$ and $T = 10s$ was set assuming steady flow ($\frac{dU}{dt} = 0$) across the leg to illustrate the possible change of drag on the BIWF support structure. The scenario was selected based on a peak storm-induced current velocity obtained from the North Atlantic Coast Comprehensive Study (NACCS)[5] dataset (Cialone et al. 2015). The dataset includes 1,050 synthetic storms that can represent various return probabilities for coastal and ocean engineering studies. NACCS results are published at save points that are distributed along the U.S. East Coast. In this project, the scenario selected was based on the storm-induced currents at NACCS Save Point 7090 (**Figure 20**), located closest to the BIWF site. Referring to **Figure 20**, the maximum simulated currents around BIWF are 1.7 meters per second (m/s), with a minimum of 0.05 m/s and mean of 0.25 m/s. Based on this, a current of 2 m/s was selected for this analysis, which represents an extreme current event at the wind farm.

[5] https://chs.erdc.dren.mil/

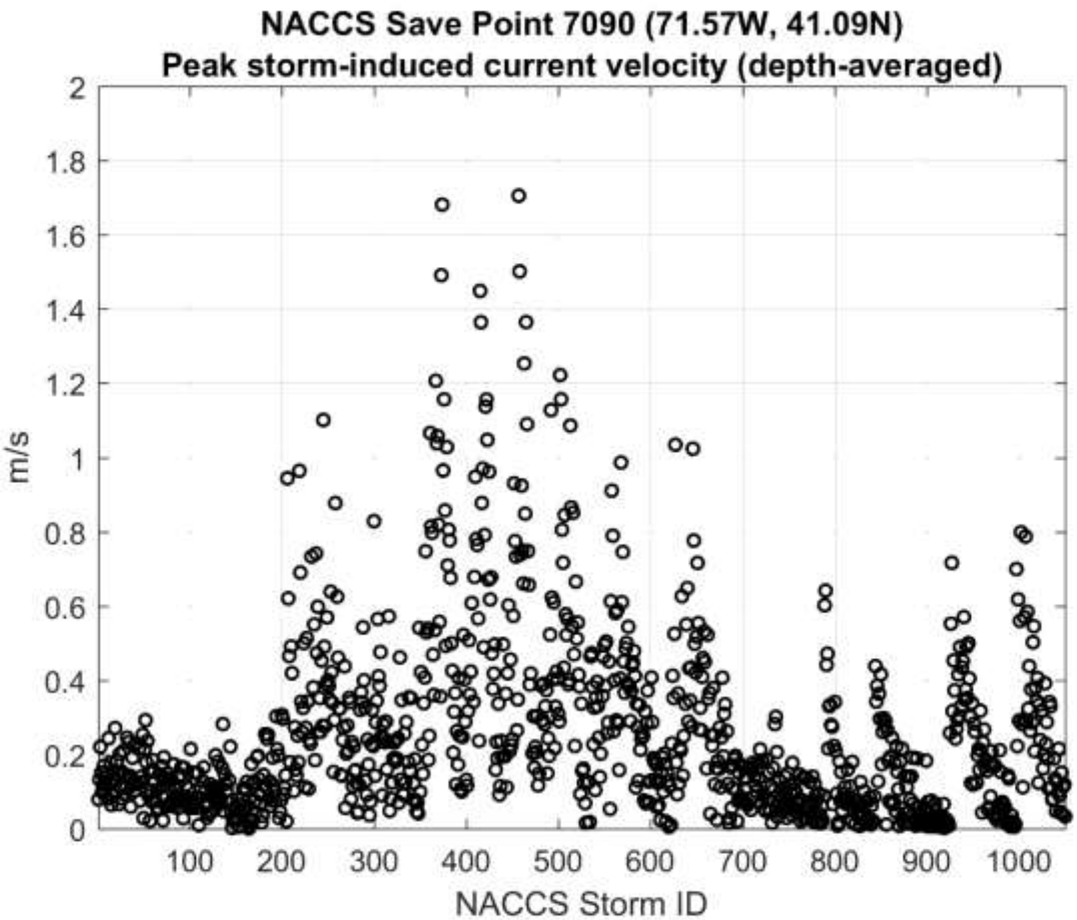


Figure 20. Peak storm-induced current velocity at NACCS Save Point 7090.

The surface roughness was assumed to be $k = 0.015$ following a similar study on the effects of epifouling by Martinez-Luengo et al. 2017. Due to a lack of detailed information about the dimensions and complexities of incorporating the configuration of the jacket structure, the southern jacket leg was assumed to be a single pile for simplicity. A control scenario without epifouling and with a smooth pile surface was added for comparison.

2.5.3.3 Comparison of the Biomass and Drag between Jacket and Monopile Structures

Using simplified support structure properties, the biomass and projected drag force on turbines from the BIWF and large monopile representative of upcoming offshore wind projects in the U.S. were compared.

Calculations were based on the estimates detailed in **Section 2.5.3.2**. For simplification, the BIWF jacket structure was treated as four small monopiles (each with a diameter of 1.27 m, length 28 m) and the compared with one large monopile (diameter 8 m, length 60 m). Both scenarios had a maximum current of 2 m/s and assumed wave period of 10 seconds.

3 Results

3.1 Benthic Vessel-Based Data Collection

3.1.1 Survey Effort

For Year 1, cluster grab samples and seabed video were collected concurrently at 39 sample stations within the three turbine and three control areas, for a total of 117 samples (**Figure 9** and **Table 2**). With the addition of the four QC samples, the final total was 121 samples. Grab sample and underwater video data acquisition occurred over three days between December 2016 and March 2017 (**Table 5**). The delay between sample days was caused by inclement weather. However, completing the sampling over this time period is not considered a concern, as data from previous studies supports that this region is stable and that there are minimal seasonal effects with respect to the benthic macrofaunal community (refer to **Section 1.4.1** for further details). Also, all sampling occurred in the winter season, so the conditions were constant throughout the data collection period. Data from this study also support that there are minimal seasonal changes. Specifically, **Figure 31** 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. Summary of vessel-based grab samples and seabed video collected within the BIWF study area in Year 1, Year 2 and Year 3

<table>
<tr><th>Sampling period</th><th>Study area</th><th>Number of sample stations</th><th>Number of samples</th><th>Date of data collection</th></tr>
<tr><td rowspan="8">Year 1</td><td>Turbine 1</td><td>9</td><td>27</td><td rowspan="2">20 December 2016</td></tr>
<tr><td>Turbine 3</td><td>9</td><td>27</td></tr>
<tr><td>Turbine 5</td><td>9</td><td>27</td><td rowspan="3">20 January 2017</td></tr>
<tr><td>Control 1</td><td>4</td><td>12</td></tr>
<tr><td>Control 2</td><td>4</td><td>12</td></tr>
<tr><td>Control 3</td><td>4</td><td>12</td><td rowspan="2">21 March 2017</td></tr>
<tr><td>QC Samples</td><td>4</td><td>4</td></tr>
<tr><td>Total</td><td>43</td><td>121</td><td></td></tr>
<tr><td rowspan="7">Year 2</td><td>Turbine 1</td><td>9</td><td>27</td><td rowspan="2">30 November 2017</td></tr>
<tr><td>Turbine 3</td><td>9</td><td>27</td></tr>
<tr><td>Turbine 5</td><td>9</td><td>27</td><td>30 November 2017
and
1 December 2017</td></tr>
<tr><td>Control 1</td><td>3</td><td>9</td><td rowspan="3">1 December 2017</td></tr>
<tr><td>Control 2</td><td>3</td><td>9</td></tr>
<tr><td>Control 3</td><td>3</td><td>9</td></tr>
<tr><td>Total</td><td>36</td><td>108</td><td></td></tr>
<tr><td rowspan="7">Year 3</td><td>Turbine 1</td><td>9</td><td>27</td><td>11 and 20 February</td></tr>
<tr><td>Turbine 3</td><td>9</td><td>27</td><td>4 February 2019</td></tr>
<tr><td>Turbine 5</td><td>9</td><td>27</td><td>4 and 11 February 2019</td></tr>
<tr><td>Control 1</td><td>3</td><td>9</td><td>11 and 20 February 2019</td></tr>
<tr><td>Control 2</td><td>3</td><td>9</td><td>20 February 2019</td></tr>
<tr><td>Control 3</td><td>3</td><td>9</td><td>20 February 2019</td></tr>
<tr><td>Total</td><td>36</td><td>108</td><td></td></tr>
</table>

For Years 2 and 3, a total of 108 co-located cluster grab samples and seabed video were collected concurrently at 36 sample stations within the three turbine and three control areas (**Figure 10** and **Figure 11, Table 5**). In Year 2, samples were collected over two consecutive days—November 30 and December 1, 2017. For Year 3, samples were collected over three days—February 4, 11, and 20, 2019. In addition, the Lagrangian floating camera system was used to complete a total of 15 transects over two days in Year 1, 12 transects over three days in Year 2, and 12 transects over four days in Year 3 (**Figure 12, Figure 13, Figure 14,** and **Table 6**).

Table 6. Dates seabed photography images were collected using the Lagrangian floating camera system for Year 1, Year 2 and Year 3.

	Study area	Number of drifts	Date of data collection
Year 1	Turbine 1	3	9 August 2017
	Turbine 3	3	
	Turbine 5	4	
	Control 1	2	28 June 2017
	Control 2	1	
	Control 3	2	
Year 2	Turbine 1	2	15 June 2018
	Turbine 3	2	17 May 2018
	Turbine 5	2	15 June 2018
	Control 1	2	12 June 2018
	Control 2	2	
	Control 3	2	
Year 3	Turbine 1	2	1 and 19 August 2019
	Turbine 3	2	1 and 19, August 2019
	Turbine 5	2	2 and 19 August 2019
	Control 1	2	27 August 2019
	Control 2	2	27 August 2019
	Control 3	2	2 August 2019

3.1.2 Particle Size Distribution (PSD) Analysis

Detailed results of the sediment grain size analysis of the vessel-collected grab samples are presented in **Appendix D**. The sediment analysis confirms the sandy nature of the local seabed within the turbine and control areas. Year 1, Year 2 and Year 3 show comparable sediment characteristics, with all samples being dominated by medium or coarse sand (**Table 7, Figure 21 through Figure 23**). More specifically, medium and coarse sand fractions, combined with very coarse sand, represent greater than 90% of the sediment composition in 115 of the 121 samples in Year 1 and in 105 of the 108 samples in Year 2 (although the remaining three samples contained >85% of the sediment composition) (**Table 7**). This pattern was also seen in Year 3, where medium, coarse and very coarse sand represent >90% of the sediment composition at 100 of 108 samples (although the remaining samples contained >84%) (**Table 7**).

Regarding finer sediments, clay and silt sized particles were recorded within 14 samples for Year 1, two samples for Year 2 and two samples for Year 3. These fractions were recovered in minimal quantities within each sample, representing less than 1% of total sediment composition in Year 1 and 2. Coarser gravel and cobble grade particles were also frequently noted from the grab samples and from contemporaneous seabed video footage (see **Section 3.1.3**). In addition, boulders were noted at stations within Control 1 in Year 1.

Table 7. Summary of grain size analysis of vessel-based sediment samples collected within each study area for Year 1, Year 2 and Year 3.

Sampling period	Study area	Total samples	Number of samples for which: Dominant grain size = medium sand	Dominant grain size = coarse sand	Combined sand fraction > 90%	Combined clay and silt > 0%
Year 1	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
Year 2	Turbine 1	27	21	6	25	0
	Turbine 3	27	3	24	27	0
	Turbine 5	27	0	27	27	0
	Control 1	9	1	8	8	0
	Control 2	9	0	9	9	1
	Control 3	9	0	9	9	1
Year 3	Turbine 1	27	21	6	20	2
	Turbine 3	27	1	26	27	0
	Turbine 5	27	0	27	26	0
	Control 1	9	2	7	8	0
	Control 2	9	0	9	9	0
	Control 3	9	0	9	9	0

Note: All samples were dominated by medium or coarse sand and few samples contained 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% for all samples. Grain size fractions are classified according to the Wentworth scale.

Table 8 reports the mean for each sediment grain size fraction. The fine fractions, clay and silt and very fine sand were minimal in Years 1 and 2. In Year 3, however, there is an increase in both clay and silt, and very fine sand particles at the Turbine 1 study area. The proportion of combined clay and silts increased from 0 to 1.0% in Year 1 and 2, to 0.to 93.4% in Year 3 (**Table 8**). The increase in range of combined clay and silts is largely due to two samples at Turbine 1 with a very high content (**Figure 23**). The average combined silt content in the Turbine 1 study area was 5.7% since most samples had a negligible content.

The proportion of fine sand (particles of diameter 150 to 250 µm) within all samples varied between 0 and 17.9% for Year 1, 0 and 14.4% for Year 2, and 0 to 15.6% in Year 3 (**Table 8**). Highest levels tended to be associated with Turbine 1 for all three years (average Year 1 = 5.5%, Year 2 = 6.2%, Year 3 = 6.8%). Levels at Turbines 3 and 5 were lower, averaging 0.7, 1.5 and 0.6% at Turbine 3, and 1.6% 0.6% and 0.6% at Turbine 5 for Year 1, Year 2 and Year 3, respectively. Among the Control areas, which were different each year, the mean levels of fine sand ranged from 0.1 to 4.5% in Year 1, 0.7 to 2.7% in Year 2, and 0.1 to 3.1% in Year 3. Based on data in **Table 8**, the combined average for Turbines 1, 3, 5, for Year 1 = 2.6%, Year 2 = 2.8%, Year 3 = 2.7%. Combined average for Control areas 1, 2, and 3 for Year 1 = 2.9%, Year 2 = 1.6% and Year 3 = 1.4%. The fine sand content in turbine study areas remained relatively constant and generally comparable to the control areas. Although the fine sand content reduces between years, the decrease is very minor.

Table 8. Mean of each sediment grain size fraction for vessel-based sediment samples collected within each study area for Year 1, Year 2 and Year 3. The range for each year, for all samples taken that year is also reported.

Sampling period	Study area	Average fraction of:					
		Clay and silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand
Year 1	Turbine 1	0.0%	0.0%	5.5%	49.6%	41.6%	3.4%
	Turbine 3	0.0%	0.1%	0.7%	29.0%	55.3%	17.9%
	Turbine 5	0.01%	0.1%	1.6%	25.9%	50.3%	22.1%
	Control 1	0.02%	0.1%	0.1%	25.7%	60.4%	13.6%
	Control 2	0.22%	0.3%	4.5%	34.7%	48.8%	11.5%
	Control 3	0.07%	0.0%	4.2%	43.9%	45.9%	6.0%
	Range	0–1.0%	0–1.8%	0–17.9%	2.9–62.2%	28.8–64.0%	0.5–42.3%
Year 2	Turbine 1	0.0%	0.0%	6.2%	49.6%	43.4%	0.9%
	Turbine 3	0.0%	0.0%	1.5%	37.8%	55.0%	5.7%
	Turbine 5	0.0%	0.0%	0.6%	29.6%	61.0%	8.8%
	Control 1	0.0%	0.0%	2.7%	32.6%	58.0%	6.7%
	Control 2	0.0%	0.0%	0.7%	31.0%	59.3%	9.0%
	Control 3	0.1%	0.1%	1.3%	37.0%	57.4%	4.1%
	Range	0–0.9%	0–0.6%	0–14.4%	16.3–57.3%	29.1–69.6%	0–30.3%
Year 3	Turbine 1	5.7%	0.3%	6.8%	46.6%	39.9%	0.7%
	Turbine 3	0.0%	0.0%	0.6%	35.6%	59.4%	4.3%
	Turbine 5	0.0%	0.0%	0.6%	31.7%	60.2%	6.4%
	Control 1	0.0%	0.0%	3.1%	43.0%	52.0%	1.9%
	Control 2	0.0%	0.0%	1.0%	37.2%	58.0%	3.8%
	Control 3	0.0%	0.0%	0.1%	24.5%	66.0%	9.5%
	Range	0–93.4%	0–6.0%	0–15.6%	1.4–58.6	1.0–70.6%	0–15.2%
Note: The range of each grain size fraction within is study area also is provided. Grain size fractions are classified according to the Wentworth scale.							

The proportion of medium sand (particles of diameter 250 to 500 µm) within all samples varied between 2.9 and 62.2% for Year 1, 16.3 and 57.3% in Year 2, and 1.4 and 58.6% in Year 3 (**Table 8**). Highest levels were consistently associated with Turbine 1 (mean = 49.6% for all three years). Levels at Turbines 3 and 5 sample stations were slightly lower, averaging 29.0%, 37.8% and 35.6% at Turbine 3, and 25.9%, 29.6% and 31.7% at Turbine 5 for Year 1, Year 2 and Year 3, respectively. Among the control areas, the mean levels of medium sand ranged from 25.7 to 43.9% in Year 1, 31.0 to 37.0% in Year 2 and 24.5 to 43.0% in Year 3. Based on data in **Table 8**, the combined average for Turbines 1, 3, 5, for Year 1 = 49.1%, Year 2 = 39.0%, Year 3 = 38.0%. Combined average for Controls 1, 2, and 3 for Year 1 = 34.8%, Year 2 = 33.5% and Year 3 = 34.9%. The turbine and control areas were similar in medium sand content over the three sampling years.

The proportion of the coarse sand fractions (particles of diameter 500 to 1,000 µm) across the full study area varied between 28.8 and 64.0% for Year 1 and 29.1 to 69.6% for Year 2 and 1.0 to 70.6% in Year 3. Levels were comparable across all the turbine and control sites for both years. In Year 1, the highest levels were associated with Turbine 3, Turbine 5, and Control 1 (mean = 55.3%, 50.3%, and 60.4%, respectively), whereas, levels at Turbine 1, Control 2, and Control 3 were slightly lower (mean = 41.6%, 48.8%, and 45.9%, respectively). In Year 2, levels were nearly equal within all study areas (mean ranges between 55.0 and 61.0%), with the exception of Turbine 1, which exhibited a relatively lower mean (43.4%). In Year 3, the content of coarse sand was similar to Year 2 and again relatively equal (mean ranges between 52.0 and 56.0%). In Year 3, Turbine 1 was again the exception with a lower coarse sand content of 39.9%.

The proportion of very coarse sand (particles of diameter 1,000 to 2,000 µm) within the samples varied between 0.5 and 42.3% for Year 1, 0 and 30.3% in Year 2 and 0 and 15.2% in Year 3 (**Table 8**). Mean levels were higher in the Year 1 samples, relative to Year 2 and Year 3. Highest levels tended to be associated with Turbines 5 (mean Year 1 = 22.1%, Year 2 = 8.8%, Year 3 = 6.4%), followed by Turbine 3 (mean Year 1 = 17.9%, Year 2 = 5.7%, Year 3 = 4.3%). Levels at stations at Turbine 1 were lower (mean Year 1 = 3.4%, Year 2 = 0.9%, Year 3 = 0.7%), and lower than those found at the control stations. Among the Control areas, the mean levels of very coarse sand ranged from 6.0 to 13.6% in Year 1, 4.1 to 9.0% in Year 2 and 1.9 to 9.5% in Year 3. Very coarse sand content in the turbine and control areas were similar across the sampling years (**Table 8**).

In summary, similar patterns can be seen in the distribution of sediment within each turbine area for Year 1 and Year 2 (**Table 8, Figure 21** and **Figure 22**). The minor temporal fluctuations evident in sediment composition in all three sampling years were reflected at the control stations, indicating the change was caused by natural variations. The data indicate grain size increased across the study area from Turbine 1 to Turbine 5. Turbine 1 exhibited the highest fractions of fine and medium sand, and, conversely, the lowest fractions of coarse and very coarse sand. The sediment became coarser moving to Turbines 3 and 5, Year 1 Control 1, and Year 1 Controls 1 and 2, which all shared similar characteristics. These areas had greater amounts of coarse and very coarse sand and less fine and medium sand, relative to Turbine 1. The Year 1 Controls 2 and 3 and Year 2 Control 3 fall mid-way along this spectrum. In Year 3, a gradient of increasing coarseness in sediment grain size can be seen moving from Turbine 1 through to Turbine 5 which is again evident in the control area samples (**Table 8, Figure 23**). However, for the first time, the Year 3 samples around Turbine 1 displayed an increase in finer sediment particles (from clay through to very fine sand), largely driven by a small number of sample sites close to the turbine structure (**Figure 23**).

Coarser grade gravel and cobble particles were not included in the particle size distribution analysis. However, an indication of the relative proportion of these sediment grades within each of the current samples is provided from cobble weight data recorded as part of data processing. Using these data, in Year 2 the greatest proportions of cobbles were found to be associated with Turbine 1 and Control 3, while lesser amounts of cobbles were recorded around Turbines 3 and 5. The same relationship was observed in Year 3 with the greatest mass of cobbles associated with the Turbine 1 and Control samples, while Turbine 3 and 5 were lower and similar to each other.

Patterns in sediment grain size with distance from the turbines were considered. Scatter plots of the levels of combined clay, silt and fine sand (particles <250 µm) for all turbine samples with respect to distance from the center of its respective turbine foundation revealed no strong correlations for Year 1, Year 2 or Year 3 (**Figure 24**). While a weak inverse relationship (R^2 = 0.191) of increasing fine sediment levels with decreasing distance to Turbine 1 was found in Year 1, the relationship did not continue in Year 2. In Year 3 the weak inverse trend was higher at Turbine 5 (R^2 = 0.245) compared to the other turbines (**Figure 24**). There were some samples collected from Turbine 1 which were particularly high in fine sediments (**Figure 23, Figure 24**) composition but no strong trend was detected (R^2 = 0.135). The high fine sediment content from the Turbine 1 study area is considered true data and is discussed with the organic content and macrofaunal data in Section 4.

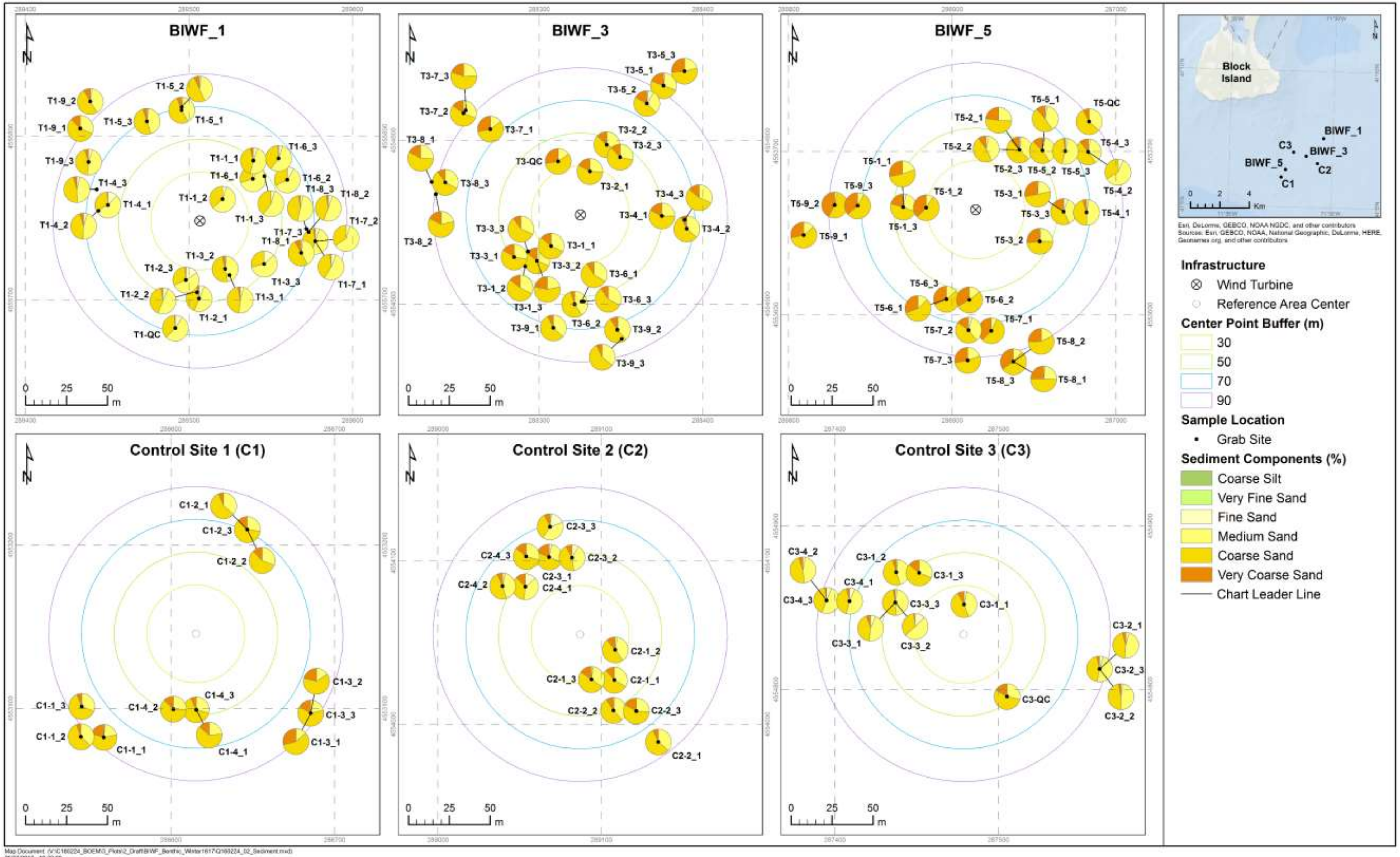


Figure 21. Distribution of sediment fractions of vessel-based sediment samples collected in Year 1.

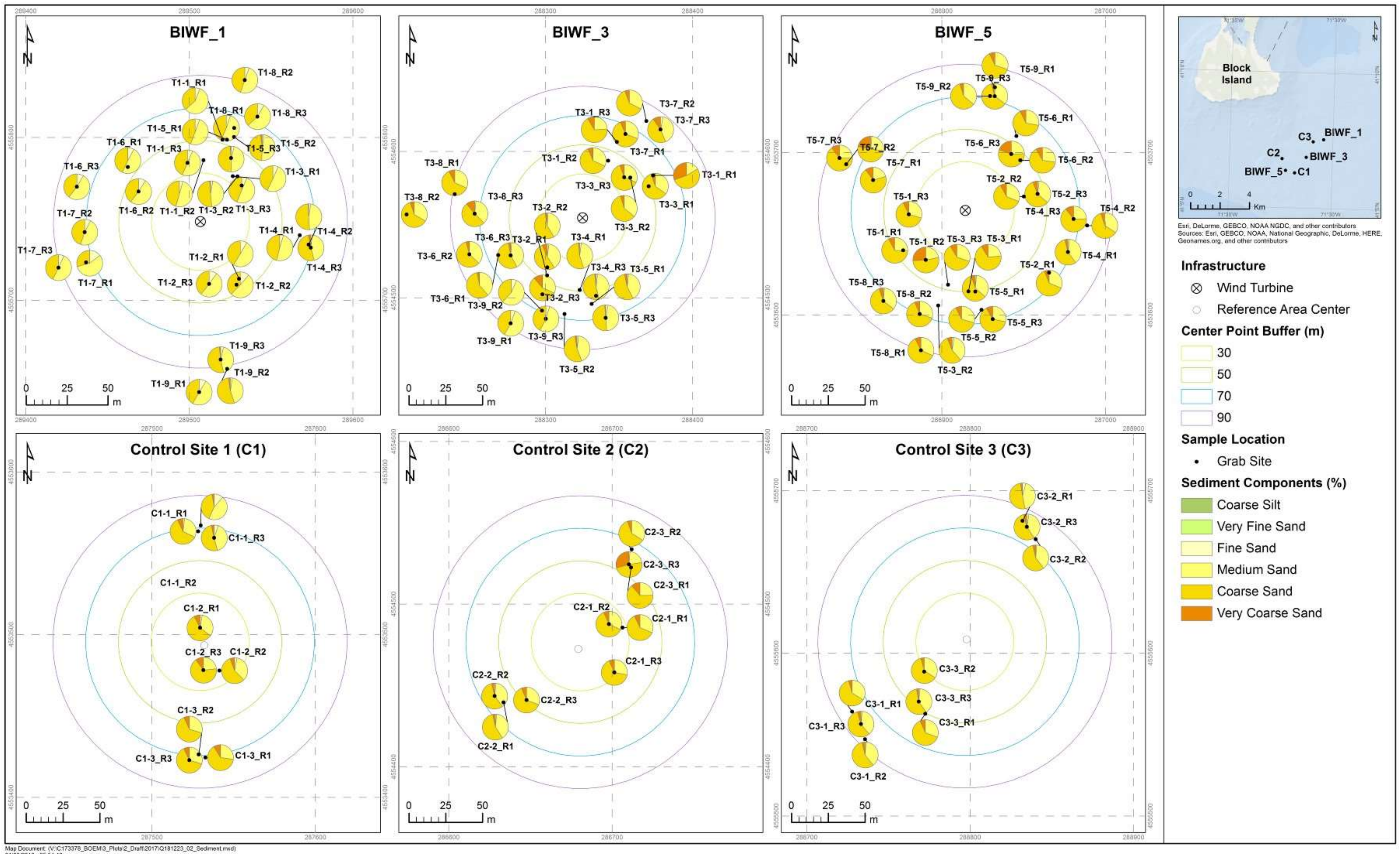


Figure 22. Distribution of sediment fractions of vessel-based sediment samples collected in Year 2.

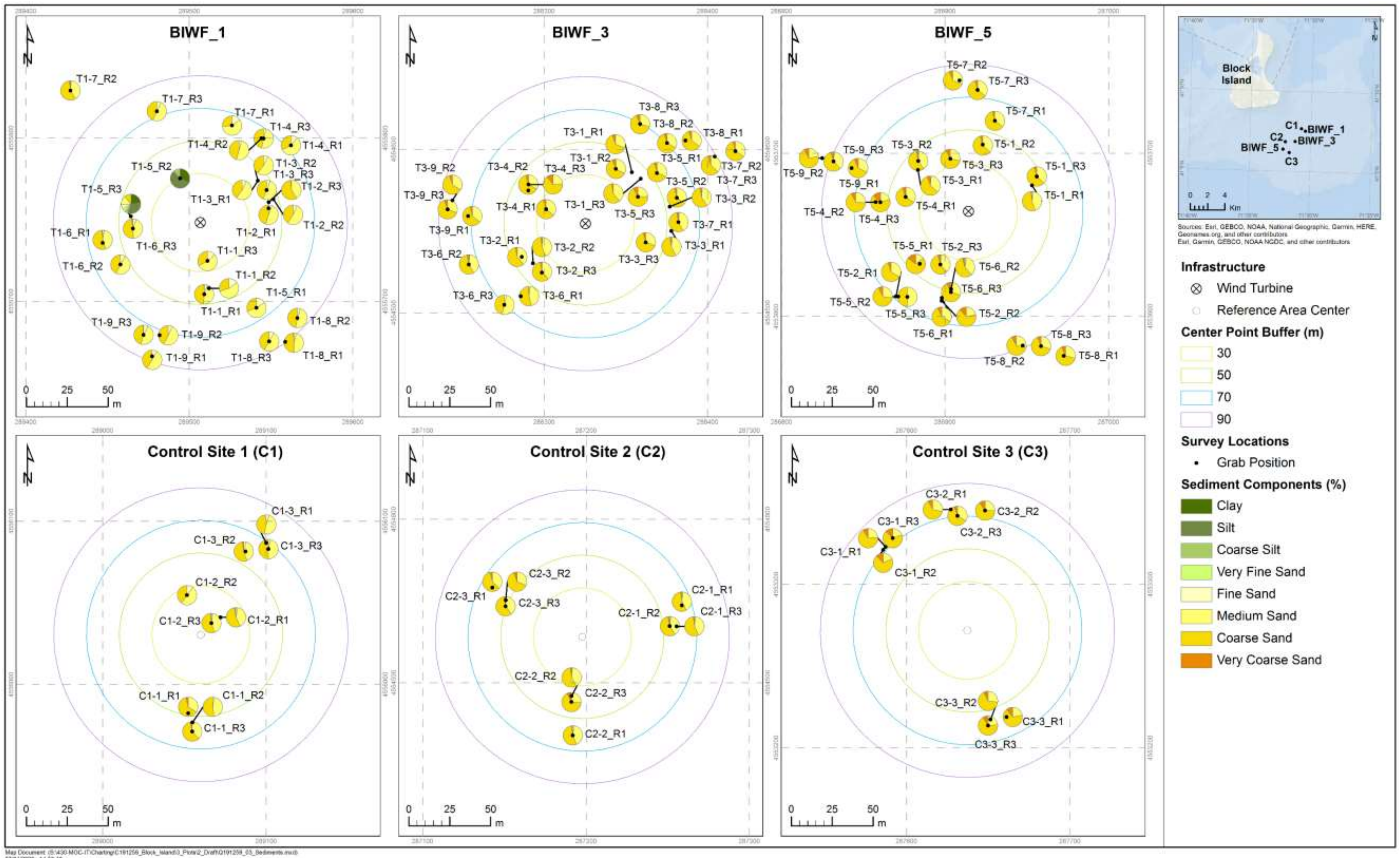


Figure 23. Distribution of sediment fractions of vessel-based sediment samples collected in Year 3.

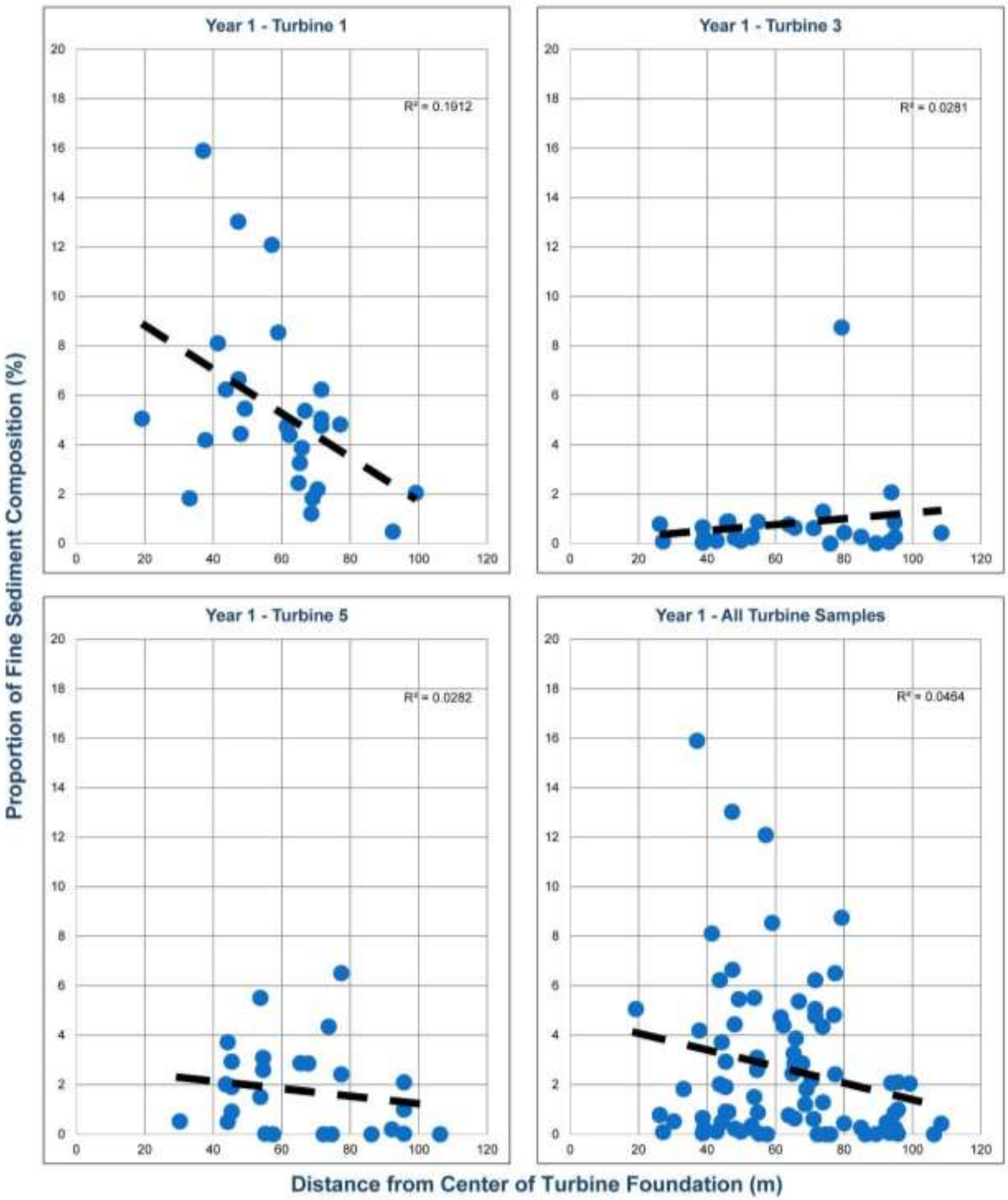


Figure 24a. Proportion of fine sediment (particles <250 μm diameter) from vessel-based sediment samples with distance from the center point under each turbine foundation structure at BIWF for Year 1.

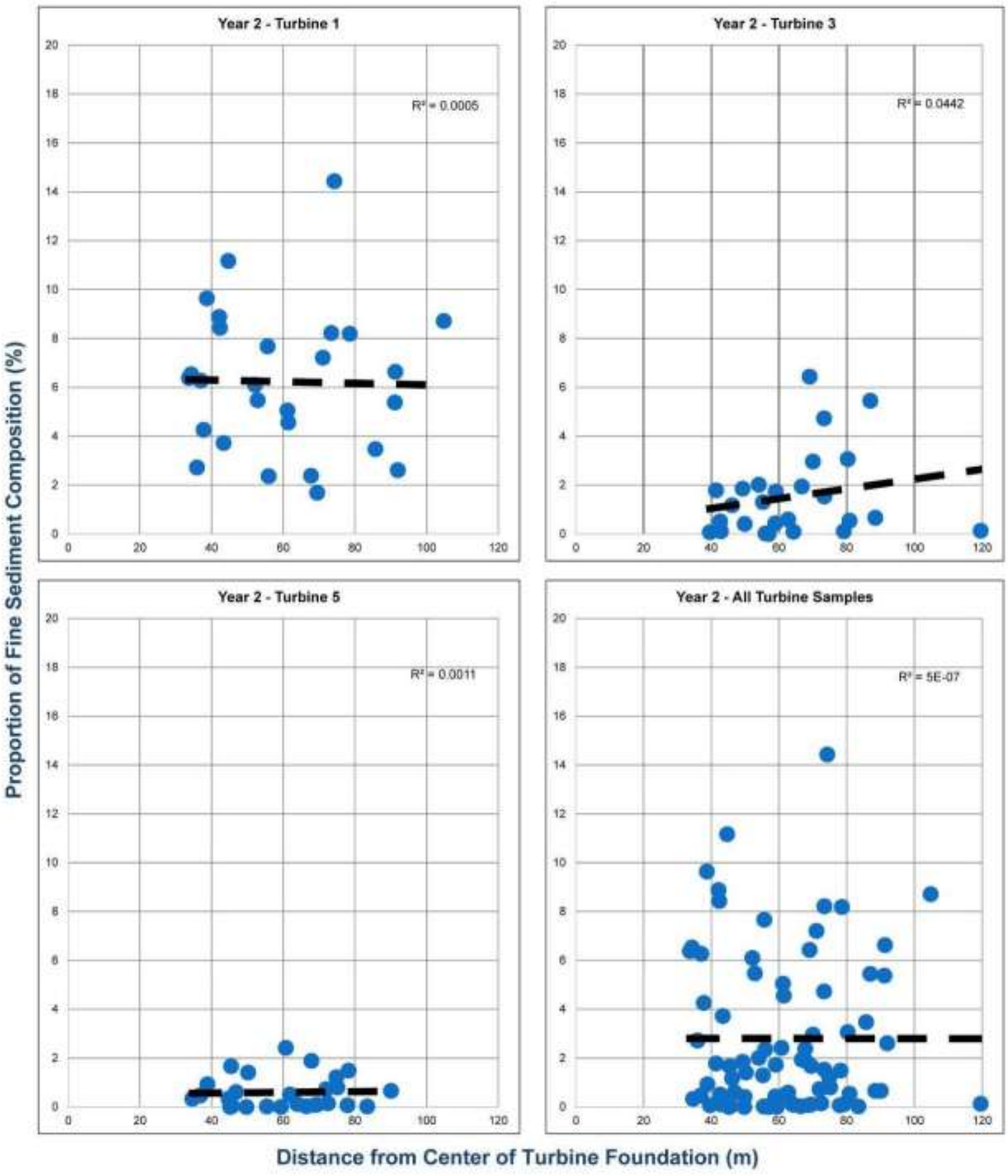


Figure 24b. Proportion of fine sediment (particles <250 µm diameter) from vessel-based sediment samples with distance from the center point under each turbine foundation structure at BIWF for Year 2.

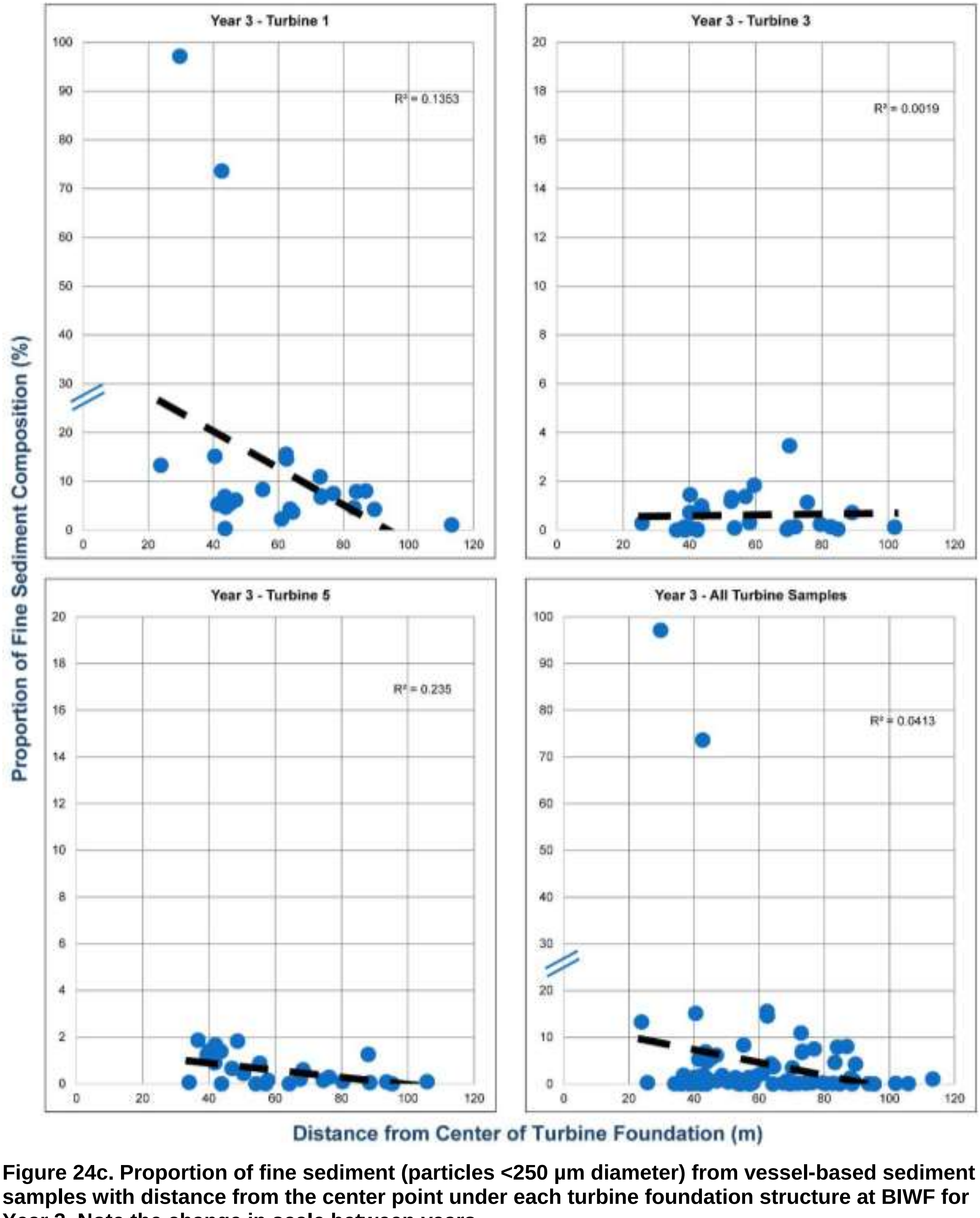


Figure 24c. Proportion of fine sediment (particles <250 µm diameter) from vessel-based sediment samples with distance from the center point under each turbine foundation structure at BIWF for Year 3. Note the change in scale between years.

3.1.3 Seabed Video Analysis

The underwater video footage collected during the vessel-based grab sampling, from Year 1, Year 2 and Year 3 complemented and provided context for the grab sample data. Visual analysis of the video provided details about the general type and distribution of various sediment types (e.g., boulder, cobble, gravel, sand) and bedforms, as well as the overall homogeneity of the seafloor in the vicinity of the grab sample locations. Detailed descriptions of the video analysis and a representative image from each sample site are presented in **Appendix E**.

In general, the video confirms that the turbine and control areas have comparable sedimentary environments, being dominated by sand of medium to very coarse grain size and with various concentrations of gravel and/or cobble present throughout. It is expected that the seabed is naturally mobile within the BIWF study area, as evidenced by the presence of sand waves and sand ripples in the video footage, resulting in the constant winnowing and erosion of fine sediment particles from the seabed. However, the degree to which this occurs varies amongst the turbines. In all three years, extensive and well-defined sand waves and ripples are visible in the video collected at all the Turbine 5 stations, whereas the Turbine 1 video footage shows that there are no visible bedforms or that there are sand waves and ripples of very low relief at each station. Turbine 3 falls in the middle of this gradient in Years 1 and 2 and closely resembles Turbine 5 in Year 3.

Control 1 in Year 1 was exceptional in that it exhibited areas of boulders, in addition to cobble, gravel, and coarse sand. This area also contained the only two sample sites found not to be homogeneous; instead, having alternating patches of cobble and gravel, and of bare coarse sand.

Regarding biological features, the presence of the blue mussel, *Mytilus edulis*, was considered the epifaunal species of greatest interest for this study and was noted from the video footage. A substantial difference in the distribution of *M. edulis* was apparent from Year 1 to Year 2 within the turbine areas (**Table 9**). In Year 1, the only evidence of *M. edulis* occupying the vicinity was the presence of empty shells at six sites within the Turbine 3 study area and one site with an individual present within the Turbine 5 study area. In Year 2, however, *M. edulis* was much more prevalent throughout the turbine areas, particularly Turbines 1 and 3. Individuals and/or clusters of individuals were noted at 27 sample sites (although a designation of living or non-living could not be confidently determined from the video), and empty shells were noted at 18 sites. In contrast, *M. edulis* was not recorded in any of the video footage collected within the Control areas for Year 1 or Year 2, with the exception of a few individuals at one site (Year 2 Control 2). In Year 3, there was again evidence of individual and clusters of *M. edulis* at eleven of the Turbine sites and the presence of shells (whole of half) at 20 sites. The increased frequency of *M. edulis* in Year 2 and Year 3 throughout all the turbine areas strongly suggests the species has increased in abundance and/or distribution. Further, that this increase did not also occur within the control areas in Year 2 indicates the change is caused by colonization of the turbine structures, rather than natural variation.

Other faunal species were visible within the video footage for all study areas, except Turbine 3 for both Year 1 and Year 2. For Year 1, barnacles were present at 31 of these sample sites (2 sites at Turbine 1, 8 at Turbine 5, 21 at Controls combined); sea stars were present at nine sample sites (1 site at Turbine 5, 8 sites at Controls 1 and 3); bivalves identified as *Astarte borealis* or *Astarte castanea* were present at 15 samples sites (Turbine 5); the sponge *Polymastia robusta*, at 6 sample sites (4 sites at Turbine 1, 2 sites at Control 1); and spider crabs *(Libinia emarginata)* were present at one site (Turbine 5).

For Year 2, barnacles were present at 17 sample sites (5 sites at Turbine 1, 4 sites at Turbine 5, 8 sites at Control 1); bivalves identified as *Astarte borealis* or *Astarte castanea* were present at 3 samples sites (Control 2); and the sponge *Polymastia robusta,* at 5 sample sites (3 sites at Turbine 1, 2 sites at Control 1).

Table 9. The number of samples stations with the presence of mussels (e.g., individuals, cluster[s], empty shell[s]) identified in the vessel-based video collected for Year 1, Year 2 and Year 3.

Sampling period	Study area	Videos sampled	Individuals (only)	Cluster(s) (only)	Individuals and cluster(s)	Empty shell(s)
Year 1	Turbine 1	26	0	0	0	0
	Turbine 3	26	0	0	0	6
	Turbine 5	27	1	0	0	0
	Turbine Total	79	0	0	0	7
	Control Areas	36	0	0	0	0
Year 2	Turbine 1	27	2	7	2	1
	Turbine 3	27	8	4	1	2
	Turbine 5	27	3	0	0	15
	Turbine Total	81	13	11	3	18
	Control Areas	27	1	0	0	0
Year 3	Turbine 1	27	2	2	0	6
	Turbine 3	27	2	4	0	6
	Turbine 5	27	1	0	0	8
	Turbine Total	81	5	6	0	20
	Control Areas	0	-	-	-	-
Note: The defined categories are unable to identify mussels as living or non-living, with the exception of "Empty Shell(s)." Also note that video was not collected at two stations in Year 1.						

The most notable difference between Year 1 and Year 2 is the absence of the bivalve, *Astarte* spp., at Turbine 5. Sea stars were also absent, although the majority of the recorded Year 1 sightings were in Control 1, which was not resampled in Year 2.

In Year 3, barnacles were observed in 15 of 27 sample sites in the Turbine 1 area but were infrequent in the Turbine 5 study area (2 of 27 samples) and not noted in the Turbine 3 study area, largely due to lack of substrate. The vessel-based grab samples confirmed a similar pattern of high *Balanus* spp., at Turbine 1 (23 of 27 sites) but showed low presence at Turbine 3 (2 of 27 sites) and none at Turbine 5. Although *Astarte* spp. were absent from footage in Year 2, they were present again in Year 3. *Astarte* spp. were observed in seven of 27 sample sites in the Turbine 5 study area but absent from the other turbine areas. The sponge *Polymastia robusta* was observed at three of 27 sample sites in the Turbine 1 study area but not recorded at others. In Year 3, sea stars also were recorded at seven of 27 sample sites at Turbine 1 but not in the other turbine study areas; noting that sea stars were absent in Year 1 and Year 2 turbine study areas. An elasmobranch egg case was recorded in the Turbine 1 study area, although it cannot be determined from footage if it was developing or hatched. Numerous elasmobranch egg cases also were evident in the seabed photography transects (**Section 3.1.4**)

3.1.4 Vessel-based Seabed Photography Analysis

Detailed field survey records for the Lagrangian floating camera deployments are presented in **Appendix C**. Hundreds of images were collected during each dive. Example still images from a subset of the data collected within the turbine and control areas are presented in **Figure 25**, and an example mosaic from Year 1 imagery is presented in **Figure 26**. The high-resolution images and mosaics 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). Further, the 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 the findings of the video and sediment grain size analyses. These findings include 1) there is no noticeable change in sediment characteristics within the turbine areas from Year 1 to Year 2 to Year 3; 2) Year 1 Control 1 is distinct relative to the other study areas in both years, as it is characterized as a more variable environment and contains boulders throughout; and 3) that the turbine and control areas have sedimentary environments characterized by medium/coarse seabed deposits (e.g., cobble, gravel, medium to very coarse grain sand), although this occurs along a gradient from Turbine 1 (finest sediments) to Turbine 5 (coarsest sediments).

The images also captured the presence of squid (*Loligo peali*), multiple male and female skates (e.g., little skate [*Leucoraja erinacea*] and winter skate [Leucoraja *ocellate*]) and elasmobranch egg cases, blackfish (*Tautoga onitis*), black sea bass (*Centropristis stiata*), striped searobin (*Prionotus evolans*), sand lance (*Ammodytes* sp.) and spiny dogfish (*Squalus acanthias*). Numerous hermit crabs, snails, sponges and sea stars were also recorded. Mussels (*M. edulis*), either as shells (whole/half) or live as individuals and in small aggregations also were evident throughout the transects.

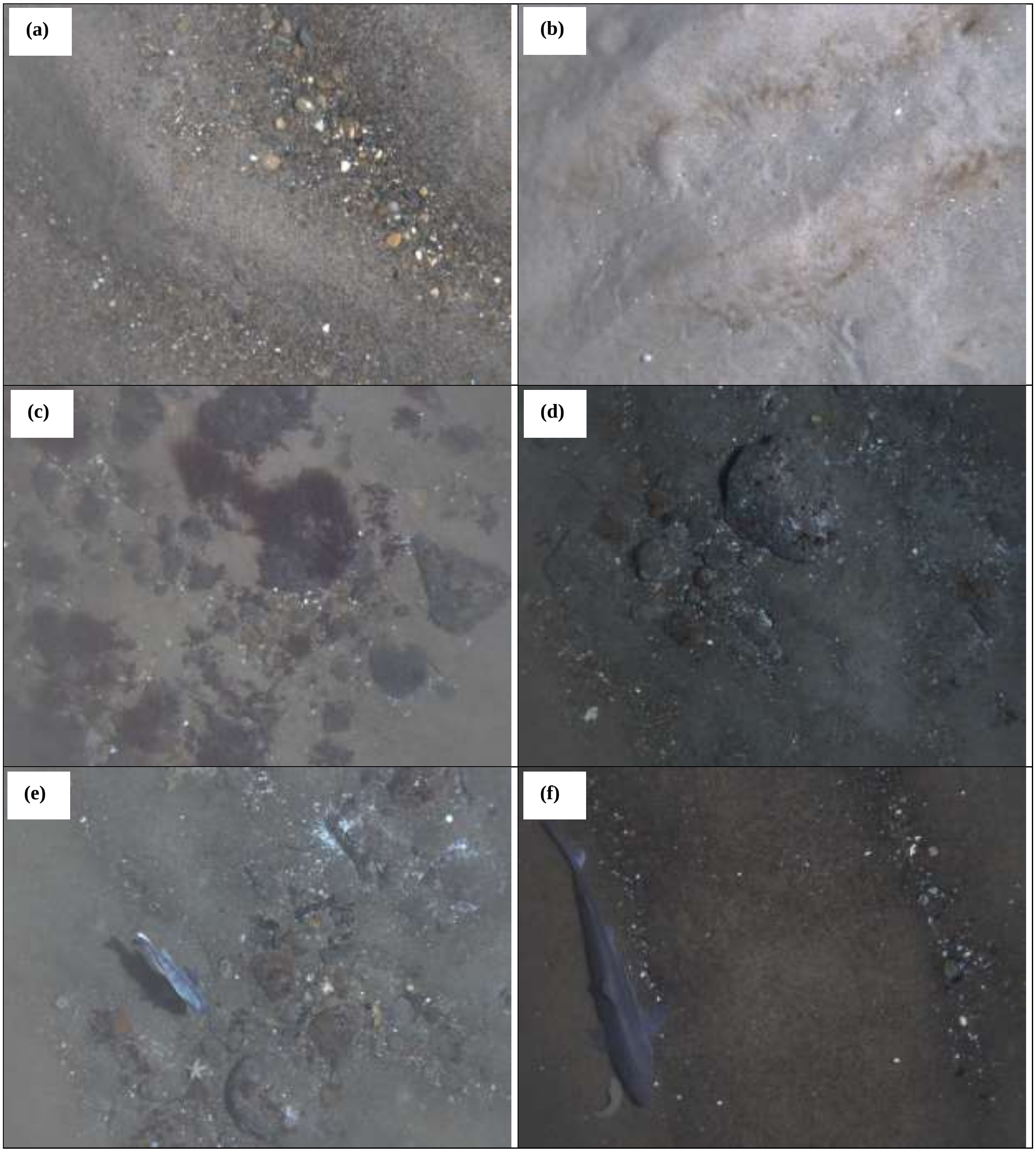


Figure 25a-f. Example images taken by the float camera system in Year 1, Year 2 and Year 3. Images (a) and (b) are representative of the seafloor environment within Turbine 1 and 3 and Control areas 2 and 3 for each year. The images show (a) areas with sand waves comprised of grain sizes ranging from coarse sand to gravel and (b) areas of fine sand. Turbine 5 exhibits patchy concentrations of cobbles and boulders (c). Control 1 in both years was notably different, being characterized by cobbles and boulders (d). Images e to l highlight some of the fauna that was present in the study areas: (e) black sea bass; (f) one of many spiny dogfish (g) school of sand lance; (h) skate and cluster of mussels on seafloor, (i) squid, (j) small live mussel aggregation, (k) numerous skates and (l) sea robins.

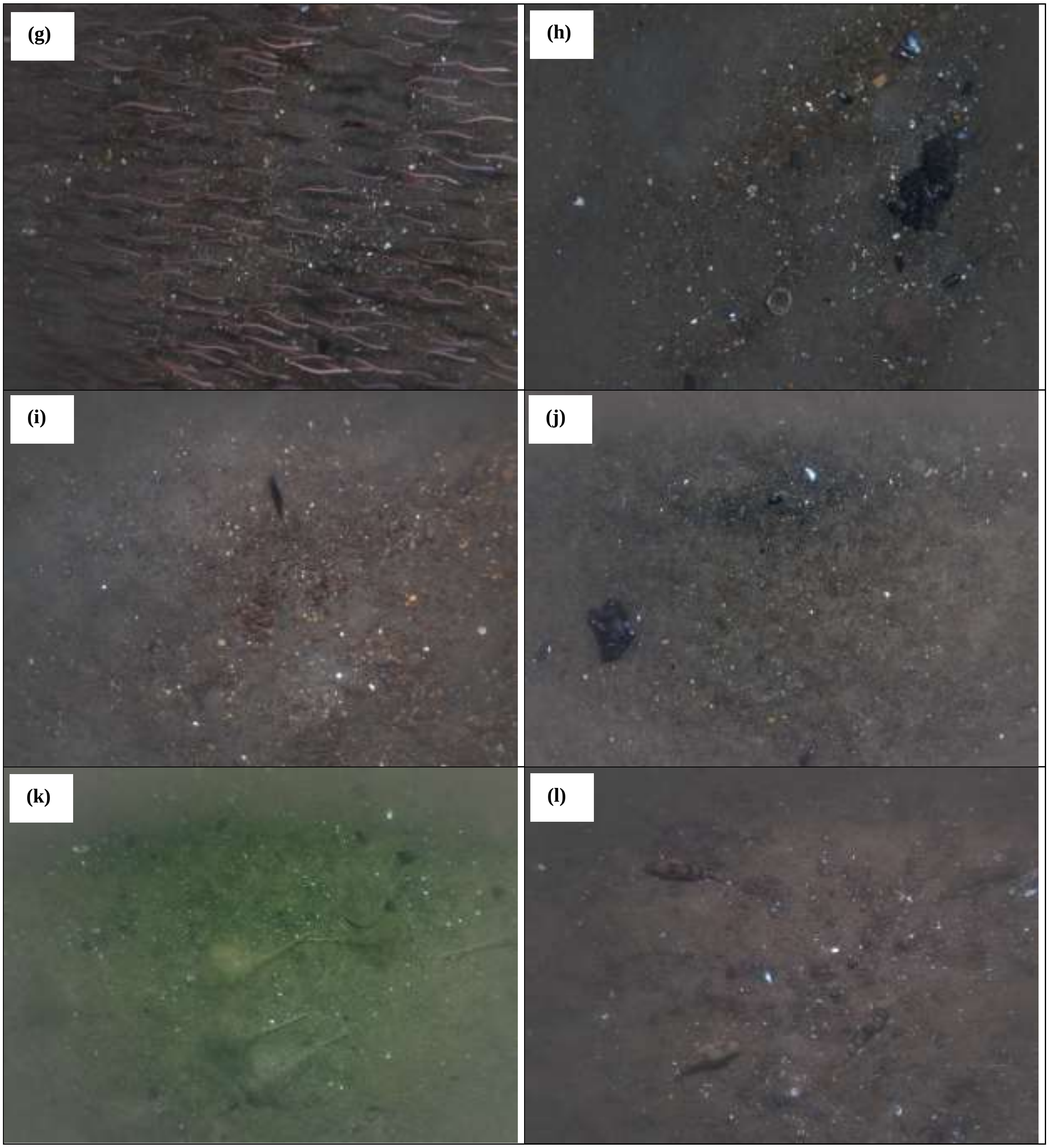


Figure 25g-l. Example images taken by the float camera system in Year 1, Year 2 and Year 3. Images (a) and (b) are representative of the seafloor environment within Turbine 1 and 3 and control areas 2 and 3 for each year. The images show (a) areas with sand waves comprised of grain sizes ranging from coarse sand to gravel and (b) areas of fine sand. Turbine 5 exhibits patchy concentrations of cobbles and boulders (c). Control 1 in both years was notably different, being characterized by cobbles and boulders (d). Images e to l highlight some of the fauna that was present in the study areas: (e) black sea bass; (f) one of many spiny dogfish (g) school of sand lance; (h) skate and cluster of mussels on seafloor, (i) squid, (j) small live mussel aggregation, (k) numerous skates and (l) sea robins.

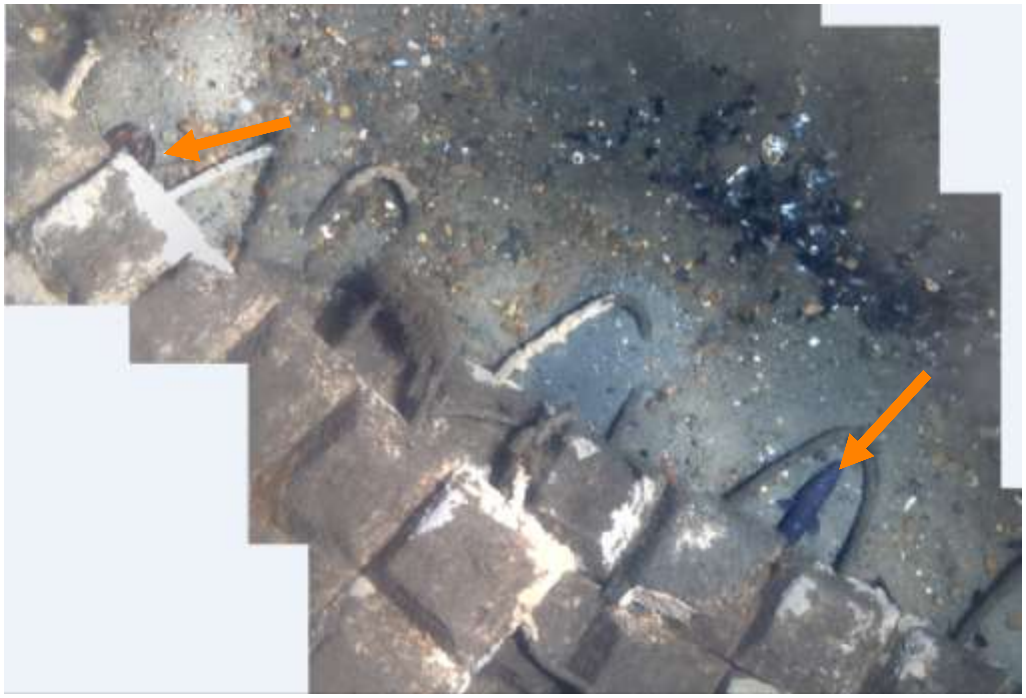


Figure 26. Example mosaic created from photographs taken by the float camera system in Year 1. The mosaics shows transition zones between gravelly and sandy seabed environments, shell hash (mostly blue mussel shells), and a portion of the concrete mat overlaid on sections of the buried cable. Also visible are fish and a lobster seeking cover under the concrete mat.

3.1.5 Sediment Organic Content

The proportion of organic matter was determined from a sediment sample (i.e., total percentage of organic matter content) and from that, the proportion of Total Organic Content (TOC) was determined (i.e., total percentage carbon within the Total Organic Matter (TOM). The results of the analysis for the TOM content and TOC content of the sediment samples collected in Year 1, Year 2 and Year 3 are presented in **Appendix F**. Minimal levels of TOM and TOC were recorded for each sample and no appreciable change is evident between Year 1,Year 2 and Year 3. However, statistically significant changes were detected between study areas within Year 3. Based on the Year 3 results, the data support rejecting the null hypotheses of no difference in organic enrichment among turbine areas ($H_0$1) and no differences between turbine and control areas ($H_0$2). However, the null hypothesis that there is no impact on distance from the wind farm foundation regarding organic enrichment can be accepted ($H_0$3), with respect to samples collected greater than 30 m from the center point of the turbine foundation. Data supporting this conclusion are presented below.

Levels of TOM in the samples collected in Year 1 ranged between 0 and 1.0%, with an average of 0.42 and 0.44% for the turbine areas and control areas, respectively (**Table 10, Figure 27**). For Year 2, values ranged from 0.06 to 1.21%. In Year 2 average TOM levels were 0.45 and 0.52% for the turbine areas and control areas, respectively. The average TOM levels calculated for Year 1 and Year 2, for each study area were broadly similar (0.43 to 0.52%), with the exception of a slightly lower average was recorded for Turbine 1 in Year 1 (0.33%). The average TOM levels for all samples in Year 3 ranged between 0.1 and 6.8%, with an average TOM of 0.54% in the turbine areas and 0.41% in the control areas (**Table 10**). In comparison to Year 2, Turbine 1 TOM had almost doubled in Year 3, and Turbine 3 had reduced by 0.11%.

Table 10. Average total organic content and total organic carbon content for each study area for vessel-based sediment samples collected in Year 1, Year 2 and Year 3.

Sampling period	Study area	Average total organic matter (%)	Average total organic carbon (%)
Year 1	Turbine 1	0.33%	0.14%
	Turbine 3	0.43%	0.19%
	Turbine 5	0.47%	0.20%
	Turbine Areas Combined	0.42%	0.18%
	Control Areas	0.44%	0.19%
Year 2	Turbine 1	0.46%	0.20%
	Turbine 3	0.42%	0.18%
	Turbine 5	0.41%	0.17%
	Turbine Areas Combined	0.45%	0.18%
	Control Areas	0.52%	0.22%
Year 3	Turbine 1	0.89%	0.38%
	Turbine 3	0.31%	0.13%
	Turbine 5	0.43%	0.18%
	Turbine Areas Combined	0.54%	0.23%
	Control Areas	0.41%	0.18%

With regards to TOC, levels for samples collected in Year 1 ranged between 0 and 0.45%, with an average of 0.18% for the turbine areas and 0.19% for the control areas (**Table 10**). The Year 2 samples had a TOC range between 0.03 and 0.52%. Average levels in Year 2 were 0.18 and 0.22% for the turbine areas and control areas, respectively. Similar to the organic content analysis, the average TOC levels calculated each year for each study area were comparable (Year 2 range = 0.17 to 0.22%, **Table 10**), although Turbine 1 in Year 1 had a slightly lower average (0.14%). In Year 3, the TOC ranged from 0.03 to 2.94% which is comparable and only slightly higher than Year 2. Average levels of TOC in Year 3 in the turbine areas were 0.23% compared to 0.18% in the Year 3 control areas. In summary, a broader range of TOC and OC, was recorded in Year 3 samples, as shown in **Figure 27**.

ANOVA tests revealed no statistically significant differences (p >0.05) in sediment TOM and TOC between study areas in Years 1 or 2. However, using the Year 3 data, ANOVA revealed statistically significant differences in levels of TOM between Turbine 1 and Turbine 3, Turbine 1 and Turbine 5 and Turbine 1 and the Control areas ($F_{(11,127)} = 4.507$, $p < 0.05$). Similarly, in Year 3, statistically significant differences were detected in the levels of sediment TOC, between Turbine 1 and Turbine 3 and also between Turbine 1 and the Control areas ($F^{(11,125)} = 4.582$, $p < 0.05$).

Analyses of the levels of TOC with distance from turbine revealed no clear relationships (**Figure 27**). The strongest trend was observed at Turbine 3 in Year 3 ($R^2 = 0.1144$). Two samples at Turbine 1 have notably higher levels of TOC in the near and intermediate distance bands, which are driving the overall higher average TOC at Turbine 1 (**Figure 27**). ANOVA tests revealed no statistically significant differences (p >0.05) in sediment TOM and TOC between distance bands in Years 1, 2 or 3 (p >0.05).

In summary, spatial difference in organic content between Turbine 1 and the other study areas in Year 3. Overall, there were still no strong relationships between organic content and the distance from turbine (**Figure 28**). However, the outliers in the Turbine 1 samples, indicate areas of comparably high concentrations, particularly at the near and intermediate ranges from Turbine 1. These samples, indicating hotspots of organic enrichment, align with the change in finer sediment fractions reported in **Section 3.1.2** and are further explained by the macrofauna recorded in **Section 3.16**.

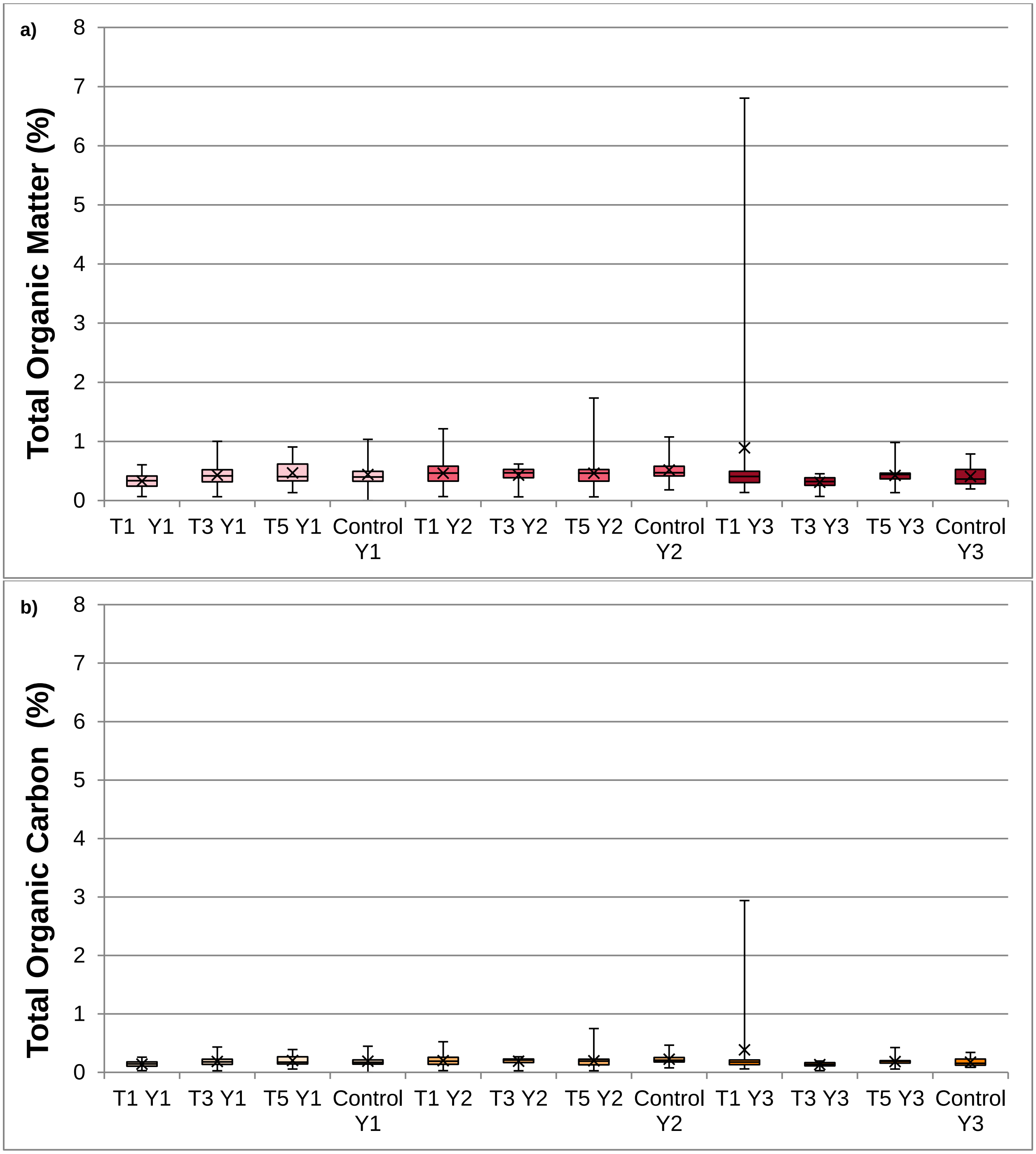


Figure 27. Box plot summarizing a) the TOM content and b) the TOC content of vessel-based sediment samples collected at the Turbines (T1, T3, T5) and Control areas in Year 1, Year 2 and Year 3.

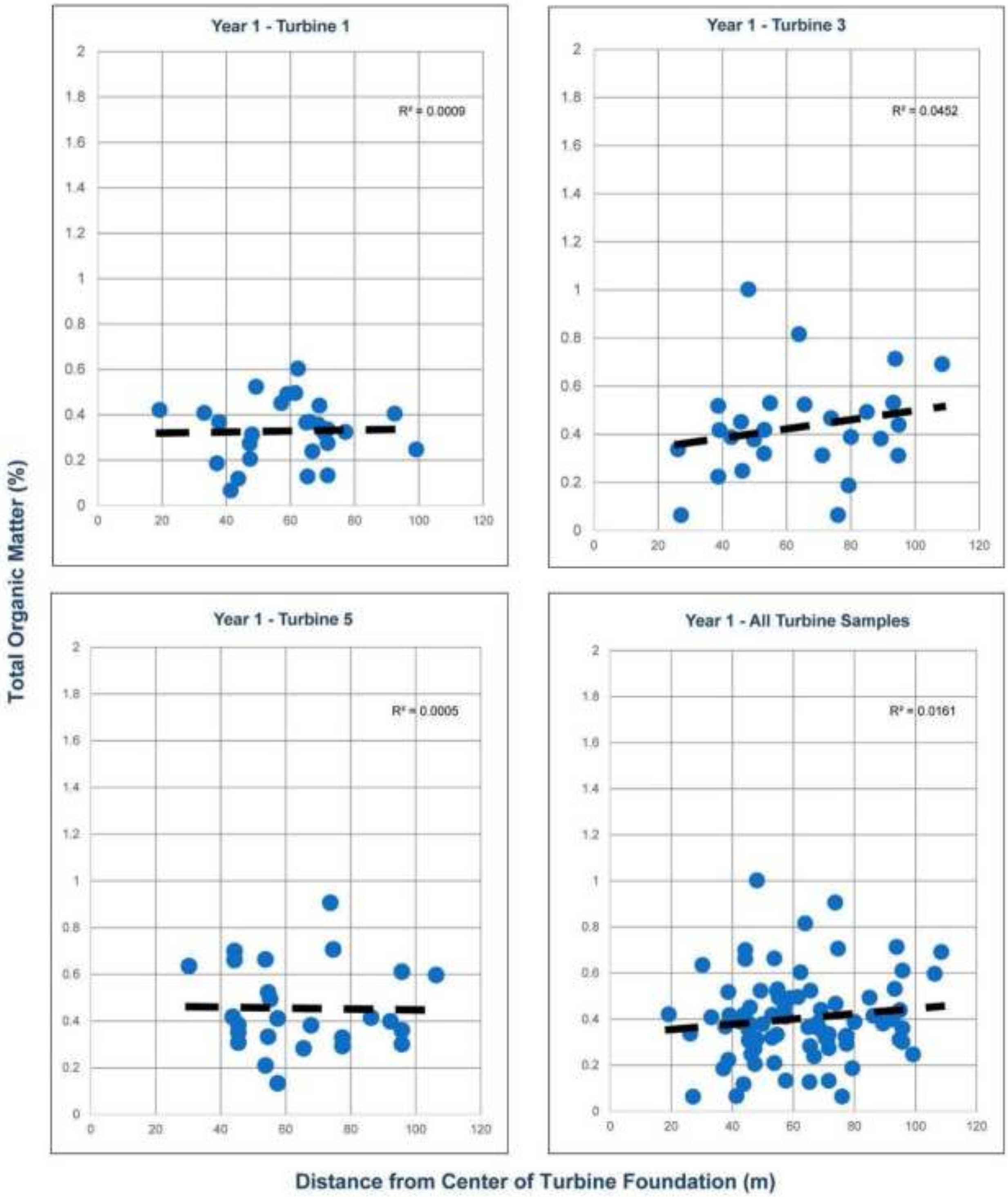


Figure 28a. Levels of TOM in vessel-based sediment samples plotted against distance from the center point under each turbine foundation structure (T1, T3, T5) at BIWF for Year 1.

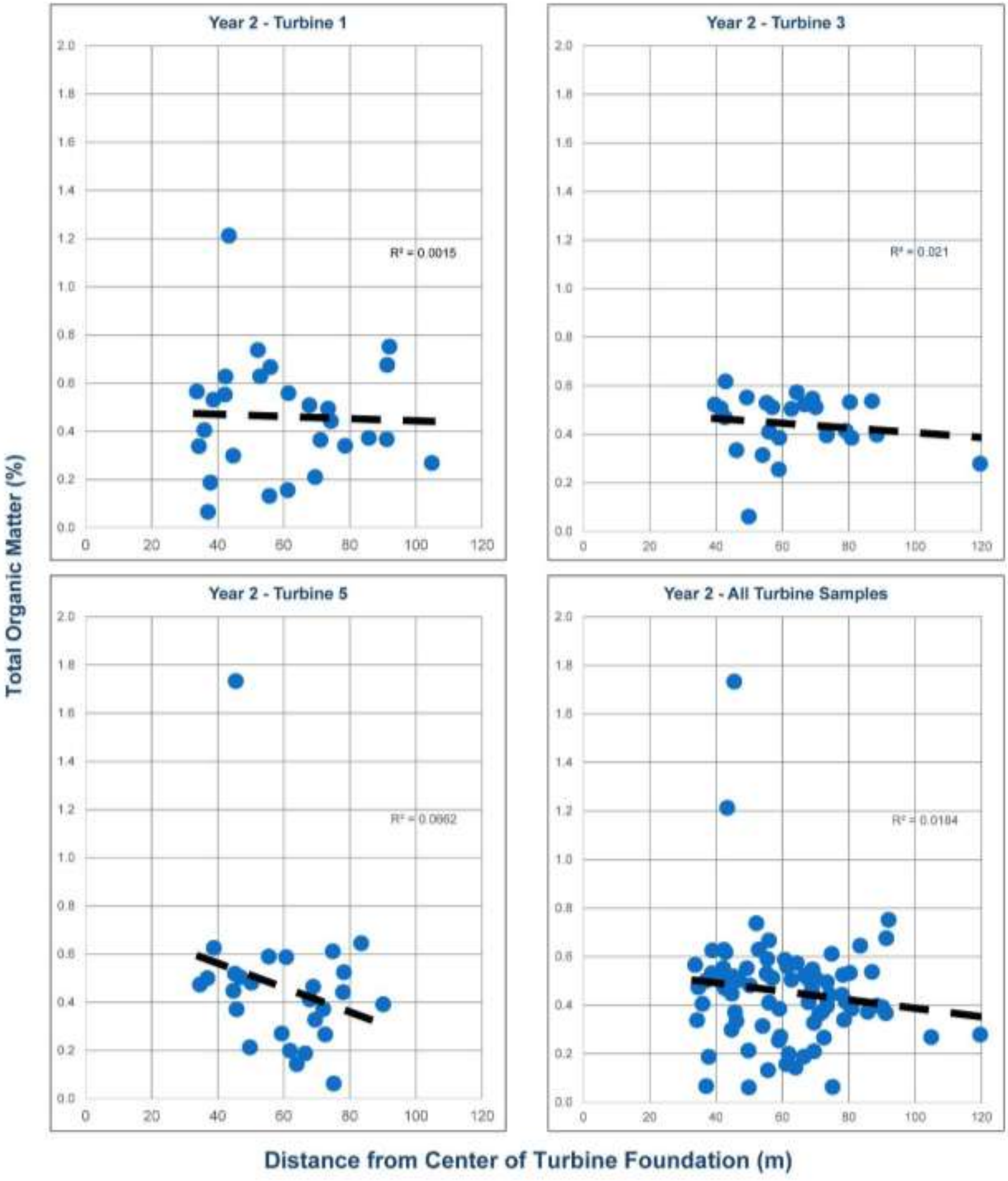


Figure 28b. Levels of TOM in vessel-based sediment samples plotted against distance from the center point under each turbine foundation structure (T1, T3, T5) at BIWF for Year 2.

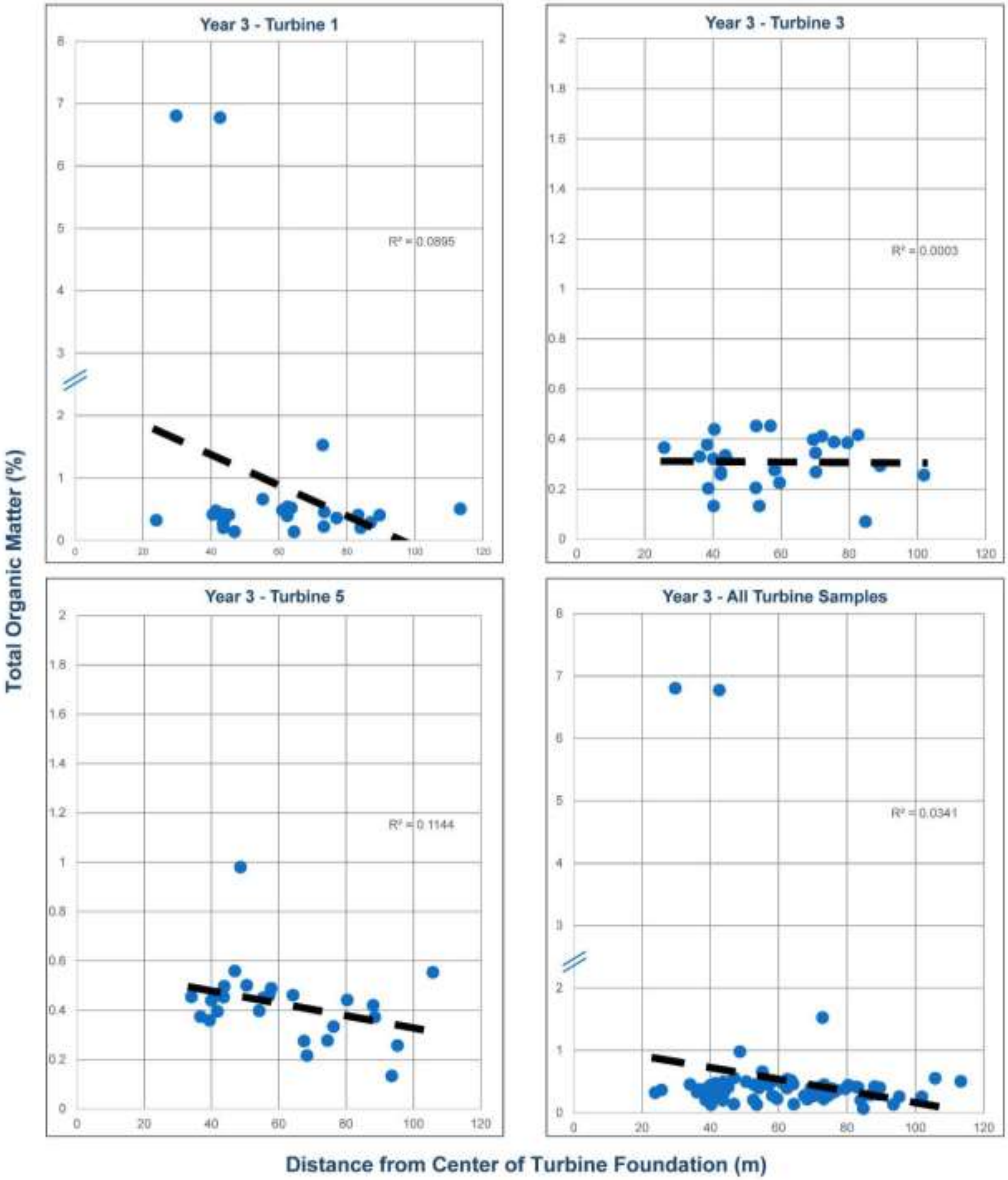


Figure 28c. Levels of TOM in vessel-based sediment samples plotted against distance from the center point under each turbine foundation structure (T1, T3, T5) at BIWF for Year 3. Note the difference in scale in Turbine 1 and All Turbine Samples graphs versus Turbine 3 and 5 graphs.

3.1.6 Macrofaunal Analysis

A summary of the total species abundance and species richness for all macrofaunal samples collected within the turbine and control areas for Year 1, 2 and 3 is provided in **Table 11**. A species abundance matrix for all samples for all three years is presented in **Appendix G**. Summary species statistics including species richness, abundance and derived univariate measures for all Year 1, 2 and 3 samples are presented in **Appendix H**.

3.1.6.1 Comparison of Sampling Years

In Year 1, a total of 139 macrofaunal species represented by 17,804 individuals were recorded from the 117 grab samples (**Table 11**; note: the four QC samples are excluded here). The majority (96.5%) of the macrofauna were annelids (i.e., polychaetes), nematodes, and crustaceans (i.e., amphipods) (**Figure 29**). From the 108 grab samples collected in Year 2, a total of 61,835 individuals belonging to 131 species were recovered. The majority (96.6%) of the macrofauna were nematodes and annelids (i.e., polychaetes). In Year 3, a total of 50,147 individuals belonging to 150 species were recovered. The majority of individuals (99.0%) were annelids (50.0%, i.e., polychaetes), followed by nematodes (20.3%), crustaceans (16.0%) and mollusks (12.7%).

The large discrepancy between the total abundance between the Year 1 and Year 2 samples is primarily attributed to an increase in nematodes. In Year 1, a total of 4,120 nematodes were identified (23.1% of total), whereas in Year 2, this number increased by a factor of 10 to 41,802 individuals (67.6% of total) (**Table 11**). The cause of this increase is unknown. When Year 1 versus Year 2 abundances are considered without nematodes, the totals are more comparable, although there is still a noticeable increase of 4,605 individuals over the three turbine areas in Year 2. Comparatively, the nematode abundance decreased in Year 3 with a total of 10,165 individuals (20.3% of total), closely resembling the proportion of nematodes observed in Year 1. In Year 3, a total of 50,147 individuals were recovered from the turbine and control samples (**Table 11**). In Year 3, annelids were the dominant phylum with 25,079 individuals. However, there was a marked increase in the number of individuals from the crustacean and mollusk phyla, with 8,010 and 6,354 individuals respectively in Year 3 samples.

With regards to species richness, a combined total of 175 species were identified across all of the Year 1 and Year 2 samples, which increased to 212 species with Year 3 incorporated (**Table 11**). Of the 175 species recovered in Year 1 and 2 combined, 93 species were recovered in both years, while 45 and 37 species were present solely in Year 1 and Year 2, respectively (**Table 12**). Of the 45 species unique to Year 1, only 11 had a total abundance greater than 10 (8 species had abundances between 19 and 50, and the remaining three species had abundances of 59, 70, and 154). For Year 2, only four of the 37 unique species had total abundances greater than 10 (they were 14, 19, 64, and 241). These results indicate that the species unique to each year have minimal influence on overall macrofaunal community composition. Rather, it is the 93 species (or likely a subset of) that are common to each year that are ecologically meaningful. Following the Year 3 analyses, 99 species were in common with Year 2 species and 51 species were present in Year 3 but not Year 2.

By phylum, the dominant faunal group in Year 1 was Annelida, which accounted for 61% of the total abundance and 42% of the total number of species (**Figure 29**). Polychaetes comprised the Annelida phylum, with the exception of one oligochaete species (with 42 individuals found within 14 samples). The second dominant phylum was Nematoda, comprising 23% of all fauna. Nematodes were identified to the phylum level, and, therefore, the number of species present cannot be provided. Crustaceans, principally amphipods, made up 12.5 and 34% of the total species abundance and richness, respectively. The remaining phyla were Mollusca, Nemertea, Copepoda, Echinodermata, and Cnidaria, with a combined contribution of 3.5 and 23% to the total abundance and richness, respectively.

Table 11. Summary of total species abundance and species richness for all vessel-based macrofaunal samples collected within the turbine and control areas for Year 1, Year 2 and Year 3. Note that the four Year 1 QC samples are not included here. Species abundance is reported for all species, excluding Nematoda.

		Year 1			Year 2			Year 3		
Study area	**Sample number (n)**	**Species richness (all species)**	**Species abundance (all species)**	**Species abundance (Nematoda excluded)**	**Species richness (all species)**	**Species abundance (all species)**	**Species abundance (Nematoda excluded)**	**Species richness (all species)**	**Species abundance (all species)**	**Species abundance (Nematoda excluded)**
All Study Areas Combined	Y1 = 117 Y2 & Y3 = 108	139	17,804	13,684	131	61,835	20,033	150	50,147	39,982
Turbine 1	27	78	1,939	1,677	86	4,896	2,056	104	16,648	14,656
Turbine 3	27	64	5,182	3,838	75	21,924	5,710	76	10,507	7,140
Turbine 5	27	79	4,925	3,424	70	16,752	5,778	76	10,971	9,146
Turbine Areas Combined	81	--	12,046	8,939	--	43,572	13,544	--	38,126	30,942
Control 1	Y1 = 12 Y2 & Y3 = 9*	76	2,212	1,844	61	3,304	1,542	68	3,891	2,542
Control 2	Y1 = 12 Y2 & Y3 = 9*	69	2,092	1,686	57	11,213	3,383	69	4,416	3,375
Control 3	Y1 = 12 Y2 & Y3 = 9*	66	1,454	1,215	45	3,746	1,564	57	3,714	3,123
Control Areas Combined	27	--	5,758	4,745	--	18,263	6,489	--	12,021	9,040

*The number of Control sites were reduced from four in Year 1 to three in Year 2 and Year 3.

Table 12. Number of species recovered in vessel-based grab samples for Year 1, 2 and 3 combined, and in each year individually.

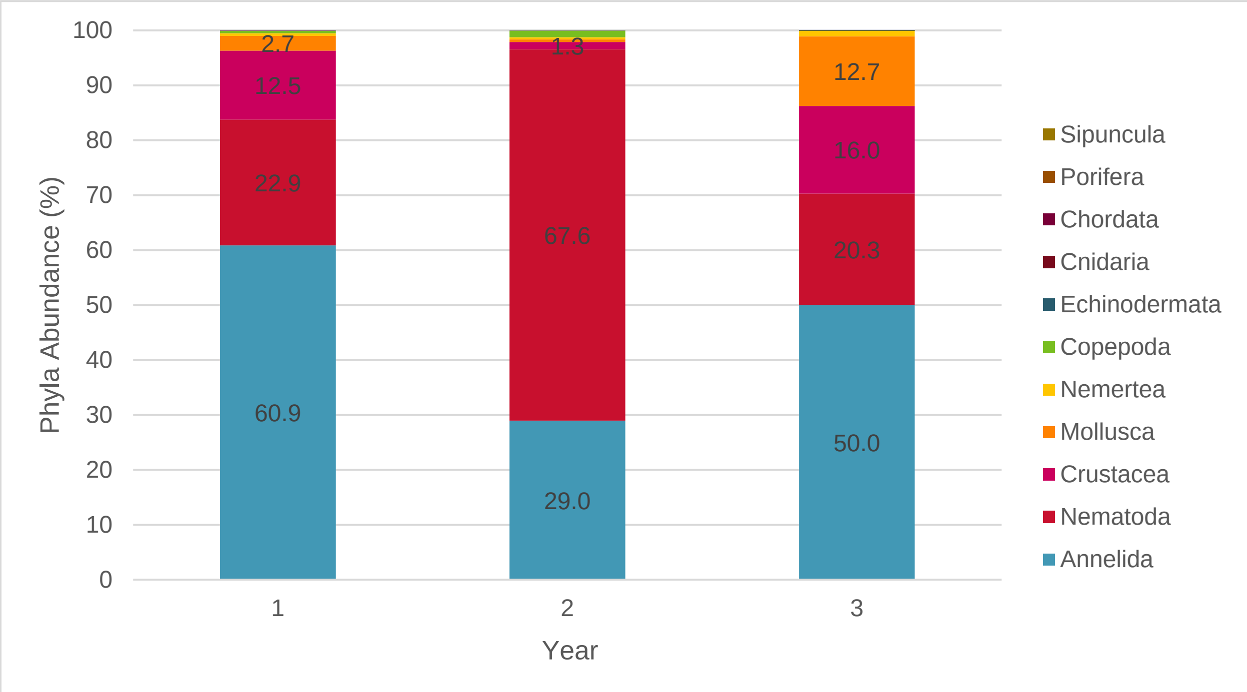
Sampling period	Number of species present
Found in Both Years 1 and 2	93
Found in Both Years 2 and 3	99
Found only in Year 1	45
Found only in Year 2	37
Found only in Year 3	51
Year 1, 2, and 3 combined	212

In Year 2, the primary and secondary faunal group switched, with Nematoda dominating, followed by Annelida. Specifically, nematodes accounted for 68% of the total abundance. Because nematodes were identified to the phylum level, the number of species present cannot be provided. The Annelida phylum was comprised of polychaete species, with the exception of one oligochaete species (with 53 individuals across 29 samples). These polychaetes contributed 29% of the total abundance and 44% of the total number of species. Crustacea and Mollusca contributed 32 and 19% to the total species richness, respectively, although each accounted for less than 1.5% of the total abundance. The remaining phyla (i.e., Nemertea, Copepoda, Echinodermata, and Cnidaria) comprised less than 1.5% of the total abundance and richness.

In Year 3, Annelida became the primary faunal group again, accounting for 50% of the total abundance. This was lower than in Year 1 where the annelid abundance was 61% of the total abundance. In Year 3, similar to Year 2, the Annelida phylum was again comprised of polychaete species (64 species, 25,019 individuals) and one oligochaete species (60 individuals, present in 28 of 108 samples). In Year 3, Nematoda accounted for 20% of the total abundance (10,165 individuals) and Crustacea accounted for 16% of the total abundance (8,010 individuals, 43 species). There was also a marked increase in Mollusca which accounted for 13% of the total abundance (6,354 individuals, 31 species). The remaining phyla (i.e., Echinodermata, Cnidaria and Chordata) accounted for less than 1% of the total abundance and richness, and the Copepoda were absent from Year 3 samples.

Overall, total richness by phylum was highly similar between Year 1 and Year 2, indicating the number of species within each phylum remained consistent over time, despite that there were unique species present in each year. This pattern holds true for comparisons between Year 2 and Year 3; the total richness by phylum is broadly similar. The Year 3 species richness increases most strongly in the phyla Annelida and Mollusca, each with seven species more compared to Year 2. Minor increases of two additional species were evident in Crustacea and Echinodermata and only one additional species in Cnidaria and Chordata. Total abundances by phylum was more variable from Year 1 to Year 2 but are broadly comparable in that both years are overwhelmingly dominated by polychaetes and nematodes, accounting for 83.8% of the total in Year 1 and 96.6% in Year 2. Also, the phyla Mollusca, Echinodermata, Nemertea, Cnidaria, and Copepoda offered minimal contributions and no appreciable change was evident between Years 1 and 2. Total abundances by phylum in Year 3 began to diverge, comparative to Year 2. The total abundance contributed by Annelida and Nematoda (combined 70.3%) in Year 3 was substantially reduced from Year 2. Furthermore, increases in total abundances of Crustacea and Mollusca were observed in Year 3. Based on Phyla, Year 3 macrofaunal composition is more comparable to Year 1, with the main distinction being an 11% decrease in Annelida, replaced with a 10% increase in Mollusca.

The most distinct difference between Year 1 and Year 2 is that annelids were just over twice as abundant as nematodes in Year 1, whereas the reverse is true in Year 2; the result of a ten-fold increase in nematode abundance in Year 2. The number of polychaetes also increased by almost a third; from 11,147 individuals in Year 1 to 17,905 in Year 2. Examination of the macrofaunal data indicates that the overall increase is due to an increase in abundance of 9 of the 15 most dominant polychaete species from Year 1 to Year 2. The greatest increase occurred for the spionid worms, *Parapionosyllis longicirrata* (+1,893) and *Sphaerosyllis erinaceus* (+1,430).



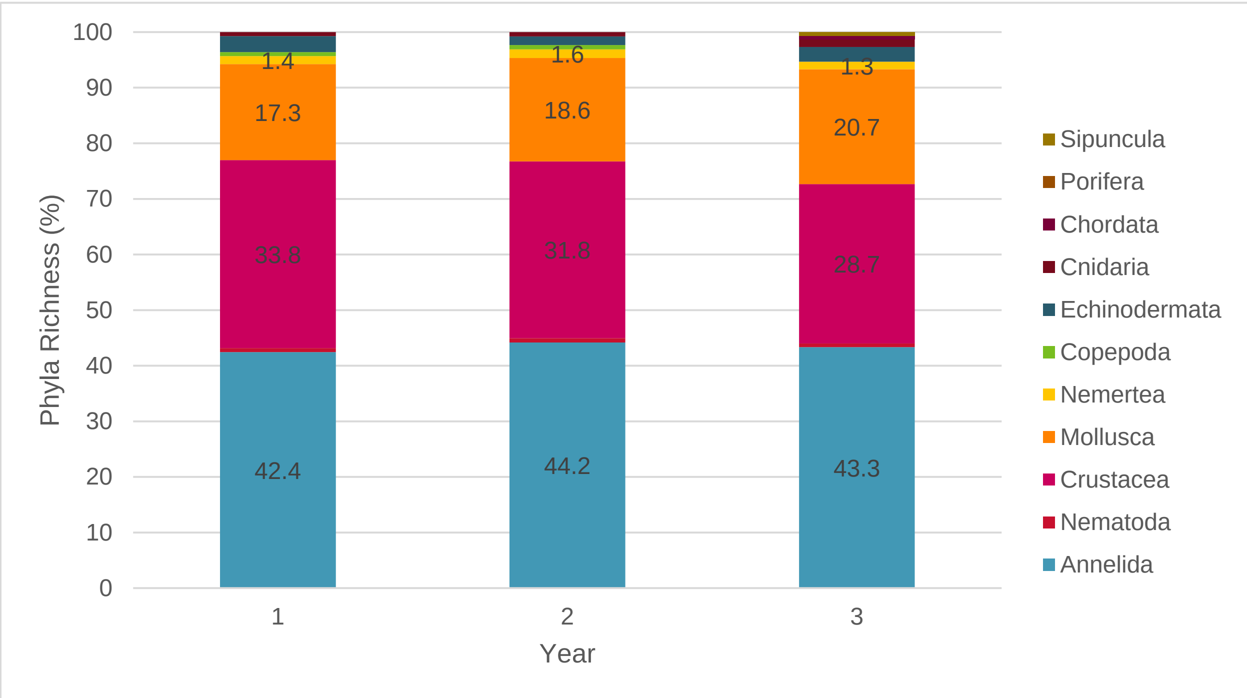


Figure 29. Proportion contribution of macrofauna identified in vessel-based grab samples, characterized by phylum, to the total abundance and total species richness for Year 1, 2 and 3.

Note: percentage labels are not shown when a phylum has a total contribution of less than 1.5%.

Variability between years is also seen in the total abundance of crustaceans, which declined from 13% in Year 1 to less than 1.5% in Year 2, although the total richness remained essentially the same (34% and 32%). Examination of the macrofaunal data showed an overall decline of all crustacean species, except for the amphipod, *Unciola irrorata*, which recorded 458 and 431 individuals in Year 1 and Year 2, respectively. The barnacle, *Amphibalanus amphitrite*, also showed a substantial decline, but the high abundance in Year 1 was attributed to samples collected within Controls 1 and 3, which were not resampled in Year 2.

The most distinct difference between Year 2 and Year 3 is the reduced abundance of nematodes and the increased abundance of Annelida, Crustacea and Mollusca. Overall, the abundance of nematodes reduced from 41,802 in Year 2 to 10,165 individuals in Year 3. The abundance of annelids increased from 17,905 in Year 2 to 25,097 in Year 3. The greatest increase in annelids was attributed to the increase in *Polycirrus eximius* (+8,104) in Year 3. The greatest increase in crusteaceans can be attributed to barnacles *Balanus* spp. (+6,325) and secondly to the amphipod *Unciola irrorata* (+557). The greatest increase in mollusks can be attributed to the bivalves, *Mytilus edulis* (+5,755) and secondly to *Astarte* spp., including *A. castanea* and *A. undata.*

For Year 1, the most conspicuous species present across all samples within both the turbine and control areas, in terms of highest overall abundances, include nematodes and the polychaetes *Polycirrus eximius*, *Polygordius* spp., *Lumbrinereis acuta*, *Pisione* sp., *Goniadella gracilis*, *Spirorbis* sp., *Sabellaria vulgaris*, *Parapionosyllis longicirrata*, *Aricidea catherinae* and *Cirrophorus* sp. (**Table 13**). Also abundant are the amphipods *Unciola irrorata*, *Ampelisca vadorum*, *Erichthonius rubricornis*, *Tanaissus psammophilus*, *Gammaropsis maculata* and *Corophium* spp, as well as the barnacle *Amphibalanus amphitrite*. Although comparatively less well represented within the samples, key mollusk species included the bivalves *Mytilus edulis*, *Spisula solidissima* and *Lyonsia arenosa*.

Of the top ten most abundant species, seven exhibited a broad distribution across the study areas. Precisely, four species were recovered in over 100 samples of the 121 samples collected (including QC samples), two were identified in 77 samples and one species was present in 76 samples (**Table 13**). Accordingly, these seven species are also on the list of top ten most frequently occurring species.

The remaining three species, despite being numerically superior, showed a patchy distribution (**Table 13**). Populations in some instances appeared to be highly localized and limited to a few grab samples only. For instance, individuals of the polychaete, *Spirobis* spp., were recovered only within Control 1 samples and in a wide range of abundances. In one of the cluster samples, 650 individuals were recorded (sample C1-1_2), but only one individual was recorded within the other two cluster samples collected at this station. Elsewhere, *Spirorbis* sp. only occurred at two other stations (within four samples) 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_3, but was only present at 21 additional cluster stations (within 40 samples) at densities between 1 and 41 individuals per grab. Similarly, 102 individuals of the barnacle *Amphibalanus amphitrite* were recorded within sample C3-4_2, but this species was absent from the other two cluster samples collected at this station and was only found at a farther 15 stations (within 27 samples) throughout the study areas.

For Year 2, the most conspicuous macrofauna present across all samples within both the turbine and control areas were nematodes, having an overwhelming total abundance of over 40,000 (**Table 13**). Polychaetes followed as the second most conspicuous macrofauna, namely *Polycirrus eximius*, *Polygordius* spp., *Pisione* sp., *Parapionosyllis longicirrata*, *Lumbrinereis acuta*, *Sphaerosyllis erinaceus*, *Parougia caeca*, *Goniadella gracilis*, *Aricidea catherinae*, *Cirrophorus furcatus*, and *Syllides longocirratus*. Amphipods were present in much lower abundances, with *Unciola irrorata* exhibiting the greatest numbers (n = 431). Key bivalve species, such as *Mytilus edulis*, *Spisula solidissima* and *Lyonsia arenosa*, also exhibited low abundances.

All of the top 10 most abundant species in Year 2 exhibited a broad distribution across the study areas. Five species were present in at least 103 of the 108 samples, and the other five species were present in at least 79 samples. Eight of these species were also on the list of top ten most frequently occurring species, although the remaining two ranked 11th and 12th on the list.

Table 13. Top 10 most abundant and frequently occurring species for vessel-based grab samples across all study areas collected in Year 1, Year 2 and Year 3.

Year 1 - Most abundant			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 121)**
Nematode*	Nematoda	4,196	119
*Polycirrus eximius**	Polychaete	1,959	77
Polygordius spp*	Polychaete	1,806	112
*Lumbrinereis acuta**	Polychaete	1,361	102
Pisione spp.*	Polychaete	1,325	76
*Goniadella gracilis**	Polychaete	918	108
Spirorbis	Polychaete	726	6
Sabellaria vulgaris	Polychaete	568	40
Amphibalanus amphitrite	Barnacle	483	27
Unciola irrorata	Amphipod	458	77
Year 2 - Most abundant			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 108)**
Nematode*	Nematoda	41,802	105
*Polycirrus eximius**	Polychaete	2,622	79
Polygordius spp*	Polychaete	2,542	108
Pisione spp*	Polychaete	2,224	81
Parapionosyllis longicirrata	Polychaete	2,186	103
*Lumbrinereis acuta**	Polychaete	1,775	104
Sphaerosyllis erinaceus	Polychaete	1,553	91
Parougia caeca	Polychaete	1,037	88
*Goniadella gracilis**	Polychaete	724	105
Aricidea catherinae	Polychaete	676	84
Year 3 - Most abundant			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 108)**
*Polycirrus eximius**	Polychaete	10726	83
Nematoda spp*	Nematoda	10165	106
Balanus spp	Barnacle	6348	28
Mytilus edulis (juveniles)	Bivalve	5755	73
Polygordius spp*	Polychaete	2670	103
Pisione spp*	Polychaete	2612	80
*Lumbrinereis acuta**	Polychaete	1488	101
Parapionosyllis longicirrata	Polychaete	1063	97
Unciola irrorata	Amphipod	988	87
*Goniadella gracilis**	Polychaete	879	94
Note: Asterisk denotes species listed in all three years. Note: QC samples are included in Year 1.			

Table 13 (continued). Top 10 most abundant and frequently occurring species for vessel-based grab samples across all study areas collected in Year 1, Year 2 and Year 3.

Year 1 - Most frequent			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 121)**
Nematode*	Nematoda	4,196	119
Polygordius spp*	Polychaete	1,806	112
*Goniadella gracilis**	Polychaete	918	108
*Lumbrinereis acuta**	Polychaete	1,361	102
*Parapionosyllis longicirrata**	Polychaete	293	82
*Unciola irrorata**	Amphipod	458	77
Polycirrus eximius	Polychaete	1,959	77
Pisione spp.	Polychaete	1,325	76
Maldanidae spp.	Polychaete	259	70
Kirkegaardia baptisteae	Polychaete	140	69
Year 2 - Most frequent			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 108)**
Polygordius spp*	Polychaete	2,542	108
Nematode*	Nematoda	41,802	105
*Goniadella gracilis**	Polychaete	724	105
*Lumbrinereis acuta**	Polychaete	1,775	104
*Parapionosyllis longicirrata**	Polychaete	2,186	103
Sphaerosyllis erinaceus	Polychaete	1,553	91
Parougia caeca	Polychaete	1,037	88
*Unciola irrorata**	Amphipod	431	86
Aricidea catherinae	Polychaete	676	84
Monticellina baptisteae	Polychaete	240	83
Year 3 - Most frequent			
Species	**Taxonomic group**	**Total abundance**	**Occurrence (n = 108)**
Nematoda spp*	Nematode	10,165	106
Polygordius spp*	Polychaete	2670	103
*Lumbrinereis acuta**	Polychaete	1488	101
*Parapionosyllis longicirrata**	Polychaete	1063	97
*Goniadella gracilis**	Polychaete	879	94
Nemertea spp (including juvenile *C. lacteus)*	Polychaete	471	89
*Unciola irrorata**	Amphipod	988	87
Polycirrus eximius	Polychaete	10,726	83
Lumbrinereis fragilis	Polychaete	293	81
Pisione sp	Polychaete	2612	80
Note: Asterisk denotes species listed in all years. Note: QC samples are included in Year 1.			

For Year 3, the most dominant macrofauna present were the polychaete, *Polycirrrus eximius* and nematodes (**Table 13**). Both of these species were also in the top two most dominant species in Year 1 and Year 2, though in reverse order. In Year 3, *Balanus* spp., returned (from Year 1) as a highly dominant species and the bivalve *M. edulis* became the fourth most dominant species, which had not been dominant in the previous two years.

The majority of the top 10 most abundant species in Year 3 exhibited a broad distribution across the sample sites (**Table 13**). The five most dominant species were present in between 28 and 106 sample sites. The third most abundant species, *Balanus* spp., had the narrowest spatial distribution, and was only detected in 28 of a possible 108 sites, whereas nematodes had the broadest spatial distribution with 106 of a possible 108 sites.

The Year 1 and Year 2 samples showed comparable spatial distribution and species dominance patterns, with nematodes and polychaetes being the most prevalent. The majority of the most conspicuous polychaete species from Year 1 continued to be present in Year 2. **Table 13** shows that six of the ten most abundant and most frequently occurring species were listed in both years. Of those, the top three most abundant species were consistent from year to year. The same is true for the top five most frequent species, although the first and second ranking species were switched.

The Year 2 and Year 3 samples shared the top five most frequent species, which were again nematode and polychaete species, although the order varied within each year. The most conspicuous species were present in all three years of sampling (**Table 13**). Six of the top ten most frequently occurring, and most abundant, species were present in all three years, although the abundances and frequencies varied from year to year.

Examination of the macrofaunal community composition by nMDS plot, indicates that Year 1 samples were more variable or disperse, whereas the overall macrofaunal community composition for Year 2 was more cohesive, as represented in **Figure 30**. While seasonal change, related to the longer sampling period, may have contributed to the apparent greater dispersion between samples in Year 1, other factors are likely responsible. For example, the dominance of nematodes in Year 2 would have increased similarity between the Year 2 samples, resulting in the observed tighter clustering of the Year 2 samples relative to Year 1 (**Figure 30**). Also, as shown in HDR (2018b), the seafloor environment and macrofaunal samples collected at Control 1 in Year 1 were not representative of the turbine areas and other control areas, so that dispersion between samples would be expected to be greater in Year 1 compared to Year 2. This also explains why Year 1 and Year 3 appear more different. Year 3 and Year 2 are generally similar in macrofaunal composition, although some samples are more dispersed in Year 3 (**Figure 30)**; these Year 3 samples are attributed to Turbine 1 sites.

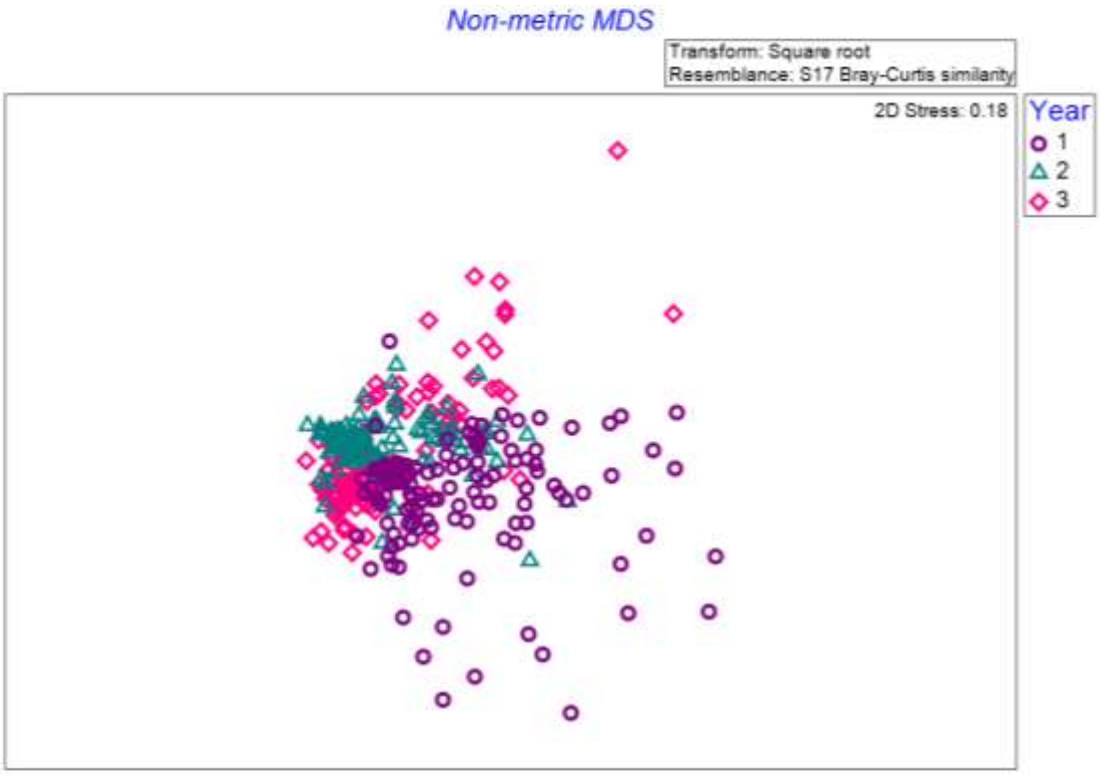


Figure 30. Non-metric MDS plot illustrating the relative macrofaunal (dis)similarities between vessel-based grab samples collected in Year 1, Year 2, and Year 3. Each symbol represents an individual grab sample. The spatial distances between each of the symbols represent the relative (dis)similarities with respect to species composition and abundance.

Note: The macrofaunal community composition was most dispersed in Year 1 but tighter clustering can be observed in Year 2 and again in Year 3. Two dispersed samples observed in Year 3 are attributed to Turbine 1.

3.1.6.2 Cluster Samples

Investigations of the similarity of macrofaunal community composition among cluster samples indicated some spatial variability present in all three sampling years. While a few cluster samples were collected close together (<3 m) and a few were separated up to 40 m, most of the cluster samples were taken within 5 m to 25 m of one another (**Figure 9, Figure 10,** and **Figure 11**). 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 plots (**Figure 31**) and SIMPER analysis (**Table 14** and **Table 15**). The nMDS plot (**Figure 31**) shows two distinct points in the Year 3 plot attribute to Turbine 1, station 5, but aside from this, the cohesiveness of cluster samples is comparable over the three sampling years.

Average similarity of samples within a given cluster were assessed by a SIMPER analysis. Cluster samples within a given sample station for Year 1 ranged in similarity between 28.32% and 76.44% (**Table 15**). Of the 39 stations sampled in Year 1, 21 stations exhibited a similarity between 50% and 69% and 7 stations had a similarity between 70% and 81% (**Table 14**). For Year 2, the average similarity of a given cluster sample ranged from 37.46% to 81.20%, with all but three of the 36 samples having a similarity between 50% and 81% (**Table 14** and **Table 15**). For Year 3, the average similarity of a given cluster sample ranged from 36.88% to 77.40%, with all but two samples having a similarity of over 50% (**Table 14** and **Table 15**). For all three years, the range of similarities was lowest at Turbine 1, whereas Turbine 3, Turbine 5, and the control areas all had higher and more comparable ranges.

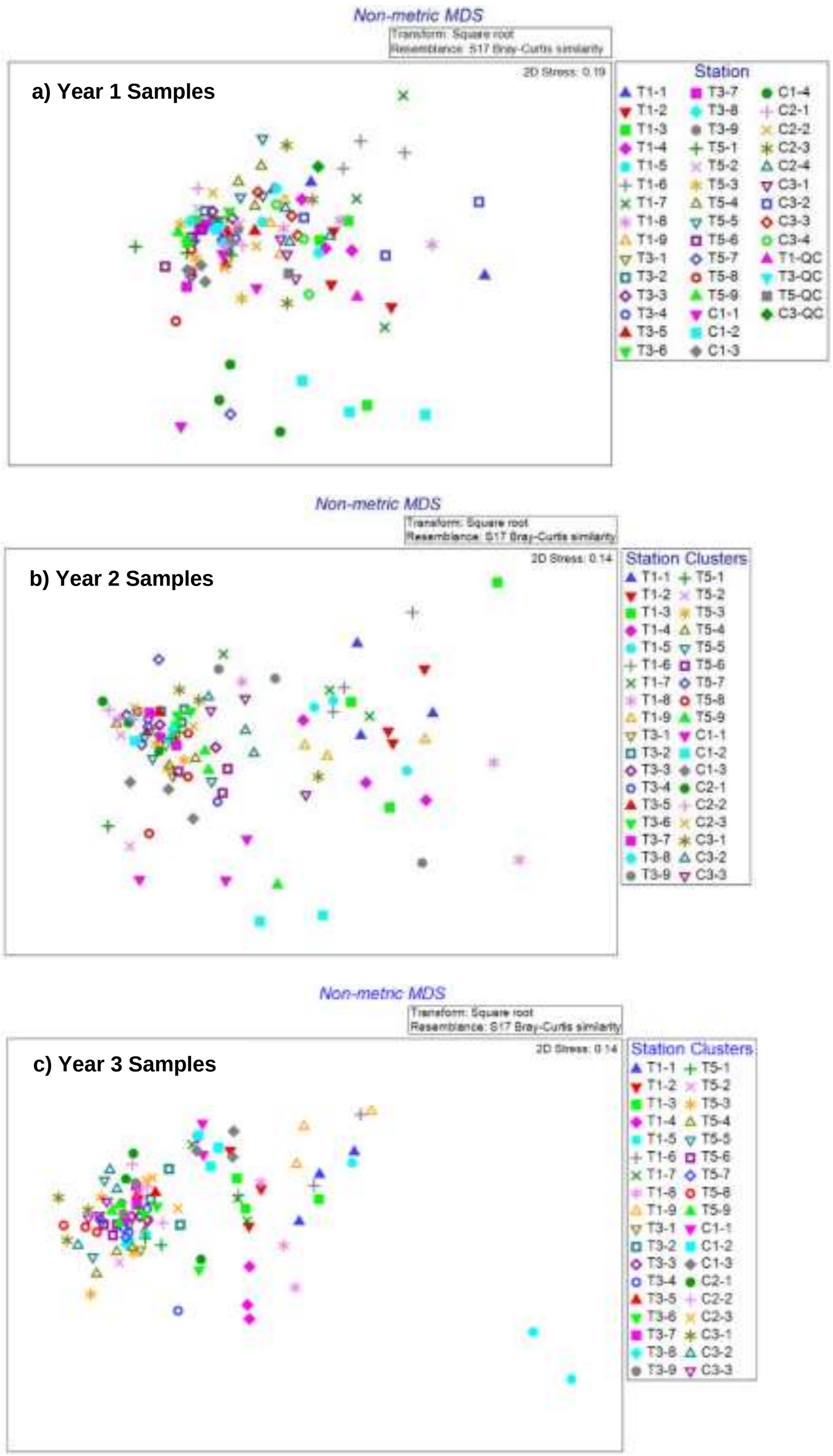


Figure 31. Non-metric MDS plot showing the relative (dis)similarities between cluster samples at each station for vessel-based grab samples collected in a) Year 1, b) Year 2, and c) Year 3. Each symbol represents an individual grab sample. The spatial distances between each of the symbols represent the relative (dis)similarities with respect to species composition and abundance.

Note: This figure demonstrates comparable cohesiveness of cluster samples over the three sampling years.

Table 14. Summary of similarity ranges exhibited by cluster samples at a given station for vessel-based grab samples collected in Year 1, Year 2 and Year 3.

SIMPER similarity range	Year 1 stations (n = 39)	Year 2 stations (n = 36)	Year 3 stations (n = 36)
28–35%	4	0	0
36–49%	7	3	2
50–69%	21	17	25
70–81%	7	16	9

Table 15. Summary of SIMPER results showing ranges of similarities of macrofaunal communities within cluster samples across all study areas and individual study areas for vessel-based grab samples collected in Year 1, Year 2 and Year 3.

	SIMPER similarity range		
	Year 1	Year 2	Year 3
All Areas	28.32–76.44%	37.46–81.20%	36.88%–77.40%
Turbine 1	28.32–59.64% (Note: all but one station ranged between 28.32 and 48.68%)	37.46–69.39% (Note: all but two stations ranged between 58.34 and 69.39%)	36.88%–63.81% (Note: all but two stations ranged between 54.85% and 63.81%
Turbine 3	56.90–71.23%	56.95–80.14% (Note: all but two stations ranged between 71.32 and 80.14%)	51.91%-76.05%
Turbine 5	37.08–76.44% (Note: all but one station ranged between 50.55 and 76.44%)	60.52–75.79%	56.76%-77.40%
Control 1	35.55–71.27% (Note: all but one station ranged between 51.54 and 71.27%)	45.78–71.27%	62.06%-77.13%
Control 2	52.02–67.48%	73.30–81.20%	52.73%-70.33%
Control 3	32.75–66.36% (Note: all but one station ranged between 53.64 and 66.36%)	64.30–70.80%	61.91%-72.27%

Variability within the cluster samples for each year is further evident through detailed examination of the dominant species at a given station. Within some stations, cluster samples were dominated by the same species, whereas at other stations, each cluster sample was dominated by a different species, and, yet, at other stations, the pattern was 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.

3.1.6.3 Comparison of Grouped Turbine and Control Areas

The data analyses suggest that there are no appreciable differences between the macrofaunal communities within the turbine and control areas when considered as two general groups in Year 1, Year 2 or Year 3.

The nMDS plots for each year and for all three years combined show there is no clear separation between the Turbine and Control samples in macrofaunal communities (**Figure 32**). The ANOSIM results support this finding. The ANOSIM was significant in Year 1, with an R value of 0.18 (p=0.001), which indicates that the macrofaunal community in turbine and control samples exhibited minimal distinction from each other. The ANOSIM result for Year 2 and Year 3 was not significant, indicating no difference between the turbine and control groups. Similarly, the ANOSIM result for Year 1, 2 and 3 combined, was significant with an R value of 0.084 (p=0.006) indicating that the turbine and control areas exhibited minimal distinction from each other.

Additionally, the SIMPER analysis shows the similarity among all turbine and control samples collected is highest for Year 2 (54.95%), followed by Year 3 (47.01%), and Year 1 (38.92%) (**Table 16**). **Table 16** also shows that a similar suite of species was responsible for the overall similarity within each year group. All the contributing species (70% cut off) in Year 1 and 2 were present in Year 3, mostly polychaetes and nematodes. However, Year 3 had two additional contributing species, namely the family Dorvilledidae (4.77%, including *Parougia caeca*, *Pettiboneia* sp. and *Ophryotrocha* sp.) and *Mytilus edulis* (3.96%).

Total species richness for the Year 2 and Year 3 samples was the only metric that indicated any distinction between grouped turbine (n = 81) and control samples (n = 27, **Table 11**). In Year 2, the turbine areas had a higher species richness (range: 70 to 86 species) compared to the control areas (range: 45 to 61 species). This increase in species richness at the turbine areas was also reflected and more pronounced in Year 3 data. In Year 3, the turbine areas had a higher species richness (range: 76 to 104) compared to the control areas (range: 57 to 69). This pattern was due to the presence of multiple species which occurred only rarely at the turbines (i.e. represented by only one or a few individuals) and increased sampling effort at the grouped turbines compared to the control study areas. When comparing the mean species richness between the combined turbine and combined control study areas, a t-test assuming unequal variances, showed that the control study areas had a significantly higher number of species in Year 2 ($t(42) = -3.3$, $p < 0.001$) and Year 3 ($t(36) = -4.15$, $p < 0.001$).

Table 16. SIMPER results showing average similarity and top contributing species (70% cut-off) across all vessel-based grab samples collected in Year 1, Year 2 and Year 3 at Turbines 1, 3, and 5. Note: Table excludes QC samples collected in Year 1.

	Average similarity	Contributing species (70% cut-off)
Year 1	38.92%	Nematoda (20.98%)
		Polygordius (13.38%)
		Lumbrineries acuta (10.26%)
		Goniadella gracilis (9.26%)
		Polycirrus eximius (7.87%)
		Pisione sp. (7.06%)
		Parapionosyllis longicirrata (4.07%)
Year 2	54.95%	Nematoda (30.44%)
		Polygordius (10.62%)
		Parapionosyllis longicirrata (7.24%)
		Lumbrineries acuta (7.19%)
		Goniadella gracilis (5.83%)
		Polycirrus eximius (4.49%)
		Pisione sp. (4.36%)
Year 3	47.01%	Nematoda (19.26%)
		Polycirrus eximius (13.72%)
		Polygordius spp. (9.61%)
		Lumbrineries acuta (6.94%)
		Pisione sp. (6.70%)
		Dorvilledidae (4.77%)
		Parapionosyllis longicirrata (4.64%)
		Mytilus edulis (3.96%)
		Goniadella gracilis (3.88%)

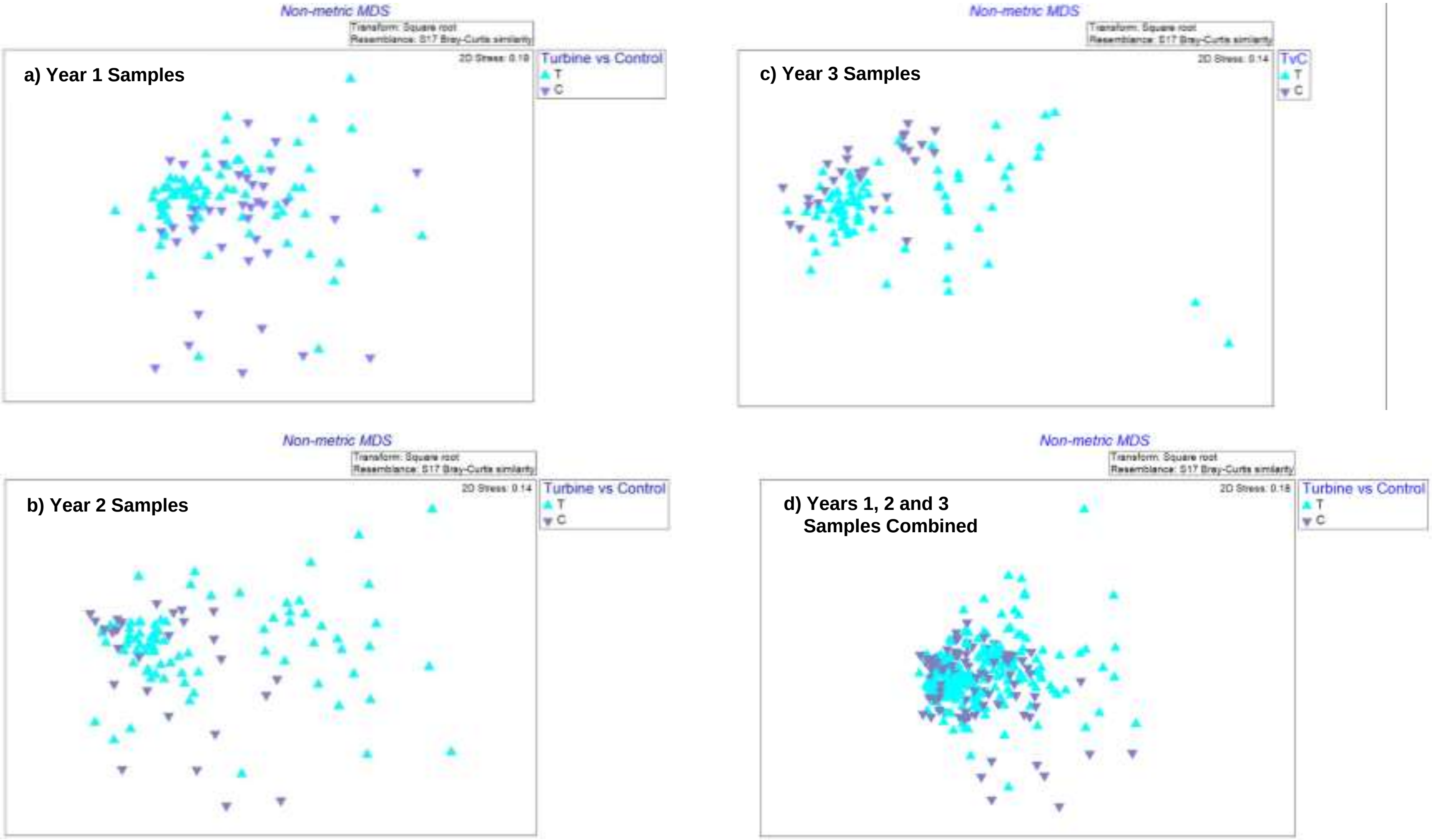


Figure 32. Non-metric MDS plot of Turbine versus control areas for vessel-based grab samples collected in a) Year 1, b) Year 2, c) Year 3, and d) Years 1, 2 and 3 combined.

Note: The plots show the relative (dis)similarity of each sample (indicated by a triangle symbol) to the other samples within the dataset based on its macrofaunal (species and abundance) characteristics. In this instance, each sample is coded (colored) according to sample location (turbine or control area). The plots show that there is no clear distinction between turbine and control sample groups suggesting a degree of similarity in terms of macrofaunal content.

3.1.6.4 Comparison of Individual Turbine and Control Areas

Overall, the data indicate that two null hypotheses can be rejected for samples collected greater than 30 m from the center point of the turbine foundation—that there will be no difference in benthic communities among turbine areas (H_01) and that there will be no difference in benthic communities between control areas and turbine areas (H_02) (see **Section 3.7**). Data supporting these conclusions are presented below. Statistically significant temporal differences between sampling years and spatial differences between study areas (within years) were detected in both the mean number of species and the mean species abundance.

Macrofaunal patterns of mean species richness, species abundance, and the Shannon Weiner index of diversity (H') for each of the study areas for each sampling year are summarized in **Table 17,** and total species richness and abundance is reported in **Table 11**. Macrofaunal patterns of species richness, species abundance, and the Shannon Weiner index of diversity (H'), as well as the spatial distribution of these indices with respect to each of the turbine or control areas for each sampling year, are presented in **Figure 34** through **Figure 42**.

Table 17. Summary of mean macrofaunal indices for vessel-based grab samples collected in Year 1, Year 2 and Year 3. Note: Table excludes QC samples collected in Year 1; and mean species abundance values are provided for (i) all species and (ii) excluding nematodes for Year 2 and Year 3.

		Turbine 1	Turbine 3	Turbine 5	Control areas
Year 1	Mean No. Species	16.6	20.7	17.3	21.8
	Mean Species Abundance	71.8	191.9	182.4	167.0
	Mean Diversity (H)	2.2	2.2	1.	2.3
	Mean Richness (d)	3.8	3.8	3.2	4.4
Year 2	Mean No. Species	19.7	23.7	22.8	25.4
	Mean Species Abundance (exc. nematodes)	181.3 (76.1)	812.0 (211.5)	620.4 (213.9)	676.4 (240.3)
	Mean Diversity (H)	1.8	1.3	1.6	1.7
	Mean Richness (d)	3.8	3.5	3.5	3.9
Year 3	Mean No. Species	24.6	23.9	22.1	28.5
	Mean Species Abundance (exc. nematodes)	616.6 (542.8)	389.1 (264.4)	406.3 (338.7)	445.2 (334.8)
	Mean Diversity (H)	1.86	1.99	1.80	2.16
	Mean Richness (d)	4.09	3.91	3.53	4.56

In Year 1, the mean species richness ranged from 64 to 80 species within a given study area. The mean number of species ranged from 16.6 species to 22.6 species, although the variance around the mean differed considerably, particularly amongst the control samples. Year 2 samples were more variable, with species richness ranging from 45 to 86 species within a given study area and mean number of species ranging between 19.7 at Turbine 1 and 25.3 for the control areas. In Year 3 samples, the mean number of species ranged from 22.1 at Turbine 5 to 28.5 for the control areas.

One-way ANOVAs incorporating the Year 1, Year 2 and Year 3 data showed that there were significant differences in the number of species recorded at the turbine areas and control areas over the years ($F_{(11, 312)} = 11.97$, $p < 0.001$). Post hoc testing revealed that differences in mean number of species were recorded between years (1 and 2, 1 and 3, 2 and 3) and within Years 1, 2 and 3. The following two paragraphs first report the temporal changes in mean species number between years and secondly, report the spatial differences detected between study areas, within years.

Statistically significant temporal changes in mean species number were observed between years. From Year 1 to Year 2, the mean number of species recorded around Turbine 5 significantly increased from 17.3 to 22.8 but was similar between Year 2 and Year 3. From Year 1 to Year 3, the number of species recorded at Turbine 1 and Turbine 5 had both significantly increased. In Year 1, the mean number of species was 16.6 which increased to 24.6 in Year 3 and similarly, at Turbine 5, the mean number of species in Year 1 was 17.3 which increased to 22.1 in Year 3. However, a significant increase in the number of species also was observed in the Year 1 to Year 3 control areas (Y1 mean = 21.8, Y3 mean = 28.5), so that pattern may be indicative of natural variation in the mean number of species, over the three-year period. However, from Year 2 to Year 3, the number of species recorded at the Turbine 1 study area significantly increased from 19.7 to 24.6, independently of the control areas. Mean species numbers for each study area and year is summarized in **Table 17**.

Statistically significant spatial changes were observed within each sampling Year. Within Year 1 and Year 2, the mean species numbers at Turbine 1 (Y1 mean = 16.6, Y2 mean = 19.7) were significantly lower than the control areas (Y1 mean = 21.8, Y2 mean = 25.3) but were not significantly different to the control area in Year 3 (i.e., a similar number were recorded for the first time). However, the mean number of species recorded at Turbine 3 (Y3 mean = 23.9) and Turbine 5 (Y3 mean = 22.1) in Year 3 were significantly lower than the species numbers recorded in the Year 3 Control area (Y3 mean = 28.5). Within each year, the control area had a higher mean number of species than the areas surrounding the Turbines (30-90 m). However, in Year 3, the mean number of species in the area surrounding Turbine 1 increased such that it equilibrated with the control areas (Y3:T1 mean = 24.6, C mean = 28.5), while the mean number of species around Turbine 3 and 5 remained similar or lower (Y3: T3 mean = 23.8, T5 mean = 22.1) . Mean species numbers for each study area and Year is summarized in **Table 17**.

The most notable difference in the three years of sampling was the sharp increase in mean species abundance in Year 3, especially at Turbine 1 (**Table 17**). In Year 1 the mean species abundance ranged from 71.8 (Turbine 1) to 191.9 (Turbine 3), while in Year 2 the mean species abundance (excluding nematodes) range was 76.1 (Turbine 1) to 240.3 (Control). In Year 3 (excluding nematodes) the range increased to 264.4 (Turbine 3) to 542.8 (Turbine 1). Although this increase in mean species abundance was seen in the control areas, the increase at Turbine 1 was much higher between Years 2 and 3. The Turbine 1 study area showed a seven-fold increase compared to a less than two-fold increase at the control area (**Table 17**).

One-way ANOVAs incorporating the Year 1, Year 2 and Year 3 data (all data, no exclusions) showed that there were significant differences in the mean species abundances recorded at the turbine areas and control areas over the three years ($F_{(11, 312)}$= 14.41, $p < 0.001$). Post hoc testing revealed that these differences were between years (1 and 3, 1 and 2, 2 and 3) and within Year 2. The following two paragraphs first report the significant temporal changes in means species abundance between years and secondly, report the significant spatial differences detected between study areas, within years.

Statistically significant temporal changes in abundance were observed. From Year 1 to Year 2, there was a significant increase in the mean abundance recorded in areas surrounding Turbine 3 (Y1 mean = 182.4, Y2 mean = 812) and Turbine 5 (Y1 mean = 182.4, Y2 mean = 620.4). Comparing Year 2 and Year 3, the mean abundance around Turbine 1 was significantly higher in Year 3 (T1: Y2 mean = 181.3, Y3 =616.6) while the mean abundance around Turbine 3 was significantly lower in Year 3 (T3: Y2 mean = 812.0, Y3 mean = 389.1). The mean abundance around Turbine 1 was also significantly higher in Year 3 compared to Year 1 (T1: Y1 mean = 71.8, Y3 mean = 616.6).

Statistically significant spatial changes were observed within Year 2. Within Year 2, the mean abundance was significantly lower around Turbine 1 (mean = 181.3) compared to Turbine 3, (mean = 812.0), Turbine 5 (mean = 620.4) and the control area (mean = 676.4).

The fluctuation in the number of species and number of individuals at each study area over the three sampling years is summarized in **Figure 33**.

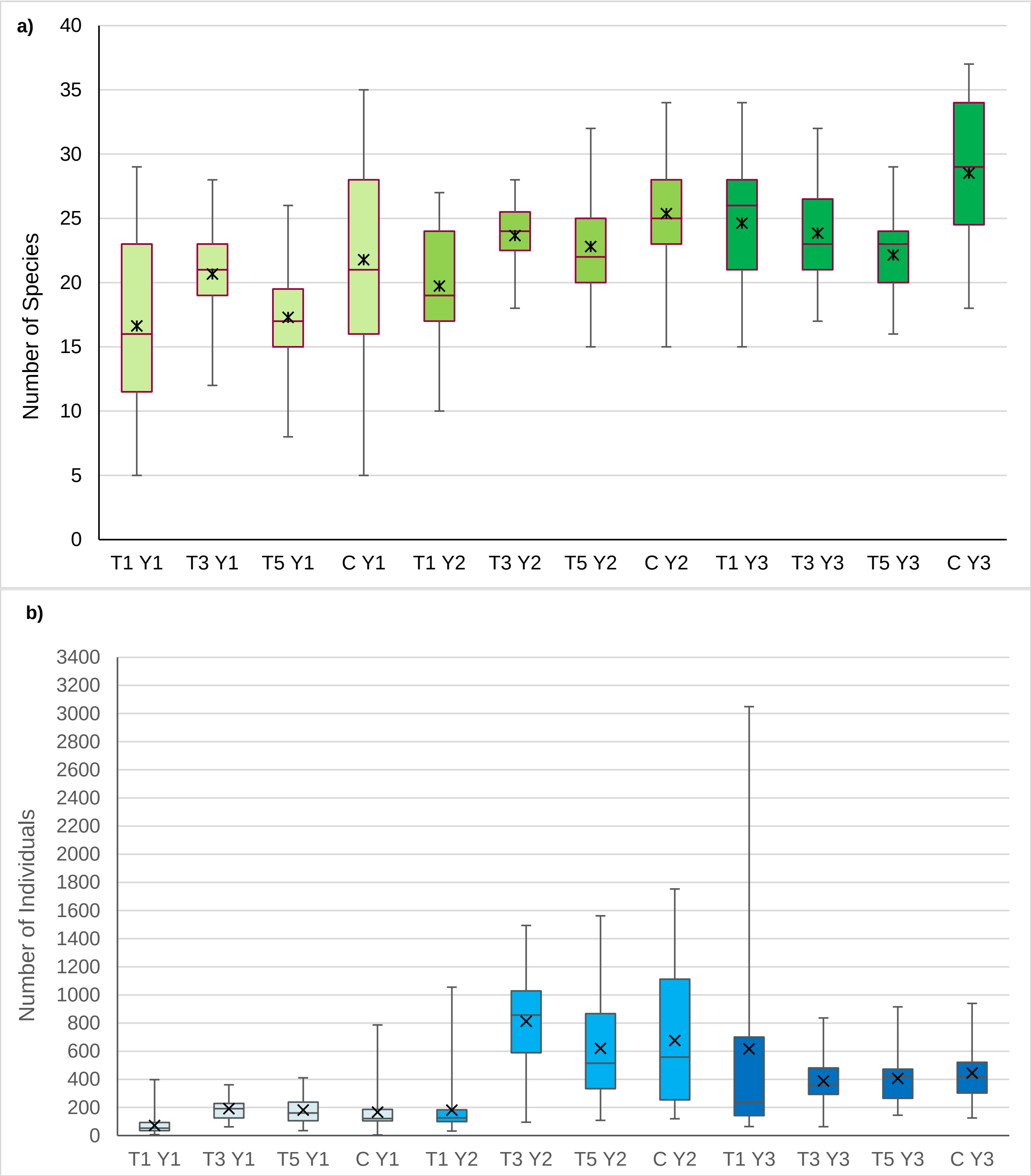


Figure 33. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of a) the number of species and b) the number of individuals at each turbine (T1, T3, T5) and all control (C) areas for vessel-based grab samples collected in Year 1, Year 2 and Year 3.

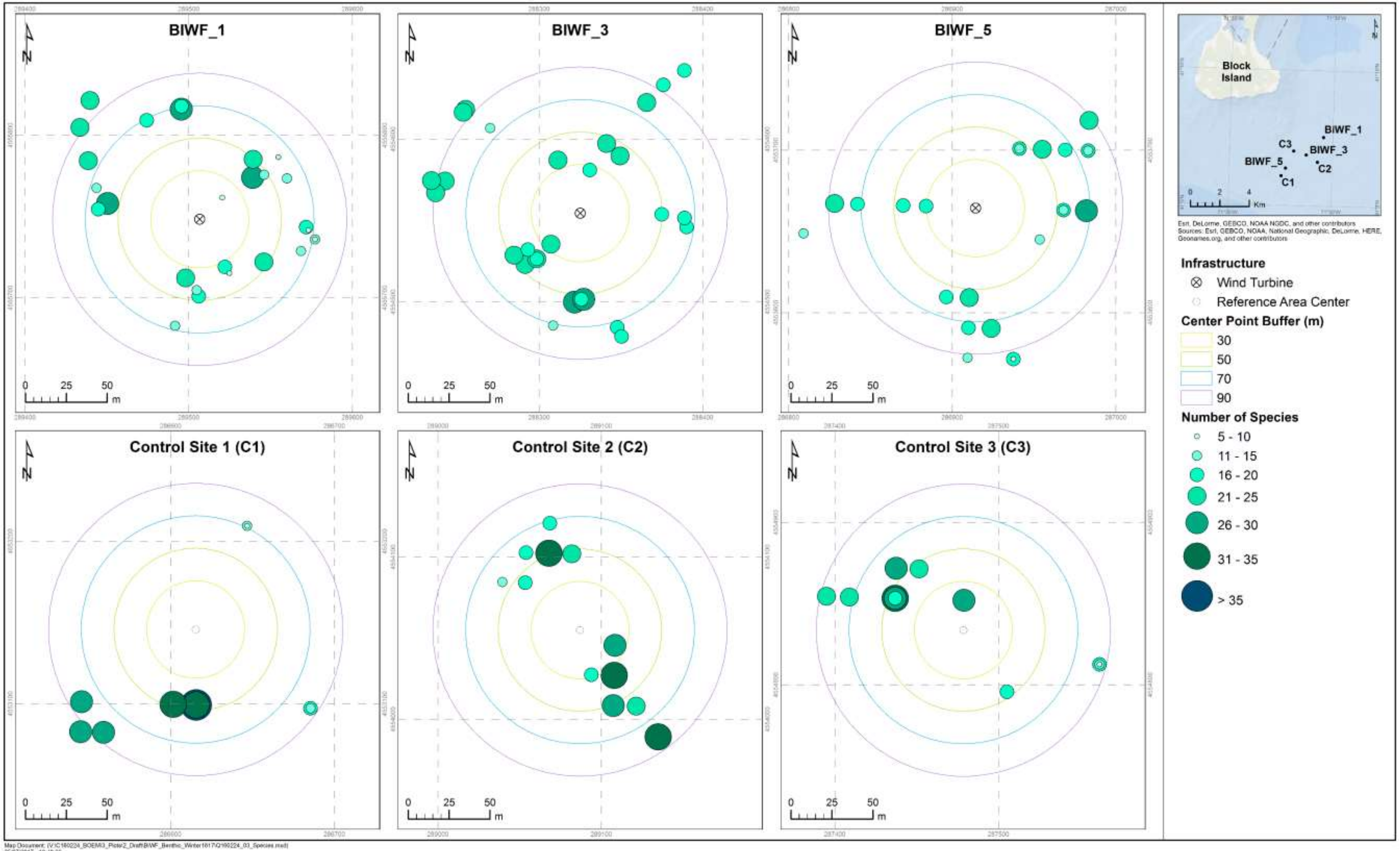


Figure 34. Distribution of numbers of species for vessel-based grab samples collected in Year 1.

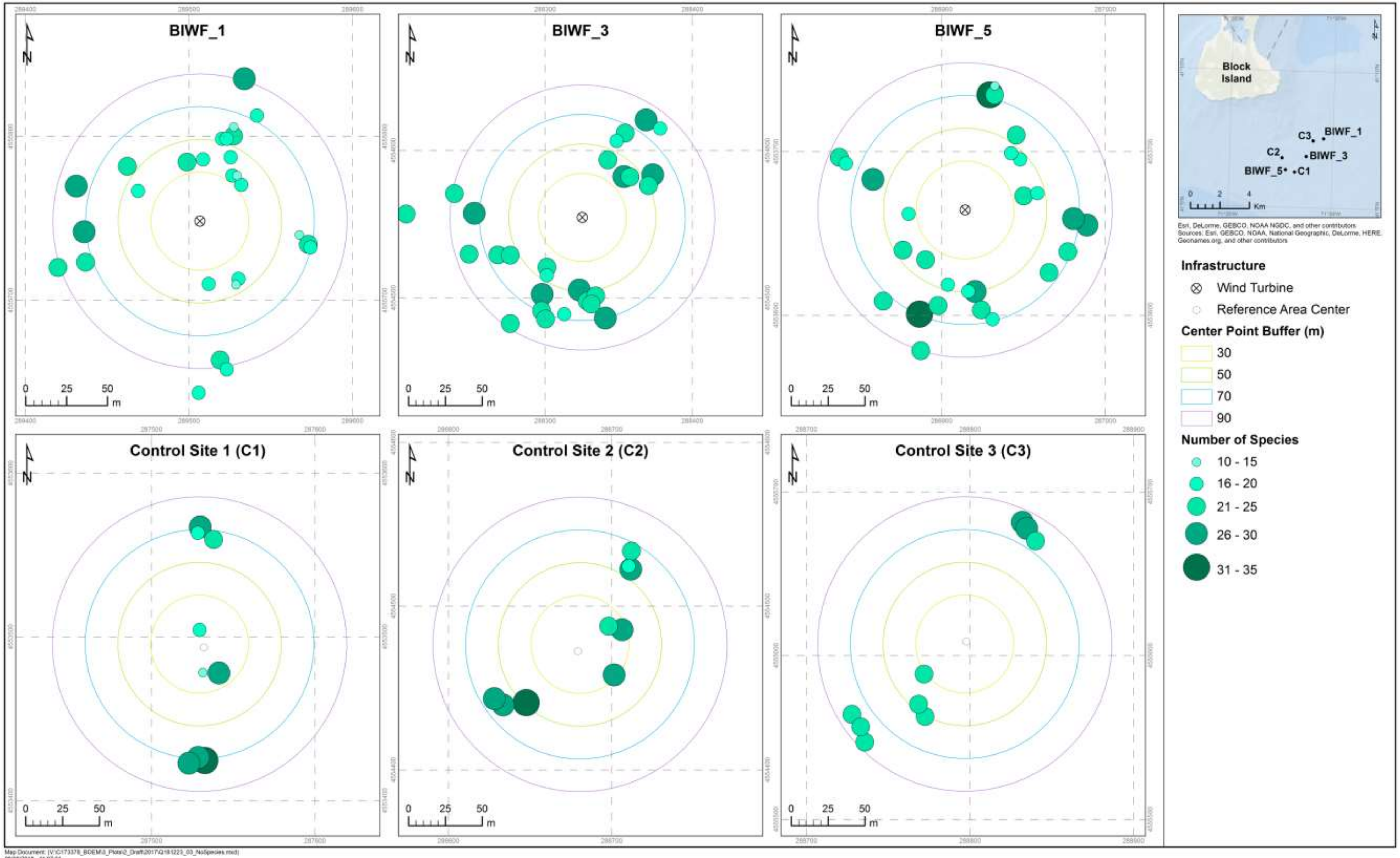


Figure 35. Distribution of numbers of species for vessel-based grab samples collected in Year 2.

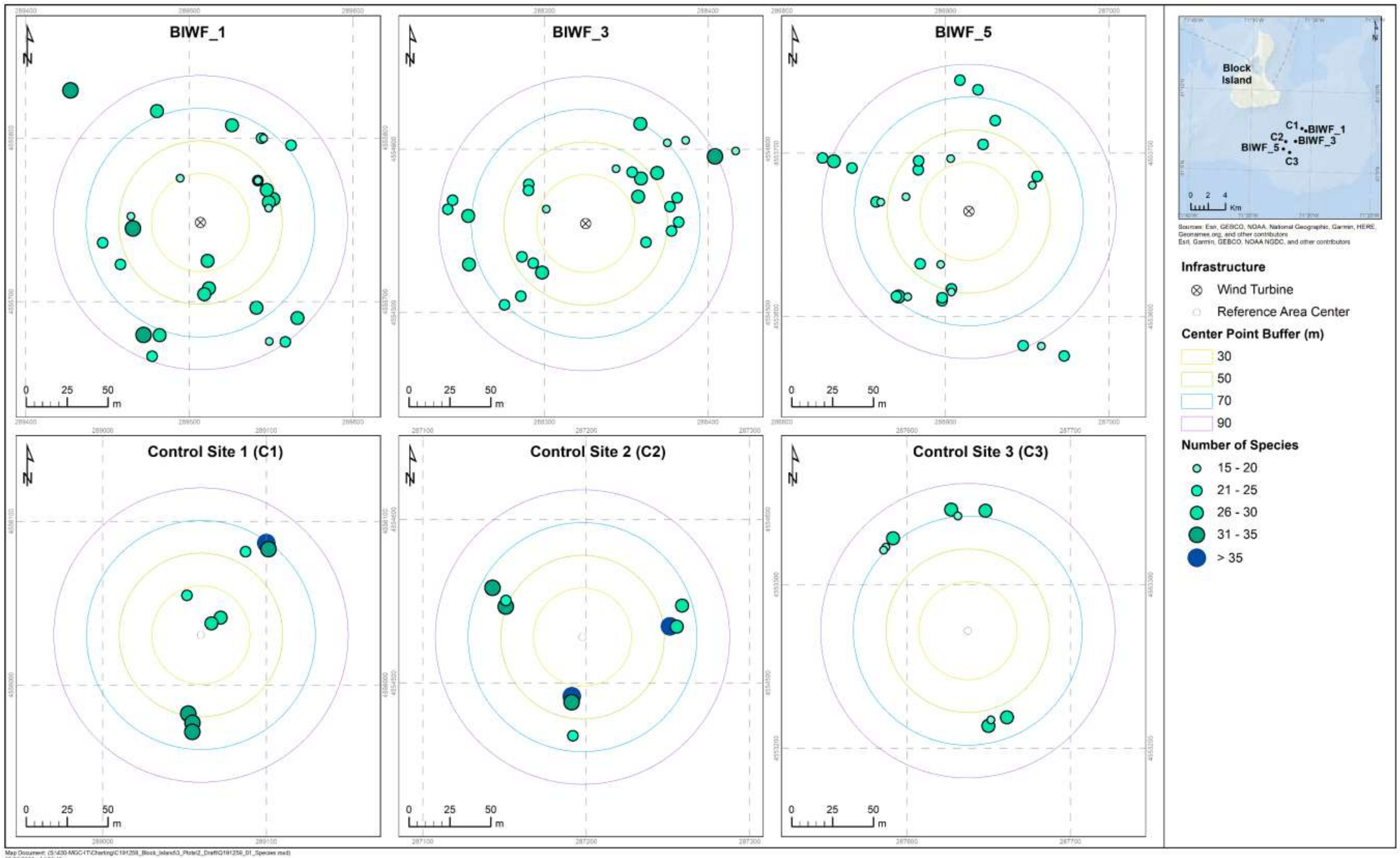


Figure 36. Distribution of numbers of species for vessel-based grab samples collected in Year 3.

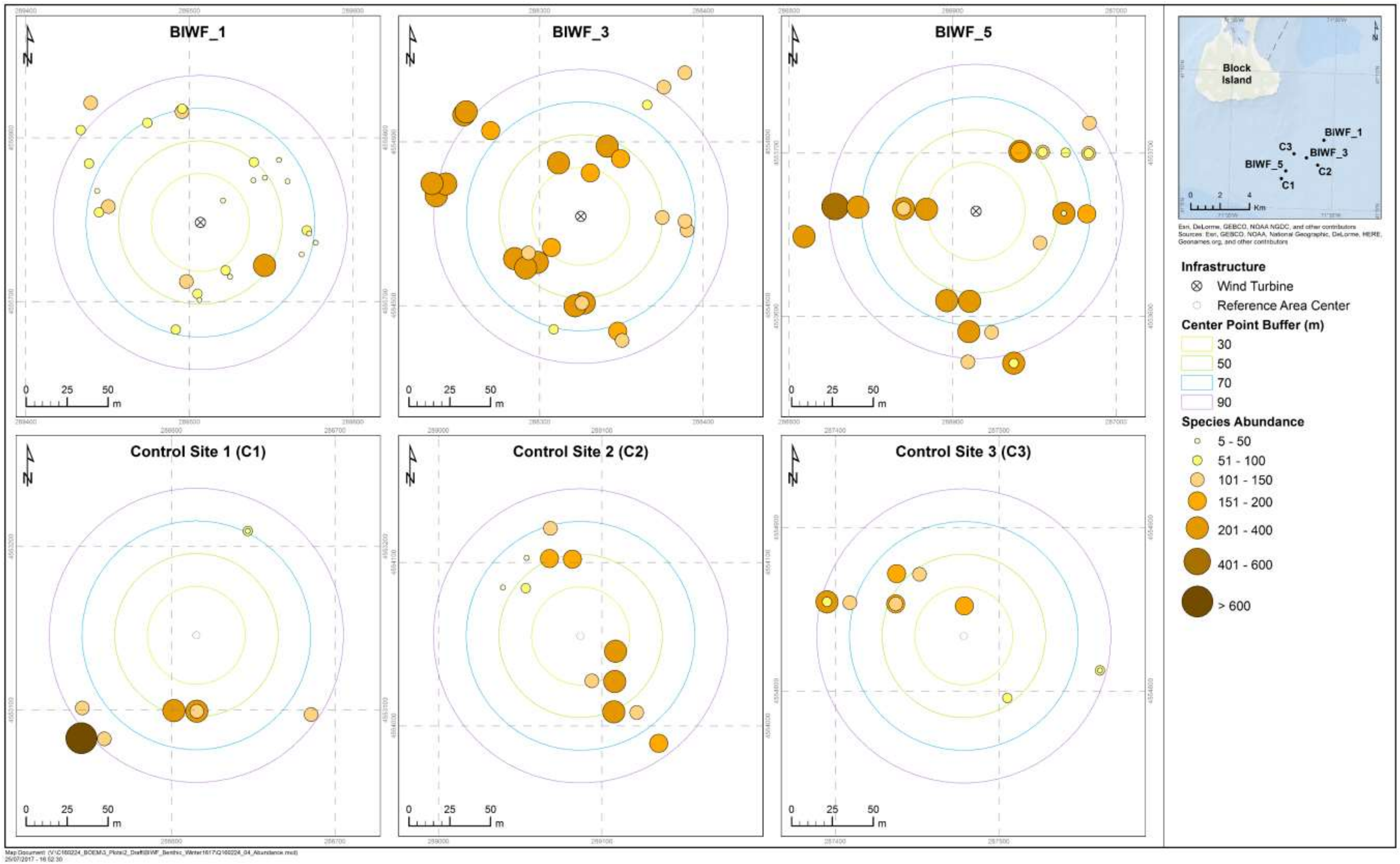


Figure 37. Distribution of numbers of individuals for vessel-based grab samples collected in Year 1.

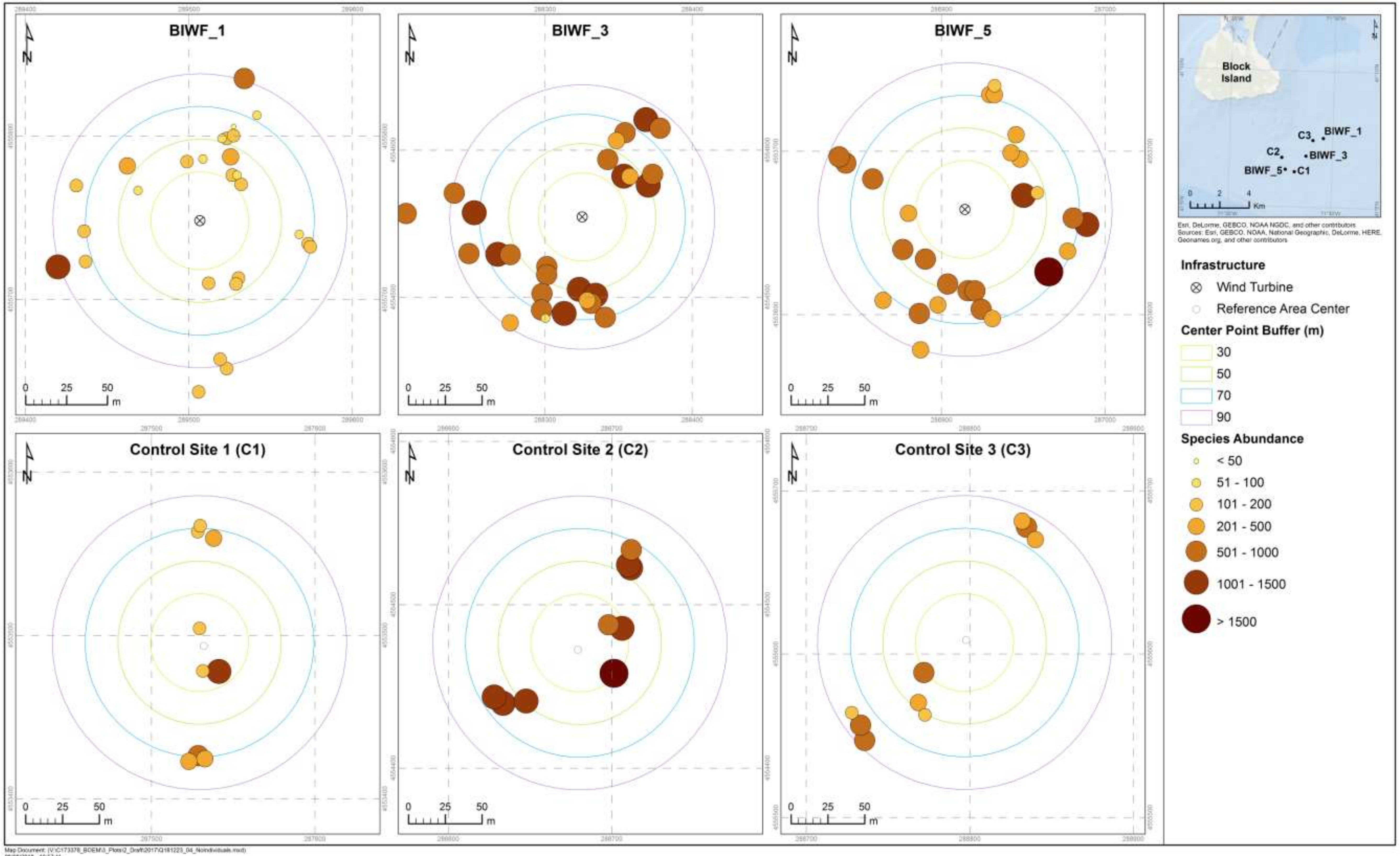


Figure 38. Distribution of numbers of individuals for vessel-based grab samples collected in Year 2.

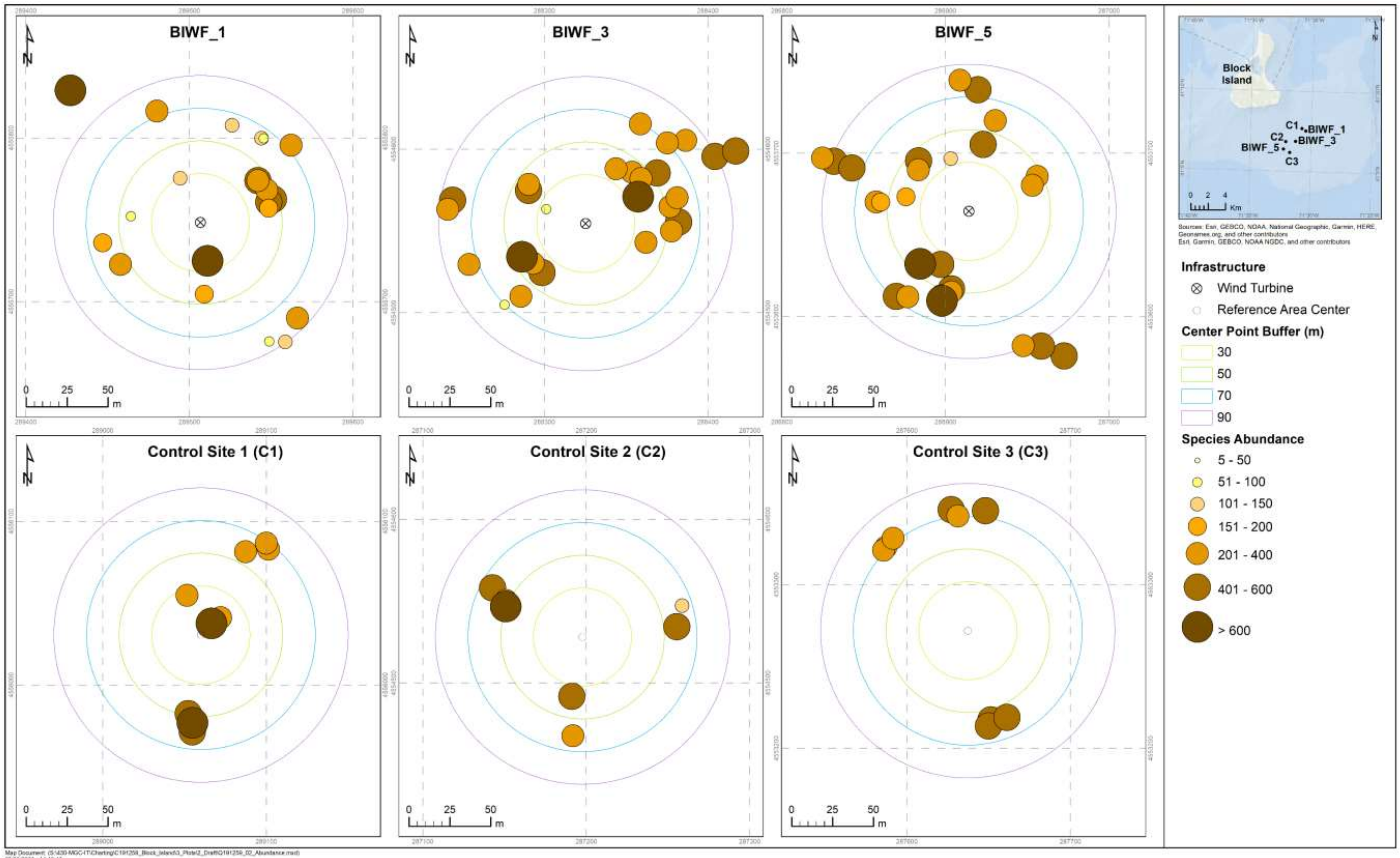


Figure 39. Distribution of numbers of individuals for vessel-based grab samples collected in Year 3.

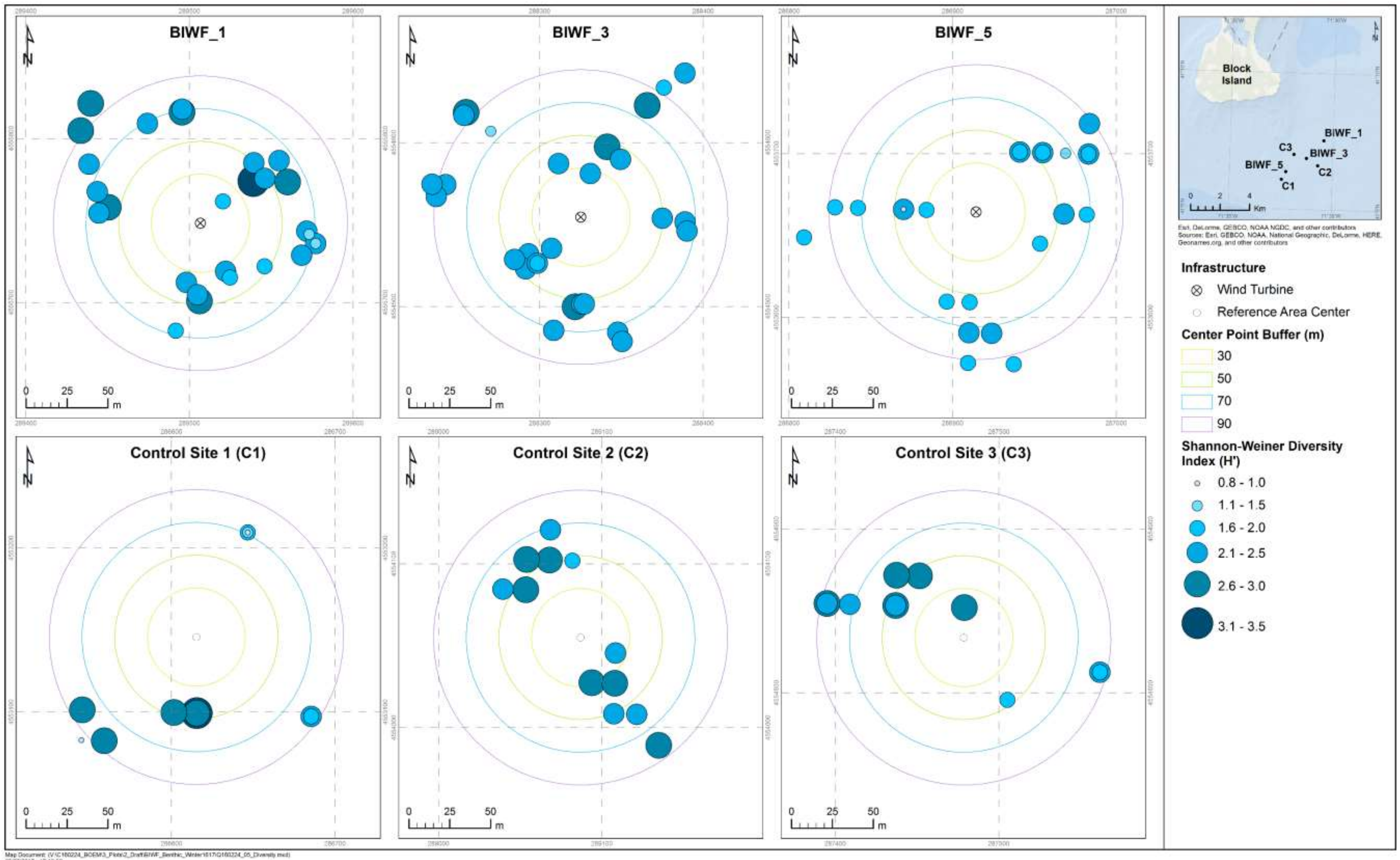


Figure 40. Distribution of the Shannon Weiner index of diversity (H') for vessel-based grab samples collected in Year 1.

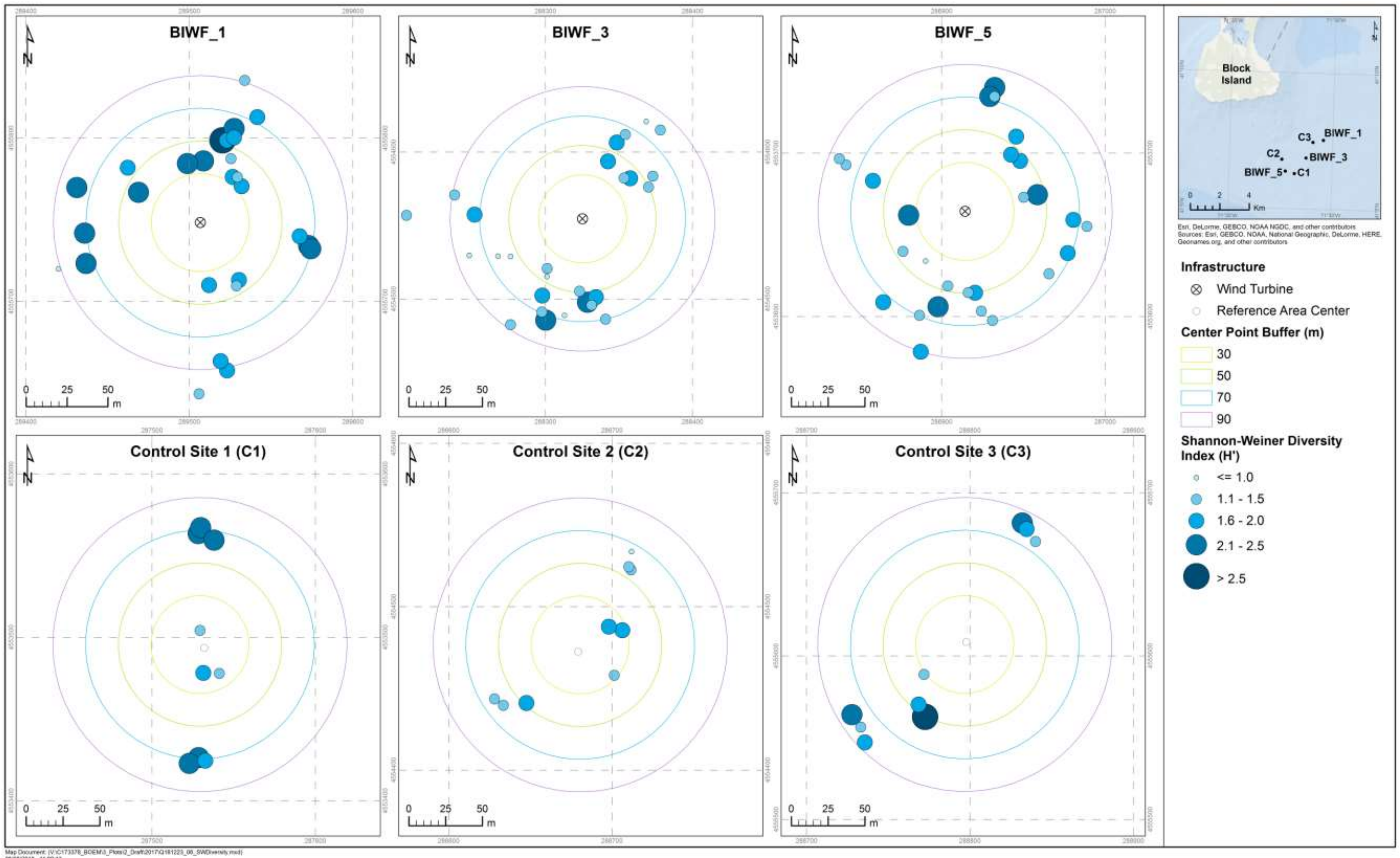


Figure 41. Distribution of the Shannon Weiner index of diversity (H') for vessel-based grab samples collected in Year 2.

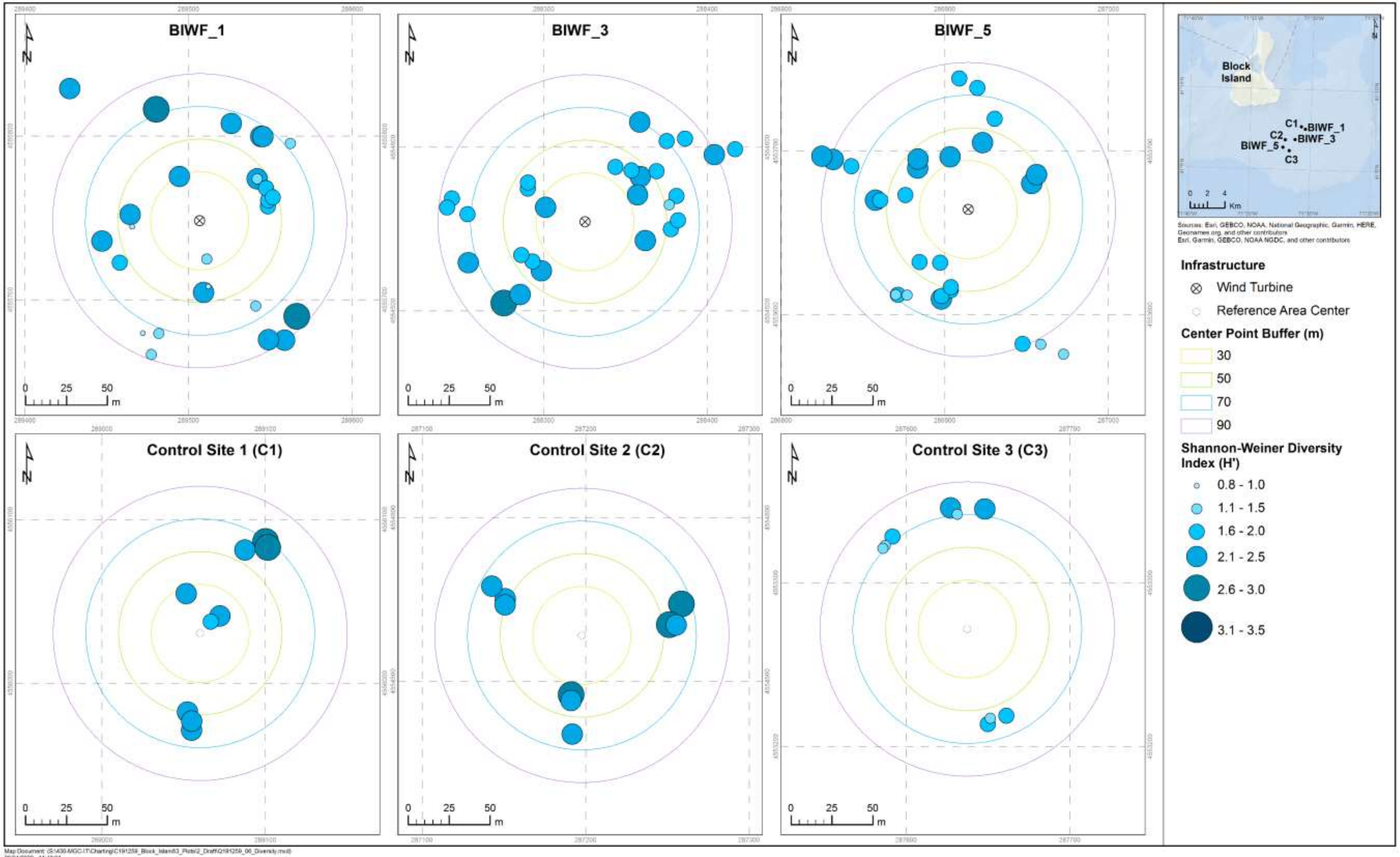


Figure 42. Distribution of the Shannon Weiner index of diversity (H') for vessel-based grab samples collected in Year 3.

Total species abundance (excluding nematodes) varied across each of the turbine areas in all three years. In Year 1, the total abundance was just over double for Turbines 3 and 5 (each approximately 3,600 individuals, excluding nematodes) compared to Turbine 1 (approximately 1,700 individuals) (**Table 11**). Within the control areas combined (n = 27), in Year 1, the combined total abundance was most similar to Turbines 3 and 5, but marginally higher. A similar pattern was evident in Year 2. The total abundance at Turbines 3 and 5 was more than double the abundance at Turbine 1 (approximately 5,700 versus 2,000 individuals, excluding nematodes, **Table 11**). Abundances in the Year 2 controls (combined) were again, most comparable to Turbine 3 and Turbine 5 but remained marginally higher (approximately 6,500 individuals).

The pattern switched in Year 3 and Turbine 1 exceeded the abundance of Turbines 3 and 5 (**Table 11**). Species abundance in Year 3 was almost one third higher at Turbine 1 (approximately 15,000 excluding nematodes) compared to Turbine 5 (approximately 9,000) and nearly double that of Turbine 3 (approximately 7, 000). The total species abundances (excluding nematodes) at the turbines are more variable in Year 3 than in Year 2, whereas abundances at the control areas were more similar (**Table 11**). As in Year 1 and Year 2, the total species abundances at the control areas (combined) continue to be most similar to that of Turbines 3 and 5 in Year 3.

The Shannon diversity index is reported in **Table 17** and **Figure 40** through **Figure 42**. In Year 1, the mean value of the Shannon diversity index (H') was comparable across Turbines 1 and 3 and the combined control areas (ranging between 2.18 to 2.26) but was lower at Turbine 5 (1.84) (**Table 17**). 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 (3.22) (**Table 17**). Mean richness for all the control areas was comparatively a little higher (4.42). Despite overall increases in mean numbers of species, mean diversity (H) values at the turbine and control areas in Year 2 were comparatively lower ranging between 1.3 (Turbine 3) and 1.8 (Turbine 1). The mean control value (1.7) was broadly representative of those calculated for the turbine location suggesting natural conditions. Mean values of Margalef's Richness (d) were similar across the different locations but were slightly lower than those recorded in 2016 ranging between 3.5 (Turbines 3 and 5) and 3.9 (controls).

Comparing the Shannon diversity index (H') for Year 2 and Year 3 data (**Table 17**), Turbine 1 appeared stable (Year 2 = 1.8 and Year 3 = 1.86) whereas Turbines 3 and 5 both increased (Year 2 = 1.3 and 1.6, Year 3 = 1.99 and 1.80, respectively). The increase in diversity index also was observed at the control areas (Year 2 = 1.7, Year 3 = 2.16) and is therefore indicative of natural variation. Therefore, the Turbine 1 diversity index did not follow the trend observed at the other turbines and control study areas. In Year 3, the highest mean richness (d) was observed at the control areas followed by Turbines 1 and 3, and the lowest score was recorded at Turbine 5.

Assessment of macrofaunal community structure using nMDS plots also indicate that the individual study areas were broadly comparable in Year 1 but differences emerged in Years 2 and 3 (**Figure 43)**. The most noticeable difference between Years 1 and 2 is that Year 2 samples were generally more cohesive within each individual study area (e.g., have higher within-study area similarities and lower among-study area dissimilarities), whereas the Year 1 samples showed more overall variability (**Table 18, Figure 43**). This is again emphasized in Year 3, where there appeared to be stronger macrofaunal community similarity within the individual study areas. However, for all three sampling years, Turbine 1 had noticeably more spread in the sample spacing indicating more macrofaunal community variability between samples. Also, the Turbine 1 samples separate out more from the Turbines 3 and 5 samples in all years, especially in Year 3, indicating a more distinct community composition. In Year 3, the average similarity is reduced compared to Year 2 at Turbine 1, whereas comparisons between Turbine 3 and Turbine 5 remains stable.

Table 18. SIMPER results of vessel-based grab samples collected within each turbine and control area in Year 1, Year 2 and Year 3 (see Figure 32 below for associated nMDS plot).

Average similarity within stations (%)					Average dissimilarity between stations (%)			
Station	Year 1	Year 2	Year 3		Station	Year 1	Year 2	Year 3
T1	38.91	55.33	44.20		T1, T3	66.47	57.14	65.28
T3	62.49	69.95	64.60		T1, T5	70.32	58.91	69.69
T5	50.49	66.80	63.54		T3, T5	48.56	33.6	39.08
C1	36.32	54.68	66.27		T1, C1	76.19	60.5	56.70
C2	51.11	75.15	62.77		T3, C1	67.03	47.28	53.00
C3	48.52	68.14	63.97		T5, C1	66.18	44.42	61.99
T1 and T3	41.96	52.94	44.47		T1, C2	63.85	62.98	65.27
T1 and T5	37.05	51.23	41.87		T3, C2	52.8	30.51	40.14
T3 and T5	53.92	67.58	62.46		T5, C2	61.9	35.26	45.51
--	--	--	--		C1, C2	71.53	47.7	46.90
--	--	--	--		T1, C3	61.67	50.64	73.02
--	--	--	--		T3, C3	61.8	39.84	43.31
--	--	--	--		T5, C3	66.21	42.68	39.52
--	--	--	--		C1, C3	72.91	48.37	62.30
--	--	--	--		C2, C3	59.11	40.76	45.67

Variable cohesivity between samples within Years 1, 2 and 3 also is reflected in the average values of the multivariate dispersion between samples within each year group (calculated from Permdisp, **Table 19**. The Year 2 samples exhibited a lower average dispersion (average dispersion = 32.20) compared to that calculated between the Year 1 samples (average dispersion = 43.05) while the Year 3 samples were intermediate (average dispersion = 37.22) thus collaborating the nMDS observations above. Examination of **Figure 43** suggests that the dispersion amongst some of the Turbine 1, Turbine 5, and control samples is lower in Year 2 and Year 3 compared to that in Year 1 and likely contributes to the apparent improvement in sample cohesiveness.

Table 19 shows results from pairwise tests between study areas within years (i.e., spatial comparisons) and differences between study areas throughout the three-year sampling period (i.e., temporal comparisons). The Permanova analyses detected significant differences in the macrofaunal assemblages existing between the turbine areas within Year 2 and Year 3 and between turbine areas and control areas for both Year 2 and Year 3. Permdisp was also significant ($F=28.91$, $p<0.001$), indicating a potential effect of dispersion in this respect. Pairwise tests of macrofaunal assemblages within each turbine study area were also significantly different across sampling Years 1, 2 and 3; however, the control areas also showed this trend. In this scenario, it is useful to consider the degree of similarity in macrofaunal assemblages (**Table 18**) and species composition in the study areas (**Table 20**).

For all years, the nMDS plots suggest macrofaunal community composition changes along a gradient moving across the BIWF study area from Turbine 1 to 5 (**Figure 43**). The control samples generally plot among the turbine samples and occupy the sample relative position on the plot from Year 1 to Year 2 (**Figure 43**). For example, in Years 1 and 2, the Control 3 samples plot midway between the Turbine 1 samples and the Turbines 3 and 5 samples, while the Control 2 samples exhibited some overlap with the Turbine 3 and 5 samples. This reflects their geographical spatial position (**Figure 7**). A similar pattern was seen in Year 3 in that the spatial position of the controls reflects the macrofaunal community of the closest Turbines (**Figure 43**). For example, in Year 3, Control 2 and 3 samples were most similar to their neighboring turbines, Turbines 3 and 5, as represented by the overlap in the nMDS plots.

Table 19. Summary of the Permanova analysis of the BIWF macrofauna data for pairwise tests between location and years, for Turbine and Control groups. BOLD denotes a significant difference.

	Pairwise tests		t	P(perm)	Unique perms
Spatial tests Yr 1	T1 Yr1	T3 Yr1	4.4859	**0.0001**	9927
	T1 Yr1	T5 Yr1	3.9501	**0.0001**	9934
	T3 Yr1	T5 Yr1	2.5803	**0.0001**	9929
	T1 Yr1	Control Y1	2.3442	**0.0001**	9912
	T3 Yr1	Control Y1	3.2733	**0.0001**	9919
	T5 Yr1	Control Y1	2.9215	**0.0001**	9916
Spatial tests Yr 2	T1 Yr2	T3 Yr2	5.6208	**0.0001**	9925
	T1 Yr2	T5 Yr2	5.7174	**0.0001**	9935
	T3 Yr2	T5 Yr2	1.9782	**0.0005**	9919
	T1 Yr2	Control Y2	4.5816	**0.0001**	9920
	T3 Yr2	Control Y2	2.2228	**0.0003**	9928
	T5 Yr2	Control Y2	2.1688	**0.0004**	9910
Spatial tests Yr 3	T1 Yr3	T3 Yr3	5.1804.	**0.0001**	9935
	T1 Yr3	T5 Yr3	5.1877	**0.0001**	9923
	T3 Yr3	T5 Yr3	2.1703	**0.0001**	9915
	T1 Yr3	Control Y3	3.9591	**0.0001**	9925
	T3 Yr3	Control Y3	2.5093	**0.0001**	9944
	T5 Yr3	Control Y3	3.9591	**0.0001**	9925
Temporal test Yr 1-3	T1 Yr1	T1 Yr3	5.8144	**0.0001**	9934
	T3 Yr1	T3 Y3	4.2352	**0.0001**	9932
	T5 Yr1	T5 Y3	3.6394	**0.0001**	9925
	T1 Yr1	T1 Yr2	3.1095	**0.0001**	9913
	T3 Yr1	T3 Yr2	5.4278	**0.0001**	9923
	T5 Yr1	T5 Yr2	4.3459	**0.0001**	9936
	T1 Yr2	T1 Yr3	3.3038	**0.0001**	9904
	T3 Yr2	T3 Yr3	4.3425	**0.0001**	9931
	T5 Yr2	T5 Yr3	4.2398	**0.0001**	9922
	Control Yr1	Control Yr2	3.7641	**0.0001**	9913
	Control Yr1	Control Yr3	3.4581	**0.0001**	9917
	Control Yr2	Control Yr3	2.7389	**0.0001**	9946

In the nMDS plots (**Figure 43**), the strongest degree of separation is between the Control 1 samples and other study areas, in all years, especially in Year 1. The separation of samples in Control 1 in Year 1 likely reflects a more distinct macrofaunal community structure because of clear differences in environmental characteristics and spatial distance, relative to the other study areas, most notably the presence of boulders and coarser substrates (as identified in the video footage and acoustic data) and shallower water depths, rather than activities associated with the BIWF project. The Year 3 Control 1 samples are noticeably tightly grouped (**Figure 43**), indicating a level of high macrofaunal community similarity among these samples.

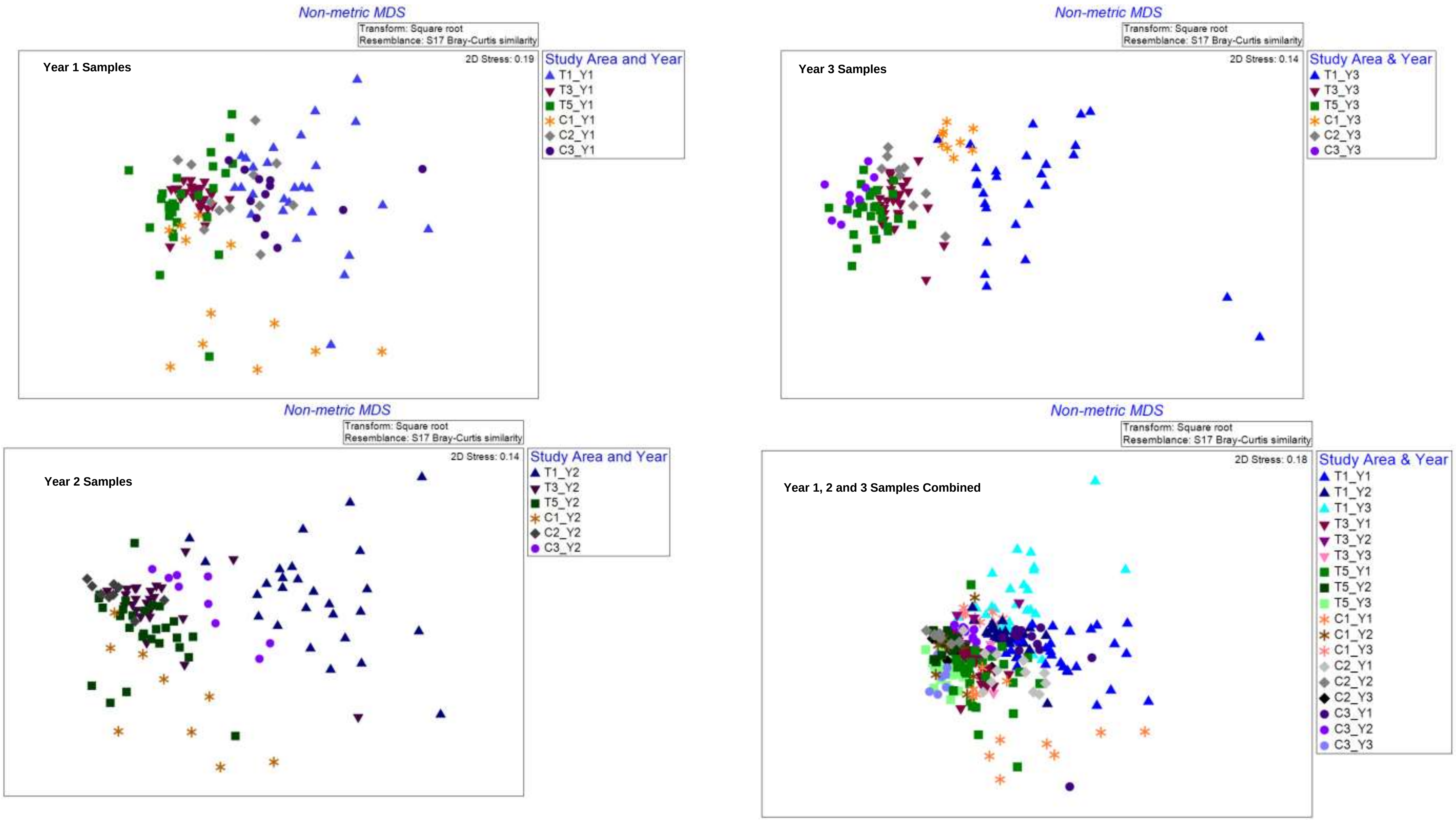


Figure 43. Non-metric MDS plot of vessel-based grab samples collected within each turbine and control area in Year 1, 2, and 3, and in all 3 years combined.

When comparing all three sample years together, in one nMDS plot, the samples exhibit a high degree of overlap, indicating similarity throughout the study area over the three sampling Years. However, the divergence in the Turbine 1 samples is apparent (**Figure 43**). A closer inspection of the species composition using SIMPER analyses, provides insights.

With regards to the turbine areas, the nMDS plots indicate that macrofaunal communities within Turbine 1 are more variable for all years (**Figure 43**). This finding is supported by the SIMPER results (**Table 18**), which state samples within Turbine 1 exhibit the lowest average similarity (Year 1 = 38.91%; Year 2 = 55.33%; Year 3 = 44.20%) in comparison to Turbine 3 (Year 1 = 62.49%; Year 2 = 69.95%; Year 3 = 64.60%) and Turbine 5 (Year 1 = 50.49%; Year 2 = 66.80%; Year 3 = 63.54). This is again corroborated by the greater average values for multivariate dispersion (Permdisp) for Turbine 1 samples for both years compared to the other turbine and control groups.

There is also substantial evidence in all years to indicate macrofaunal communities at Turbines 3 and 5 were more similar to one another relative to Turbine 1 (e.g., refer to **Table 11, Table 15, Table 17 to Table 20, Figure 34,** and **Figure 43**). Specifically, the nMDS plots in **Figure 43** show the Turbine 1 samples separate out from the samples collected at Turbines 3 and 5, especially in Year 2 and in Year 3. Conversely, Turbines 3 and 5 samples are clustered together and overlap for all years. The SIMPER results complement the nMDS plots, reporting the lowest average dissimilarity between Turbines 3 and 5 (Year 1 = 48.56%; Year 2 = 33.6%; Year 3 = 39.08%) (**Table 18**).

Comparatively, the average dissimilarity was greater between Turbines 1 and 3 (Year 1 = 66.47%; Year 2 = 57.14%; Year 3 = 65.28%), and between Turbines 1 and 5 (Year 1 = 70.32%; Year 2 = 58.91%; Year 3 = 69.69%). Further, when combining the Turbines 3 and 5 samples, SIMPER reported an average similarity of 53.92%, 67.58% and 62.46% for Year 1, Year 2 and Year 3, respectively. Comparatively, the combined averaged similarities were noticeably lower for Turbines 1 and 3 (Year 1 = 41.96%; Year 2 = 52.94%; Year 3 = 44.47%) and for Turbines 1 and 5 (Year 1 = 37.05%; Year 2 = 51.23%; Year 3 = 41.87%).

The results of the ANOSIM analyses mimic the patterns identified in the nMDS plots and SIMPER analyses. ANOSIM reports similar R values for each year (Year 1 = 0.459; Year 2 = 0.453; Year 3 = 0.45, each $p = 0.001$), which suggests there was a distinction within each of the six areas in each year. Turbines 3 and 5 continued to exhibit the lowest degree of distinction (R: Year 1 = 0.251, Year 2 = 0.133, Year 3 = 0.221; $p = 0.001$), compared to Turbines 1 and 3 (R: Year 1 = 0.582, Year 2 = 0.729; Year 3 = 0.671; $p = 0.001$) and Turbines 1 and 5 (R: Year 1 = 0.552, Year 2 = 0.792; Year 3 = 0.76; $p = 0.001$). This result was particularly pronounced in Year 2 and Year 3.

A closer inspection of the species characterizing each turbine and control area shows high agreement in dominant species and general composition across all sampling years and across the different study areas (**Table 20** and **Table 21).** Dominant species in all years included nematodes, *Goniadella gracilis*, *Polycirrus eximius*, *Polygordius* spp., *Lumbrinereis acuta*, *Pisione* sp., and *Unciola irrorata*, all of which were common to two or more of the turbine and/or control areas (control areas not listed in **Table 20** and **Table 21**). Conspicuous differences in species identities between areas or sampling years were not apparent in Year 1 and Year 2. However, in Year 3, the barnacle *Balanus* sp. and bivalve *M. edulis* became the top two dominant species at Turbine 1 but were not listed for Turbines 3 or 5. Similarly, *L. acuta* was listed fifth at Turbines 3 and 5, and Dorvilleidae spp was listed fourth at Turbine 5, but the species were not listed elsewhere in any sampling years.

With respect to sampling years, four of the five dominant species at each of the turbines in Year 1 continued to dominate in Year 2 (**Table 20**). In all years, the most dominant polychaete at Turbine 3 and 5 was *P. eximius.* In Year 2, within the top five, the polychaete, *Parapionosyllis longicirrata* became a dominant species at Turbines 3 and 5, replacing the polychaete, *L. acuta*. Although both species also were present in high abundances for Year 2, they were not listed in the top five but became dominant again in Year 3 (Turbines 3 and 5, **Table 20**). *Parapionosyllis longicirrata* also replaced the polychaete, *Sabellaria vulgaris*, at Turbine 1 in Year 2 but was absent from the top five in Year 3.

The disappearance of *S. vulgaris* from the current dataset for Turbine 1 likely was attributable to the patchy distribution of the species; it did not become dominant again in Year 3. *Goniadella gracilis* remained dominant and within the top five over the three-year period but only at Turbine 1. Collectively, *Polycirrus eximius*, *Polygordius* sp. and *Pisione* sp. were consistently dominant throughout the three-year period. In Year 3, the three turbines did not have a common polychaete species but did share the nematode dominance. Turbines 1 and 3, shared the dominant polychaete *Polygordius* spp. and Turbines 3 and 5 shared both *Pisione* sp. and *L. acuta*.

For the turbine areas in Year 1 and 2, for a given year, four of the same species dominated within Turbines 3 and 5, three of which were dominant at Turbine 1. The most apparent difference across turbine areas was the variation in the abundances of these dominant species (**Table 20**). This pattern was consistent from Year 1 to Year 2. The discrepancy in species abundances, rather than the species composition, between areas likely accounts for the differences in macrofaunal community structure identified in the ANOSIM tests. In Year 3, only one species was common to all turbines, although there were two species in common between Turbines 1 and 3, and four in common between Turbines 3 and 5.

Table 20. Numerically dominant species for vessel-based grab samples collected within each turbine area for Year 1, Year 2 and Year 3. Note: Asterisk denotes species listed in all years, within turbine study areas.

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

Table 20. Numerically dominant species for vessel-based grab samples collected within each turbine area for Year 1, Year 2 and Year 3. Note: Asterisk denotes species listed in all years, within turbine study areas.

Sampling period	Study area	Dominant species	Taxonomic group	Abundance	Occurrence (n = 27)
	Turbine 5	*Nematoda**	Nematode	10,974	25
		*Polycirrus eximius**	Polychaete	876	27
		*Pisione**	Polychaete	786	27
		*Polygordius**	Polychaete	742	27
		Parapionosyllis longicirrata	Polychaete	741	27
Year 3	Turbine 1	*Balanus* spp.	Barnacle	6,381	23
		Mytilus edulis (juveniles)	Bivalve	5,283	21
		Nematoda spp.*	Nematode	1,992	26
		Polygordius spp.*	Polychaete	824	24
		*Goniadella gracilis**	Polychaete	265	24
	Turbine 3	*Nematoda* spp.*	Nematode	3,376	27
		*Polycirrus eximius**	Polychaete	3,073	27
		Pisione sp*	Polychaete	746	27
		Polygordius spp.*	Polychaete	715	27
		Lumbrinereis acuta	Polychaete	471	25
	Turbine 5	*Polycirrus eximius**	Polychaete	4,868	27
		Nematoda spp.*	Nematode	1,825	26
		Pisione sp.*	Polychaete	1,158	27
		Dorvilleidae spp	Polychaete	490	26
		Lumbrinereis acuta	Polychaete	385	25

Table 21. Summary of top contributing species (70%) from the SIMPER analysis and mean numbers from the vessel-based grab samples to compare species identities across turbine and control areas (untransformed data) for Years 1, 2 and 3.

Turbine 1		Turbine 3		Turbine 5		Controls	
Species	**Mean No.**	**Species**	**Mean No.**	**Species**	**Mean No.**	**Species**	**Mean No.**
Year 1							
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* spp.	7.14
Polygordius spp.	6.3	*Pisione* sp.	23.89	*Polygordius* spp.	31.85	*Goniadella gracilis*	10.97
Unciola irrorate	3.7	*Lumbrinereis acuta*	17.63	--	--	*Lumbrinereis acuta*	9.44
Nephtys bucera	2.11	*Polygordius*	17.81	--	--	*Unciola irrorata*	6.61
Sabellaria vulgaris	14.15	--	--	--	--	--	--
Year 2							
Nematoda	105.19	Nematoda	600.52	Nematoda	406.44	Nematoda	436.07
Polygordius spp.	20.04	*Polycirrus eximius*	31.04	*Polycirrus eximius*	32.44	*Pisione* sp.	26.07
Goniadella gracilis	11.22	*Pisione* sp.	27.07	*Pisione* sp.	29.11	Polygordius spp.	23.7
Year 3							
Nematoda	73.78	Nematoda	121.90	*Polycirrus eximius*	180.54	Nematoda	110.41
Balanus spp.	234.00	*Polycirrus eximius*	120.27	Nematoda	63.96	*Polycirrus eximius*	102.63
Polygordius spp.	30.52	*Pisione* sp.	29.70	*Pisione* sp.	42.21	*Polygordius* spp.	30.74
Mytilus edulis	198.33	--	--	--	--	*Unciola irrorata*	21.15
--	--	--	--	--	--	*Lumbrinereis acuta*	18.22

Interest in determining the patters of *M. edulis* presence within the 30 to 90 m area was intiated due to increased observations of mussels within close ranges of the turbine in Year 2. The presence of *M. edulis* on the turbine foundation structures (**Section 3.5**) and the development of mussel aggregations within the turbine footprints and very near-field area as evidenced by the seabed photography (**Section 3.2.3**) and diver-based sampling (**Section 3.2**) was observed throughout the course of the sampling regime, particularly in Years 2 and 3. Within the 30 to 90 m sampling area, *M. edulis* also became listed as one of the top contributing species (**Table 21**) and ranked one of the most numerically dominant species in Year 3 (**Table 20**). For that reason, a closer look at *M. edulis* presence and abundance within the 30 to 90 m are was warranted.

As evidenced by **Figure 44**, *M. edulis* were present in samples from each study area in Year 1 but in low numbers from each study are (<10 samples). A lower frequency of mussels in samples was recorded in Year 2 but in Year 3, the frequency of mussel had substantially increased in the 30 to 90 m area across al study areas but was most pronounced at the 30 to 90 m areas surrounding Turbine 1. The mean abundance of mussels was 198 individuals per sample (standard 0.06 m^2 area). A closer inspection of the data indicated that the density of mussels was highly variable within the Year 3 samples ranging from zero to 1,720 individuals per sample. Specifically, three samples had high abundances of juvenile mussels (>800 to 1,800 individuals per sample) while two samples had an unsually high number of adult mussels (>25 individuals, 3.0 to 5.0 cm). All of these samples with high abundances of mussels occurred in samples around Turbine 1 as shown in **Figure 45**, although *M. edulis* also was present around Turbines 3 and 5. Comparing **Figure 45** with the distribution of organic matter demonstrates that the samples with the highest mussel abundances also are the samples with the highest degree of organic enrichment (**Figure 28**, **Section 3.2.4**) and futher, those samples were also subject to the strongest degree of sediment fining as shown in **Figure 23, Section 3.2.2**. As such, there is evidence of patches of strong change occurring within the 30 to 90 m sampling area. Seabed video collected while grab sampling (**Section 3.1.3**) further supports that these areas may not be small isolated patches but that the sampling may have captured a larger area of change characterized by dense mussel aggregations (**Figure 46**).

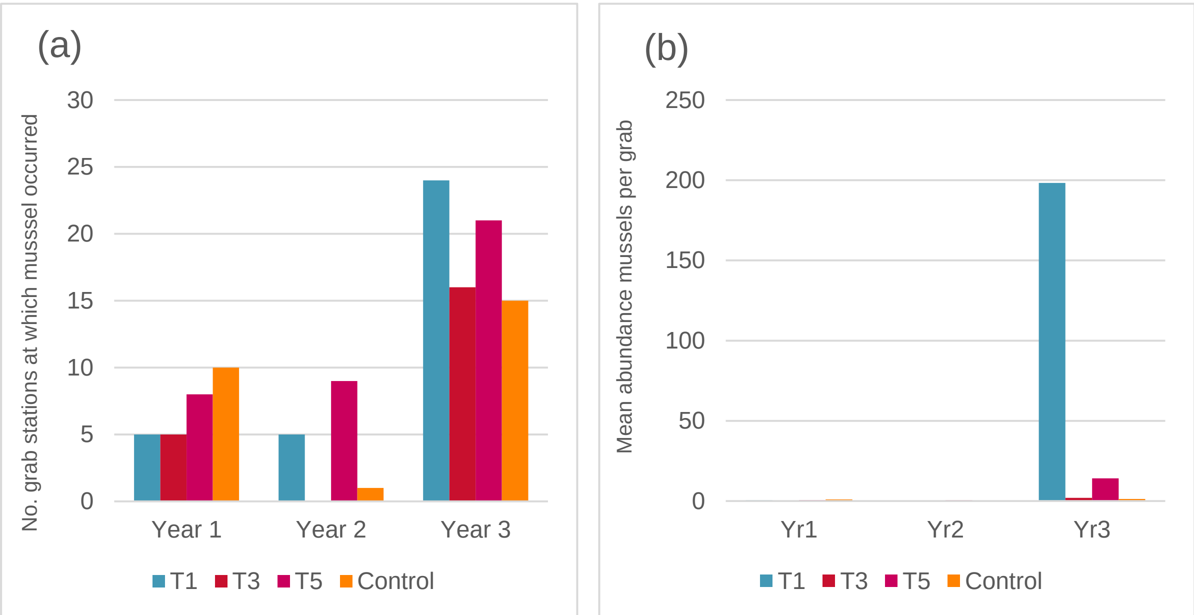


Figure 44. Occurrence (a) and mean abundance (b) of mussels (*Mytilus* sp.) at vessel-based grab sample stations over the three-year monitoring period.

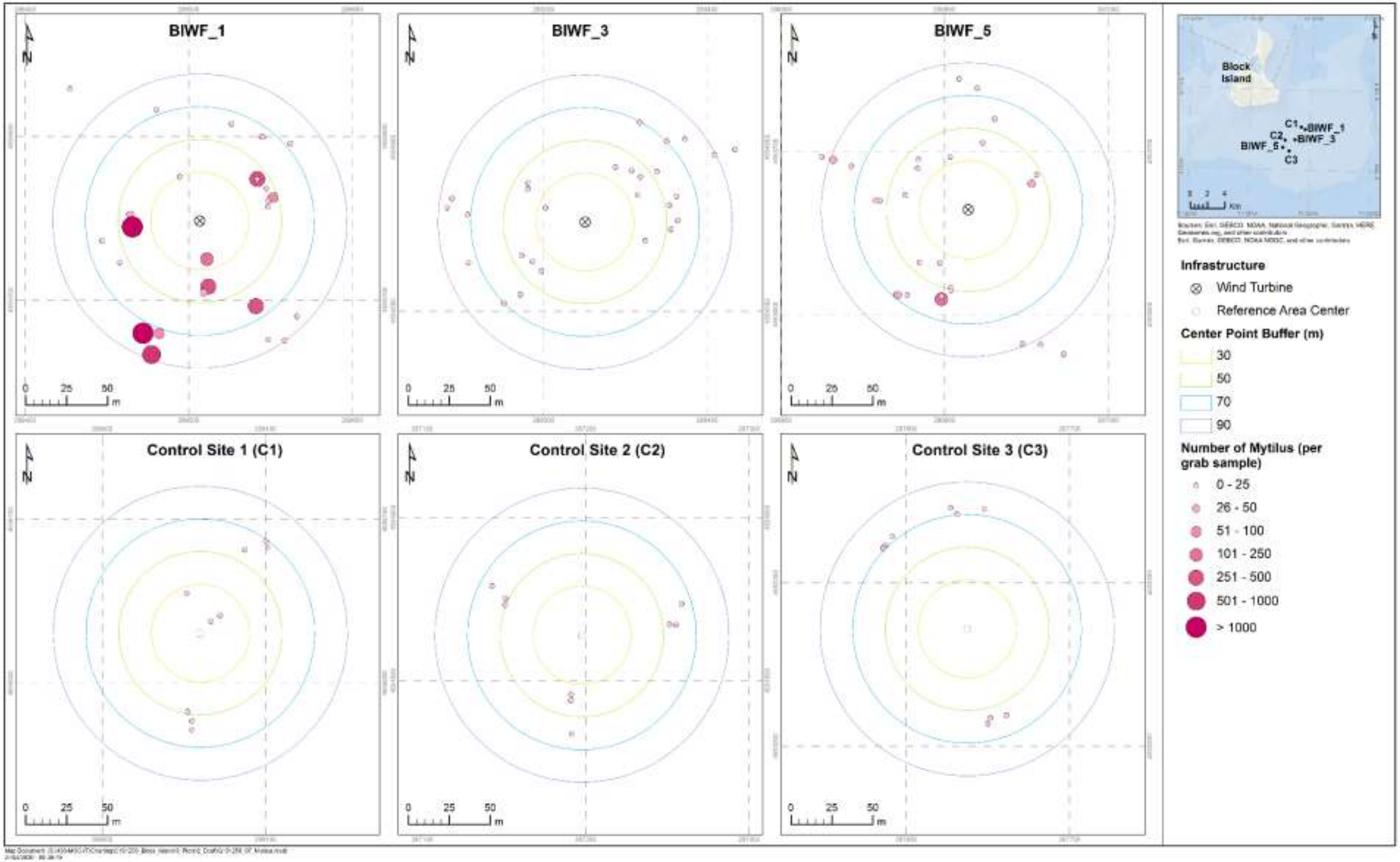


Figure 45. Distribution of abundance of mussels, *Mytilus* edulis, in vessel-based grab samples in Year 3, demonstrating the increase in abundance of *M. edulis* around Turbine 1.

Figure 46. A screengrab from the seabed video collected when deploying the Smith McIntyre grab sampler in the 30 to 90 m area. Specifically, this is a screengrab of sample T1-5-r3 collected 42.6 m from the center of Turbine 1 which had 39 adult mussels within one sample (0.06 m^2) and appears to be representative of a larger area of mussel aggregation.

3.1.6.5 Comparison of Distance Bands

Several analyses were undertaken to investigate local differences in macrofaunal communities as a function of distance between 30 and 90 m from the center point of the turbine structures, which shows that in general, there was no clear relationship. Therefore, the null hypothesis that there is no clear impact of distance from the wind farm foundation regarding benthic communities can be accepted ($H_0$3) with respect to samples collected greater than 30 m from the center point of the turbine foundation. Data supporting this conclusion are presented in the following paragraphs. However, it is noteworthy that although there is sufficient evidence to reject this null hypothesis, there were observations of patches of macrofaunal changes within 50 m of the center of Turbine 1 and some evidence from the SIMPER analysis which supports changes in macrofaunal communities up to 90 m from the Turbine. Note also that only the 30-90 m data is considered here, but there is diver-based evidence of strong macrofaunal changes occurring within the turbine footprints (**Section 3.2.5**) and at close range to the Turbine (**Section 3.1.6.4**).

The only notable results from the Year 1 and 2 data, are from the Turbine 1 Year 2 regression plots, which suggest a weak relationship of increasing species richness and abundance with increasing distance from the turbines (R^2 = 0.1293 (**Figure 47**) and 0.1754 (**Figure 48**), respectively). This weak relationship was not observed in the Year 3 sampling data. Rather, the number of species and abundance appears to have similar variability across distance bands (**Figure 47** and **Figure 48**). At Turbine 1, the abundance is notably higher and more variable than the other turbines, and that trend is observed across all distance bands sampled (**Figure 48**).

Table 22 compares mean number of species and number of individuals for the different distance bands for each turbine and control study area in each Year. Comparing Year 1 and Year 2 indicates that there was generally a greater species variety and abundance of individuals at each distance band around each turbine location in Year 2. Similar observations for the grouped control samples suggested that this was a natural condition. In Year 2, the highest abundance was recorded within the near-field distance band (within 30 to 50 m) of Turbine 3 (943.14 individuals) and was largely attributed to the presence of exceptionally high numbers of nematodes here. Comparatively high faunal abundance was also noted at intermediate and far distances at Turbine 3 and were again attributed to high nematode numbers.

Two-way ANOVA of the data for factors ‘distance band’ and ‘turbine and year’ identified a significant difference in the numbers of species between Years 1 and 2 ($F_{(7,192)} = 9.3941$, $p < 0.001$) which subsequent follow up Tukey HSD tests identified as a significantly higher number of species within the far field (70 to 90 m) distance band at Turbine 5 in Year 2 compared to Year 1 ($p <0.05$). The mean number of species recorded at far field locations at Turbine 5 in Year 1 was 15.91 compared to 24.22 species in Year 1 (**Table 22**).

Key species present far from Turbine 5 in Year 2, and which were not represented in Year 1 included *Pseudomystides* sp., *Syllides* sp., *Cirrophorus furcastus, Marphysa bellii*, oligochaetes and *Leptosynapta* sp. While not specifically recorded within the far distance band at Turbine 5 in Year 1, these species were nonetheless generally characteristic of the study area and have been recorded during both sampling periods at other turbine and control sampling locations. It is thus unlikely that these records represent a significant ecological change at this location but merely reflects the patchy distribution of benthic species within the wider area. Species numbers were not significantly different between other pairwise tests. There was no significant interaction between the two factors.

Comparing Year 3 to Year 2 shows that the strongest increase in the number of species across all three distance bands occurred at Turbine 1 (**Table 22**). Comparatively, Turbine 3 had a similar number of species in the near and far distance bands but an increase in the intermediate distance band and Turbine 5 exhibited on a small increase in the near distance band and a minor reduction in the number of species in the intermediate and far distance bands. Comparing the mean number of individuals between Year 2 and Year 3, there was a decrease evident in all distance bands around Turbines 3 and 5, but a strong increase is evident in the mean number of individuals in all distance bands around Turbine 1 (**Table 22**). The increase in abundance evident in the intermediate and far distance bands exceeds the abundance of the control area; comparatively, there is at least a two-fold increase in the aforementioned Turbine 1 study areas. However, this increase is observed in all distance bands and therefore does not constitute a trend with distance from turbine.

Two-way ANOVAs were repeated using the Year 1, 2 and 3 data and the same factors: the ‘distance band’ (near, intermediate and far) and the interaction of ‘turbine and year.’ The analysis showed that the species numbers and abundance were not significantly different between distance bands or between distance bands with turbine and year interactions ($p >0.05$).

Table 22. Mean numbers of species, numbers of individuals for each distance band, sampling location and year (vessel-based grab sample data).The distances bands were defined as near (30–49 m), intermediate (50–69 m) and far (70–90 m) from the center point of the turbine foundations.

	Year 1 (2016)				Year 2 (2017)				Year 3 (2019)			
	Turbine 1	Turbine 3	Turbine 5	Control	Turbine 1	Turbine 3	Turbine 5	Control	Turbine 1	Turbine 3	Turbine 5	Control
Mean No. species												
near	17.60	21.56	17.14	21.78	17.80	23.86	20.43	25.37	24.82	23.09	21.70	28.52
intermediate	16.09	20.33	19.11		18.88	22.80	23.09		22.86	24.43	21.56	
far	16.00	20.17	15.91		22.67	24.40	24.22		25.78	24.33	23.38	
Mean No. individuals												
near	91.10	215.22	197.71	167.04	130.90	943.14	528.57	676.41	643.55	364.83	371.09	445.22
intermediate	58.91	179.17	176.00		126.00	794.90	664.00		238.14	390.00	472.30	
far	63.33	180.83	177.91		286.56	737.30	638.33		878.0	426.37	425.43	

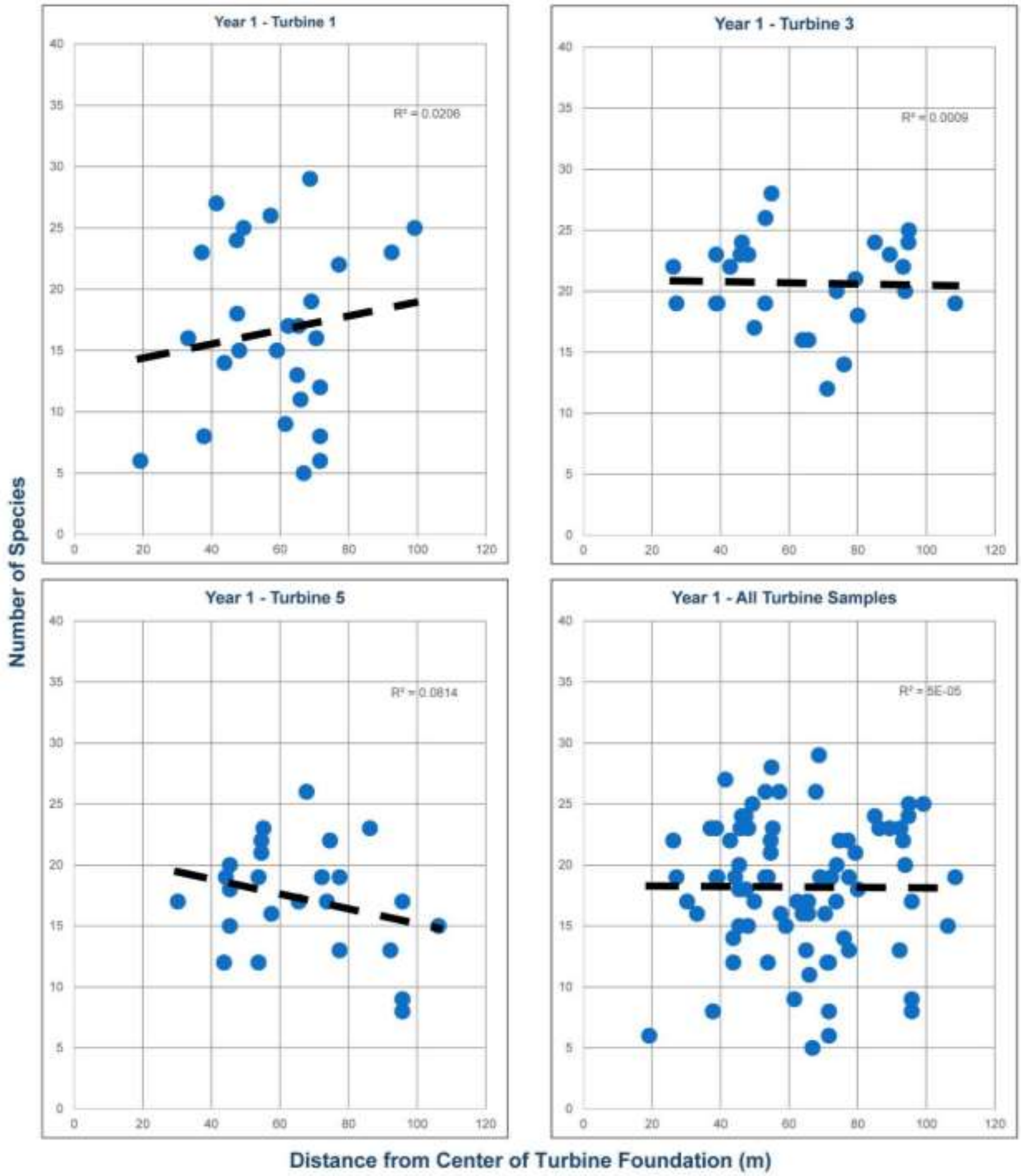


Figure 47a. Number of species per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 1.

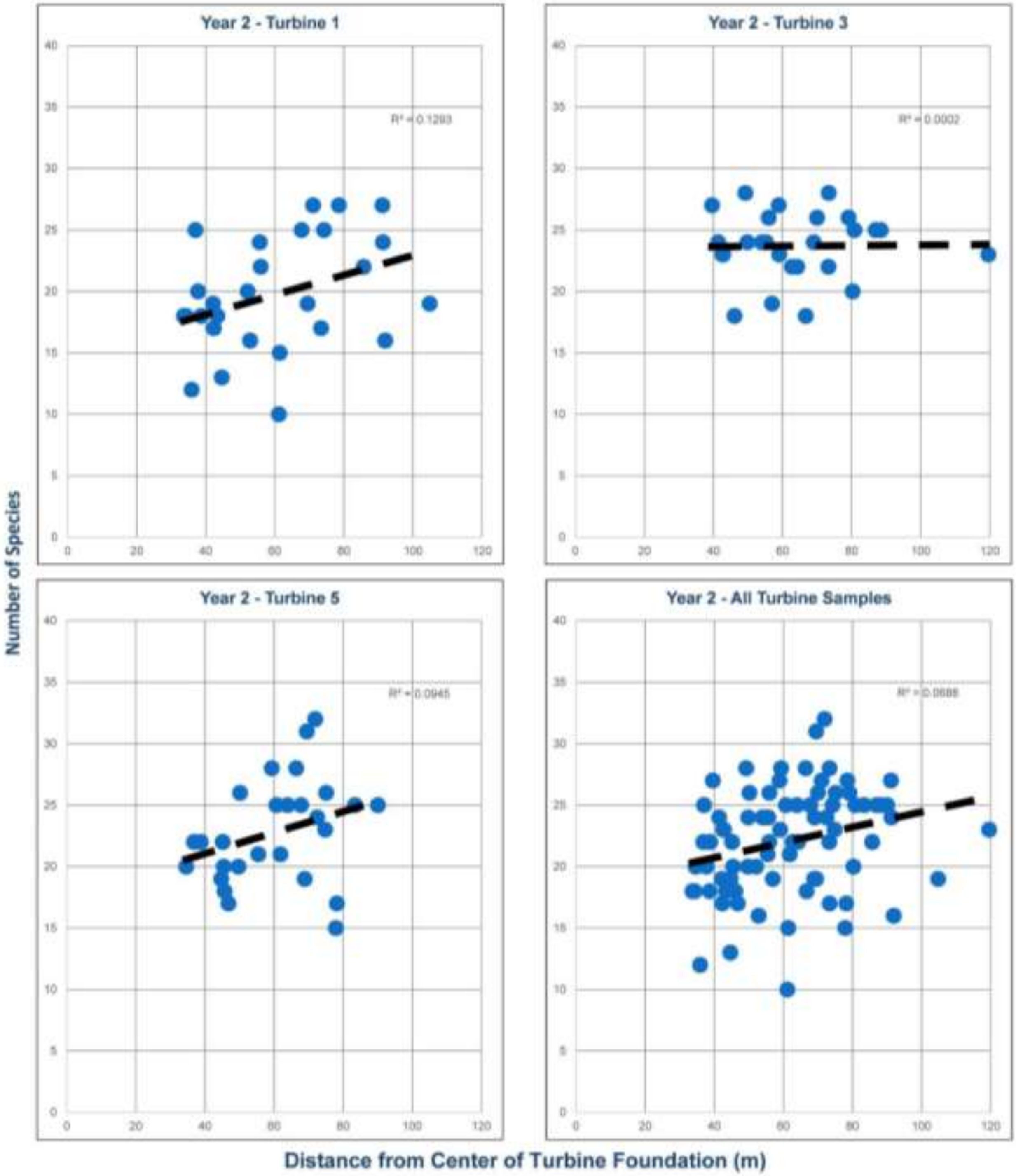


Figure 47b. Number of species per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 2.

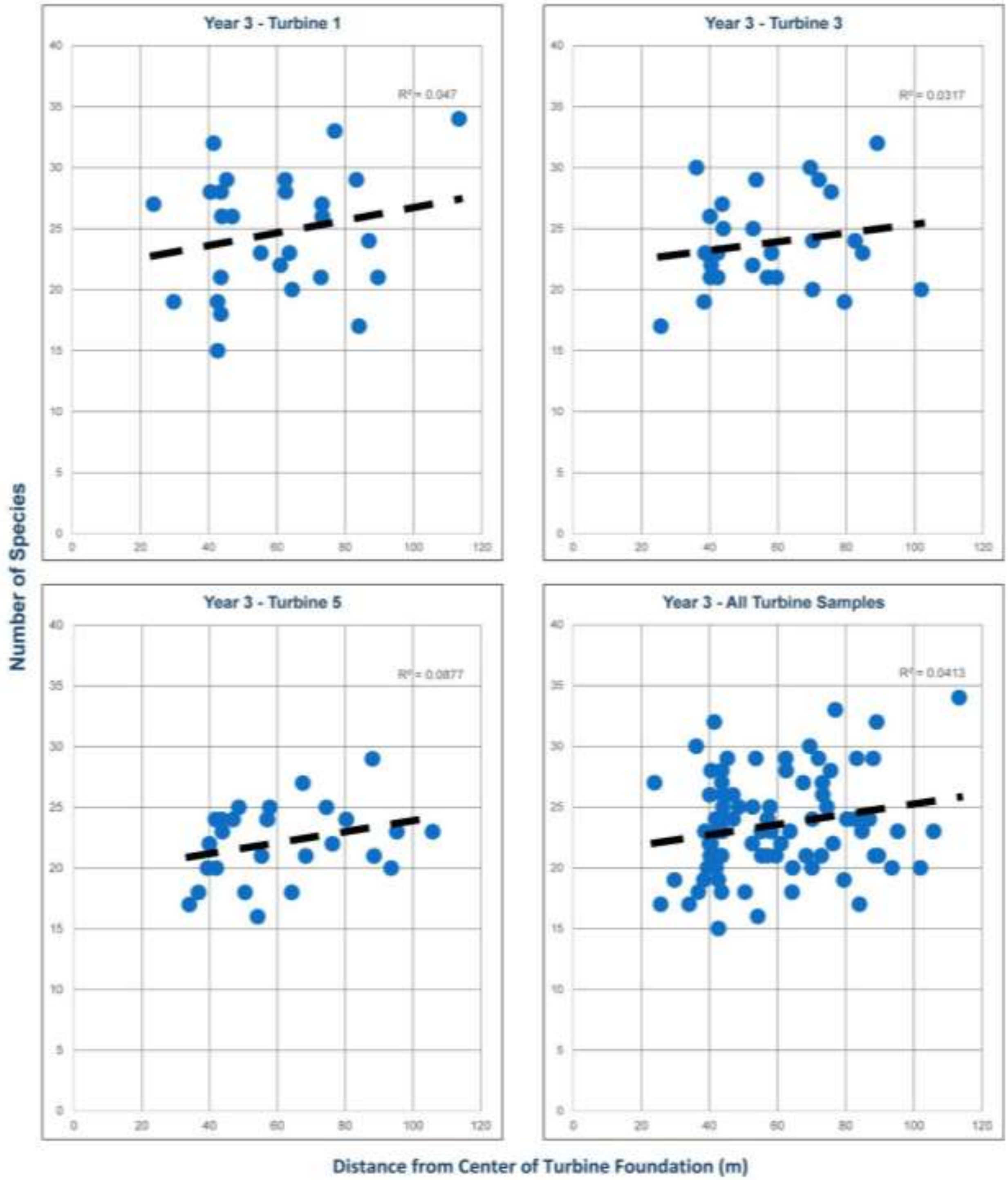


Figure 47c. Number of species per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 3.

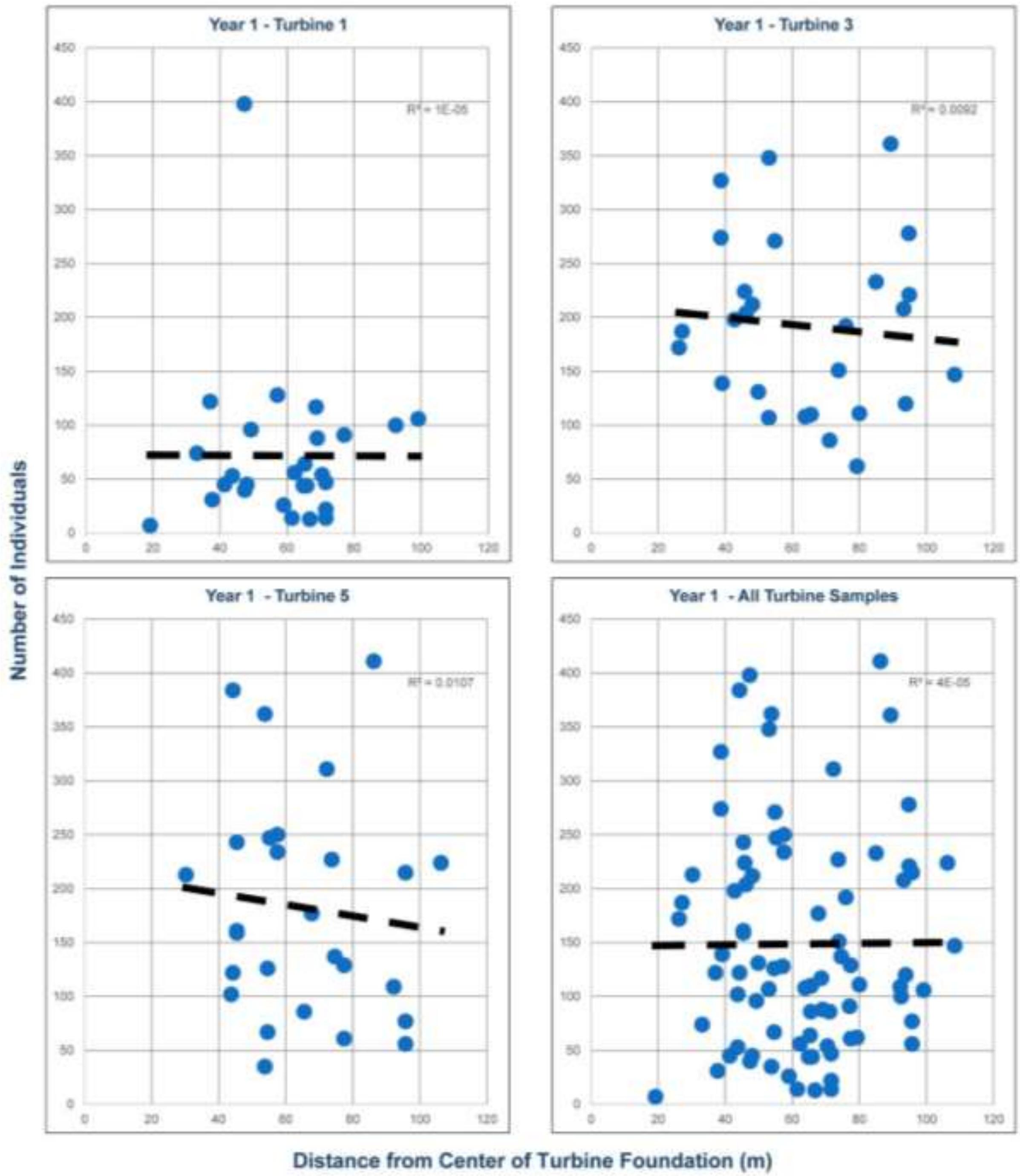


Figure 48a. Number of individuals per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 1. Please note the different axes between years.

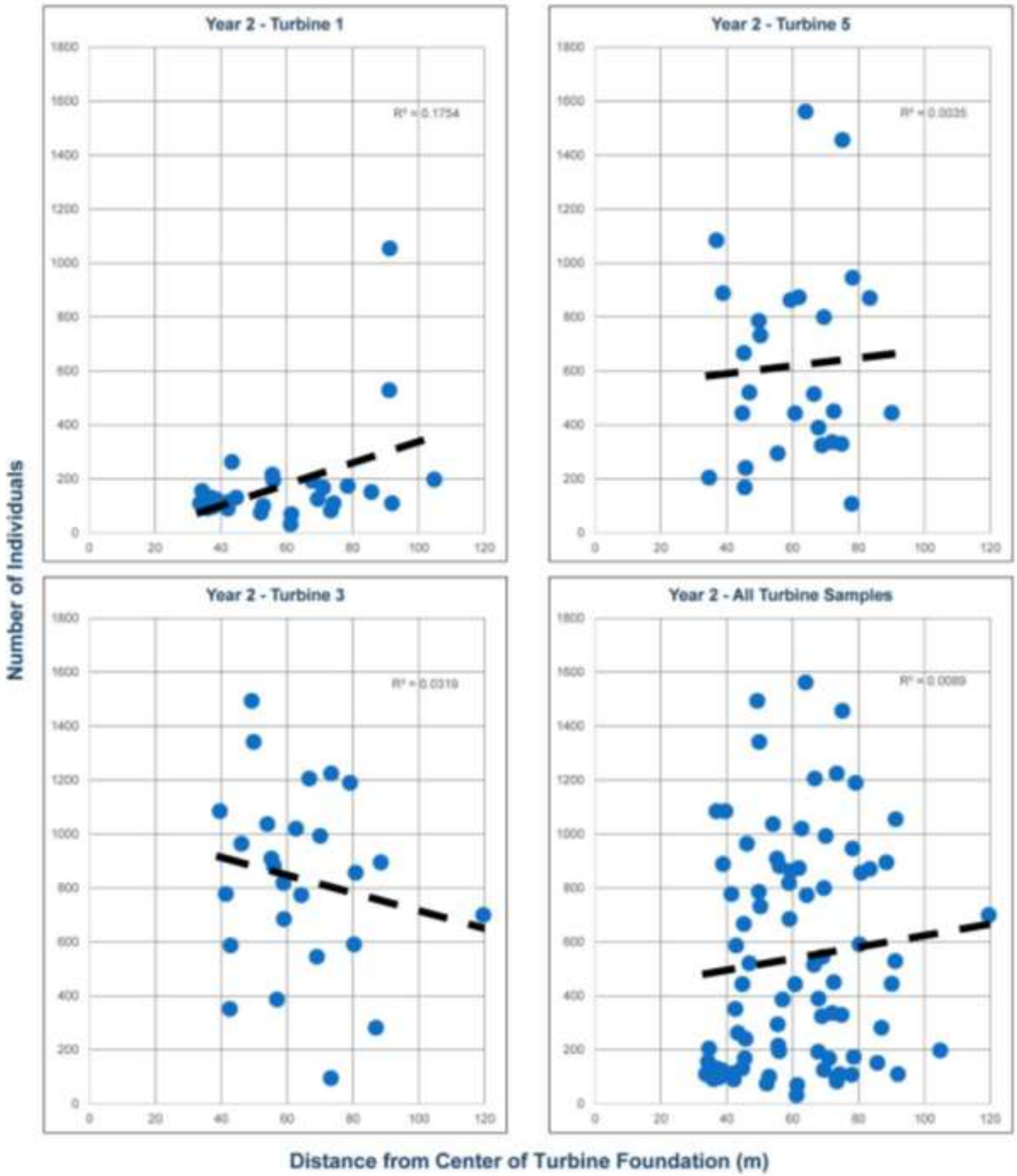


Figure 48b. Number of individuals per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 2. Please note the different axes between years.

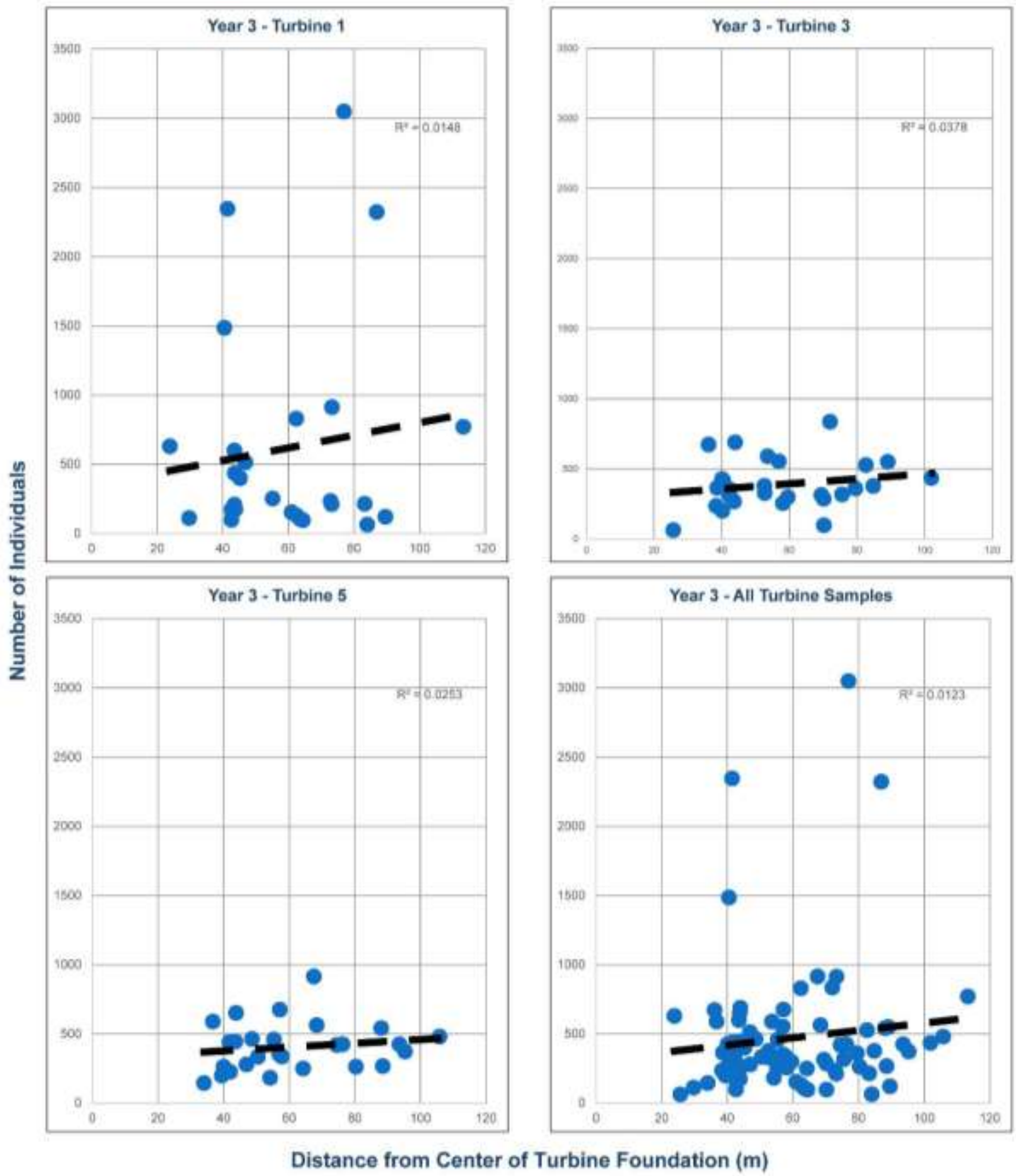


Figure 48c. Number of individuals per vessel-based grab sample with distance from the center point under each turbine foundation structure for Year 3. Please note the different axes between years.

Figure 49. nMDS plots of macrofaunal samples according to distance from the center point of each turbine for each turbine area for each Year. "Near," "Mid," and "Far" represent the 30–49 m, 50–69 m, and 70–90 m distance bands, respectively.

Note: Each sample is represented by a symbol and the distance separations between each of the symbols represent the relative (dis)similarities with regard to species composition and abundance.

With regard to spatial differences in community composition, ANOSIM performed on the sample data between distance bands for each turbine for each year revealed no significant differences (*p* >0.05) between any of the pairwise comparisons, suggesting comparable macrofaunal communities within a 90 m radius of each turbine in all sampling years. ANOSIM performed on all three years also detected no significant differences in macrofaunal communities between distance bands (*p* >0.05).

Permanova analyses were in agreement with ANOSIM for all years. Statistical comparison of the multivariate faunal data using Permanova did not identify any significant differences in community structure between the different distance bands at each turbine location (**Table 23**). This suggests that there were no significant gradient effects on benthic community structure beyond 30 m and within 90 m from each of the turbine foundations. Temporal tests of distance bands at each turbine were all statistically significant for comparisons between Year 1 and Year 2 and Year 2 and Year 3 (**Table 23**).

The macrofauna within the near, intermediate and far distance bands at each turbine study areas (30 to 90 m) are not statistically different within sampling years but were statistically different between sampling years in all turbine areas. Distance from each turbine doesn't seem to be an influencing factor although changes are occurring within each distance band over time. Although no clear trend of macrofaunal change is detected as a function of distance from the turbine within the 30-90 m area, there is evidence from the SIMPER analysis which support patches of change occurring within the 30 to 90 m areas, particularly around Turbine 1.

Referring to **Table 24** it is evident that around Turbine 3 and 5 the top contributing species are similar in each distance band, but for Turbine 1 the top contributing species vary. Specifically, at Turbine 1, *M. edulis* and *Balanus* spp. were the top contributing species in the near-field area but in the intermediate and far distance bands those species are present, but with lower contributions. This supports the statement that change is occurring within the 30 to 90 m area as detailed in **Section 3.1.6.4** and that the macrofaunal changes are observed in the further distance bands, although do not constitute a trend with distance from the turbine at this time. Note though, that the macrofaunal changes occurring within the footprint and very near-field area are excluded from this analysis.

Table 23. Summary of the Permanova analysis of the BIWF macrofauna data for pairwise tests between Turbine distance bands and sampling years. BOLD denotes a significant difference.

	Pairwise tests		t	P(perm)	Unique perms
Distance band groups					
Spatial tests Yr 2	T1 near yr2,	T1 far yr2	1.2526	0.0725	9401
	T1 intermediate yr2,	T1 far yr2	1.2159	0.1401	8193
	T1 intermediate yr2,	T1 near yr2	1.1475	0.1779	8894
	T3 intermediate yr2,	T3 far yr2	1.0571	0.3233	9805
	T3 far yr2,	T3 near yr2	1.1862	0.199	6824
	T3 intermediate yr2,	T3 near yr2	0.75274	0.8724	5696
	T5 near yr2,	T5 far yr2	0.87246	0.6755	6634
	T5 intermediate yr2,	T5 far yr2	0.83289	0.7541	9650
	T5 near yr2,	T5 intermediate yr2	1.0671	0.3208	8570
Spatial tests Yr 3	T1 near yr3,	T1 far yr3	1.0149	0.3691	9644
	T1 intermediate yr3,	T1 far yr2	1.1322	0.2087	6626
	T1 intermediate yr3,	T1 near yr3	1.0626	0.3401	8527
	T3 intermediate yr3,	T3 far yr3	0.72108	0.9509	6674
	T3 far yr3,	T3 near yr3	0.90684	0.6582	9653
	T3 intermediate yr3,	T3 near yr3	0.80718	0.8336	8506
	T5 near yr3,	T5 far yr3	1.2302	0.0956	8872
	T5 intermediate yr3,	T5 far yr3	1.3388	0.05	8182
	T5 near yr3,	T5 intermediate yr3	1.1451	0.189	9388
Temporal test	T1 near yr2,	T1 near yr1	2.1542	**0.0001**	9419
	T1 intermediate yr2,	T1 intermediate yr1	1.8644	**0.0002**	8105
	T1 far yr2,	T1 far yr1	2.4975	**0.0001**	8126
	T3 near yr2,	T3 near yr1	3.0756	**0.0002**	4288
	T3 intermediate yr2,	T3 intermediate yr1	3.9038	**0.0001**	9452
	T3 far yr2,	T3 far yr1	3.2534	**0.0001**	9632
	T5 near yr2,	T5 near yr1	2.437	**0.0002**	6652
	T5 intermediate yr2,	T5 intermediate yr1	3.7319	**0.0001**	9673
	T5 far yr2,	T5 far yr1	2.42	**0.0002**	8131
Temporal test	T1 near yr3,	T1 near yr1	3.3913	**0.0001**	9654
	T1 intermediate yr3,	T1 intermediate yr1	1.5528	**0.0015**	6620
	T1 far yr3,	T1 far yr1	2.9736	**0.0002**	8147
	T3 near yr3,	T3 near yr1	2.3376	**0.0002**	9637
	T3 intermediate yr3,	T3 intermediate yr1	3.1073	**0.0002**	6610
	T3 far yr3,	T3 far yr1	2.445	**0.0001**	8168
	T5 near yr3,	T5 near yr1	2.3787	**0.0001**	9389
	T5 intermediate yr3,	T5 intermediate yr1	3.1227	**0.0001**	8138
	T5 far yr3,	T5 far yr1	2.9093	**0.0002**	8132

Table 24. SIMPER results showing average similarity and top contributing species (70% cut-off) of vessel-based samples collected in the near (>30–49 m), intermediate (50–69 m) and far (70–90 m) distances from the center of the turbine foundation in Year 3 (data for Year 1 and 2 not shown).

		Turbine 1	Turbine 3	Turbine 5
Year 3	Near	**Average Similarity: 48.74**	**Average Similarity: 62.60**	**Average Similarity: 60.76**
		Balanus spp.(16.13%)	*Nematoda* spp. (17.42%)	*Polycirrus eximius* (23.5%)
		Mytilus edulis (13.86%)	*Polycirrus eximius* (15.11%)	*Nematoda* spp. (14.62%)
		Nematoda spp. (13.24%)	*Polygordius* spp. (10.14%)	*Pisione* sp. (12.43%)
		Polygordius spp. (11.92%)	*Pisione* sp. (9.91%)	*Dorvilleidae* (8.4%)
		Goniadella gracilis (6.18%)	*Lumbrinereis acuta* (7.65%)	*Lumbrinereis acuta* (5.98%)
		Lumbrinereis acuta (4.88%)	*Dorvilleidae* (5.19%)	*Polygordius* spp. (5.44%)
		Nephtys spp. (4.64%)	*Aricidea cerrutii* (3.97%)	-
		-	*Goniadella gracilis* (3.57%)	-
	Intermediate	**Average Similarity: 36.51**	**Average Similarity: 67.99**	**Average Similarity: 67.95**
		Nematoda spp. (15.79%)	*Polycirrus eximius* (20.58%)	*Polycirrus eximius* (26.14%)
		Polygordius spp. (8.53%)	*Nematoda* spp. (18.67%)	*Nematoda* spp. (15.03%)
		Mytilus edulis (8.43%)	*Polygordius* spp. (8.47%)	*Pisione* sp. (12.6%)
		Exogone spp. (7.62%)	*Pisione* sp. (7.65%)	*Polygordius* spp. (5.35%)
		Lumbrinereis fragilis (7.55%)	*Lumbrinereis acuta* (6.43%)	*Parapionosyllis longicirrata* (5.21%)
		Nephtys spp. (5.95%)	*Aricidea catherinae* (4.54%)	*Dorvilleidae* (5.08%)
		Goniadella gracilis (5.39%)	*Aricidea cerrutii* (4.12%)	*Lumbrinereis acuta* (5.02%)
		Lumbrinereis acuta (4.9%)	-	-
		Parapionosyllis longicirrata (4.84%)	-	-
		Balanus spp. (4.3%)	-	-
	Far	**Average Similarity: 45.73**	**Average Similarity: 63.26**	**Average Similarity: 52.95**
		Nematoda spp. (16.48%)	*Nematoda* spp. (20.82%)	*Polycirrus eximius* (29.34%)
		Polygordius spp. (13.51%)	*Polycirrus eximius* (19.8%)	*Pisione* sp. (12.74%)
		Balanus spp. (13.12%)	*Pisione* sp. (8.8%)	*Nematoda* spp. (12.29%)
		Goniadella gracilis (7.38%)	*Polygordius* spp. (8.74%)	*Lumbrinereis acuta* (7.81%)
		Nephtys spp. (5.55%)	*Dorvilleidae*. (4.78%)	*Dorvilleidae* (5.23%)
		Lumbrinereis acuta (5.2%)	*Parapionosyllis longicirrata*. (4.5%)	*Unciola irrorata* (4.12%)
		Mytilus edulis (4.46%)	*Lumbrinereis acuta* (4.36%)	-
		Cirratulidae (4.24%)	-	-
		Dipolydora spp. (4.17%)	-	-

3.1.6.6 Comparison of Biomass within Turbine Areas

Biomass measurements were introduced in Year 3. These data are detailed in **Appendix I**. From the vessel-based benthic grab sampling (30 to 90 m from the turbines), the macrofaunal wet or dry biomass of the samples was measured and collated by phylum.

Overall, when combining the turbine samples (T1, T3 and T5), the Arthropoda were responsible for the highest contribution to the sample dry biomass, with a total of 37.19 g dry weight (average = 0.46 g, n = 81), followed by the Annelida (total = 18.70 g, average = 0.23 g) and the Chordata (total = 6.37 g; average = 0.08 g). Comparatively, within control areas the greatest contribution of dry biomass was from the Annelida with a total of 5.57 g (average = 0.21, n =27), followed by the Arthroopda and Actinaria which each had a total dry biomass of <0.5 g.

Considering the turbine study areas individually, Turbine 1 had the highest biomass for Arthopoda, 99% of which was attributed to two individuals of *Cancer borealis*. The second highest contribution of dry biomass at Turbine 1 was from Annelida (total 3.31 g, average 0.12 g, n = 27; **Figure 50**). The Annelida dominated the biomass contribution at Turbine 3 (total = 7.27 g, average = 0.30 g) and 5 (total = 8.11 g, average = 0.30 g), followed by the Chordata (T3 total = 4.01 g, average = 0.15 g; T5 total = 2.37 g, average = 0.09 g).

The turbine samples combined contained a total wet Mollusca biomass of 970.76 g (average= 11.99 g, n = 81) compared to a total of 62.81 g at the control areas (average = 2.32 g, n = 27; **Figure 51**). Therefore, the average wet biomass contributed by the Molluska was 80% greater within the Turbine samples. The highest proportion of the Molluska biomass was contributed from the Turbine 1 study area which recorded a total of 746.71 g (average = 27.66 g). Turbine 3 and 5 had more similar Molluska biomass with totals of 119.59 g (average = 4.43 g) and 104.47 g (average = 3.87 g), respectively. The wet biomass of the mussel *M. edulis* was responsible for 92.5% of Mollusca biomass at Turbine 1 but was negligible within the Turbine 3 and 5 study area. It is notable however that 120 juvenile mussels weighed 0.001 g.

In addition to the phyla biomass, *Balanus* spp. were measured separately as wet biomass. When combining all turbine samples, the total wet biomass of *Balanus* spp. was 99.16 g (average = 7.93 g) and was present in 24 of 81 samples. The total wet biomass of *Balanus* spp. was contributed from the Turbine 1 study area 98.95 g (average = 4.30 g) where it was present in 23 of 27 samples, with the exception of one sample contributed from the Turbine 3 study area (0.22 g). Comparatively, the total wet biomass of *Balanus* spp., within the Control areas was 0.69 g (average, 0.17 g, n = 27).

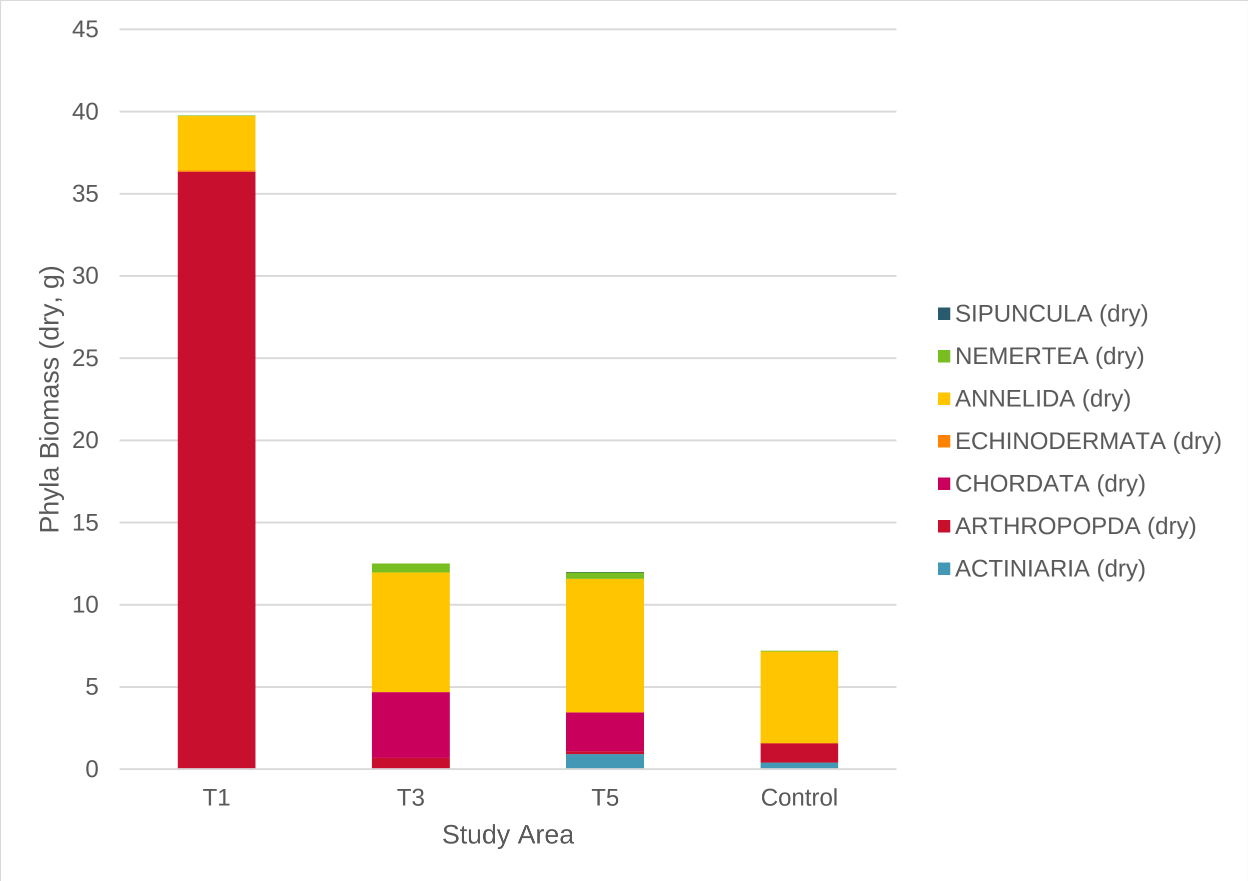


Figure 50. Total biomass (dry weight) by phyla collected in the vessel-based grab samples 30–90 m from the turbines and in the control areas. Note, Molluska are excluded from this graph and reported as wet weight, per study area in Figure 52.

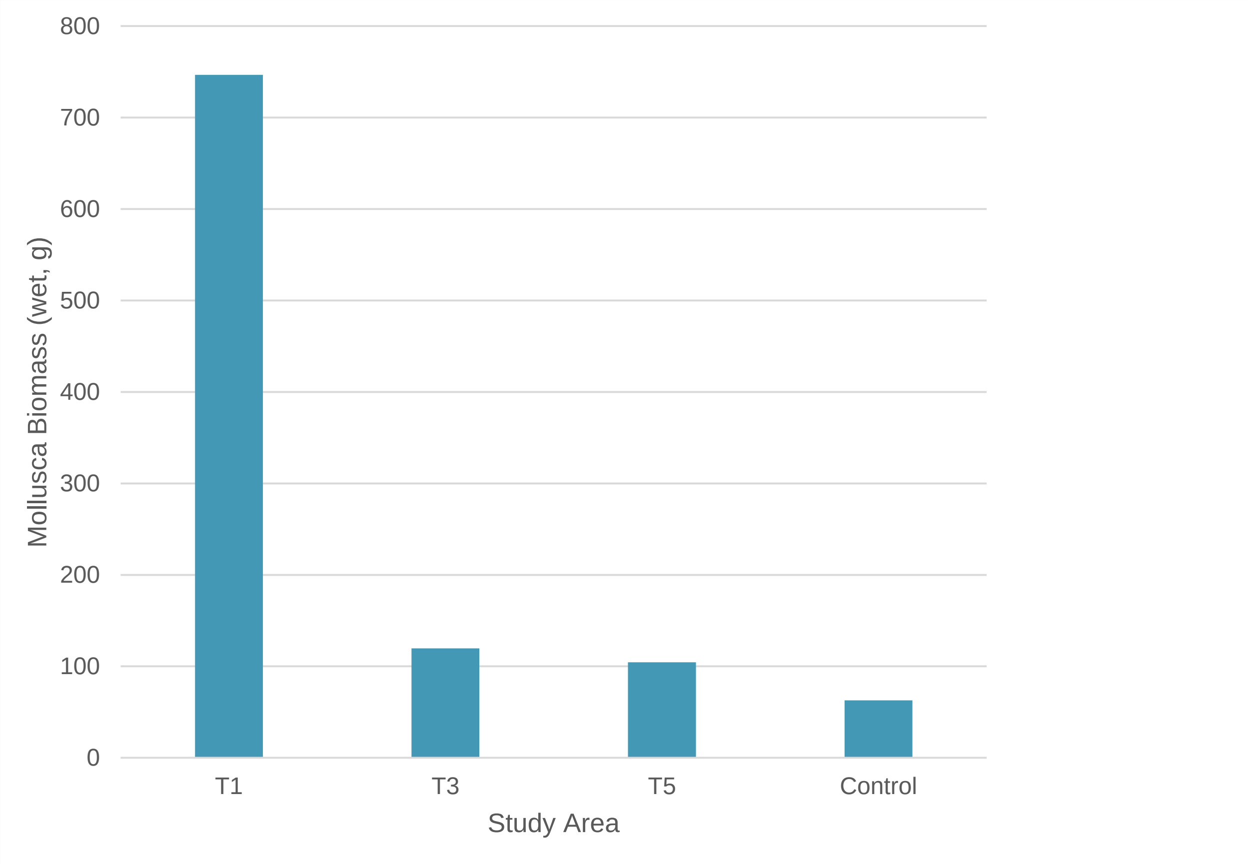
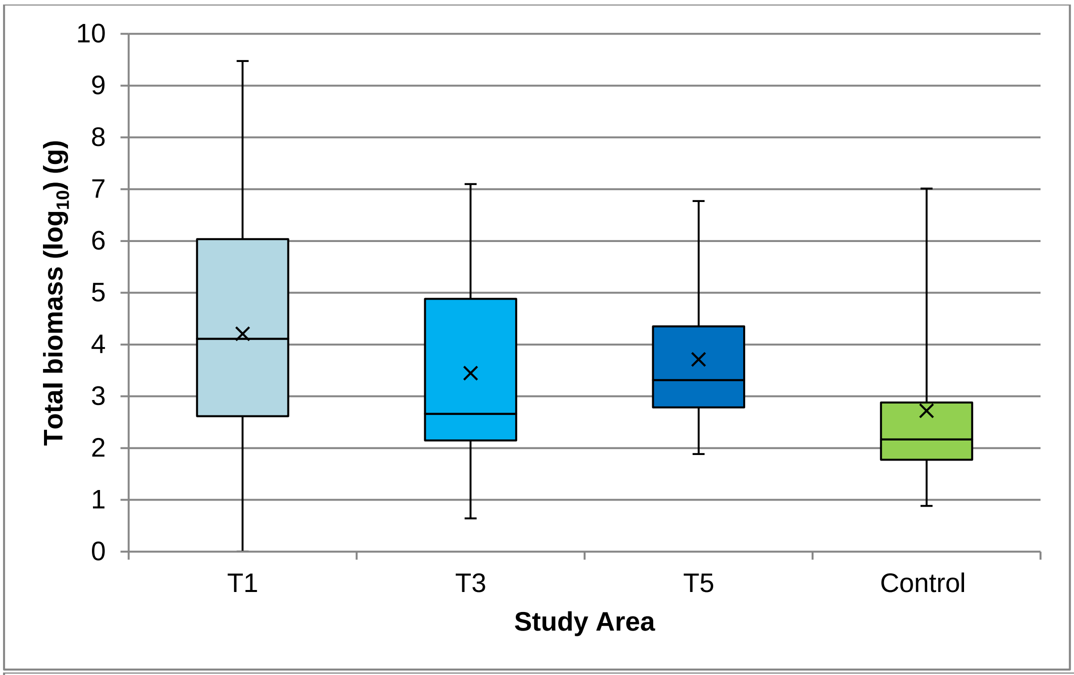


Figure 51. Total biomass of Mollusca (wet weight) collected in the vessel-based grab samples 30–90 m from the turbines and the control areas. *Mytilus edulis* biomass contributions were weighed separately.

Although the phyla were measured in terms of both dry and wet weight, they were measured in this way consistently across all turbine samples. Therefore, the total biomass (including wet and dry weights) can be compared between turbine and control study areas and between predetermined distance bands within turbine study areas (near, intermediate and far, **Figure 8**). **Figure 52** highlights the variability in total biomass present across the study areas and within distance bands. Statistical comparisons revealed that the toal biomass at Turbine 1 and Turbine 5 were significantly greater than the control study areas ($p = 0.01$). Considering the distance bands within study areas, there was greater variability but there were differences between turbine distance bands and between turbine distance bands and control areas ($p = 0.02$). The Turbine 1 near distance band and Turbine 5 intermediate area has a greater total biomass that the Turbine 3 near distance band. Additionally, the Turbine 1 near, Turbine 3 far and Turbine 5 intermediate distance bands had a greater total biomass than the control areas.



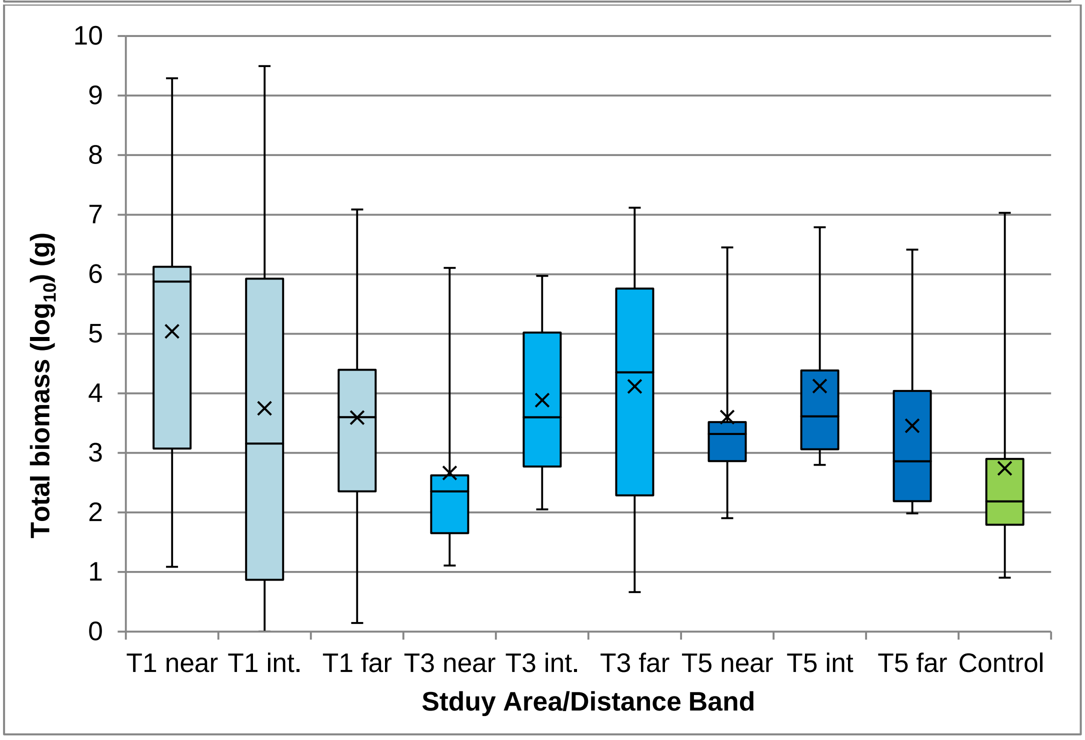


Figure 52. Total biomass (log10) for vessel-based samples collected (a) at each turbine (T1, T3, T5) and control areas and (b) within 'near,' intermediate (int) and 'far' distance bands at Turbines 1, 3 and 5 in Year 3.

3.2 Benthic Diver-Based Data Collection

3.2.1 Survey Effort

In Year 2, five grab samples were collected by divers within the footprint of each turbine structure (**Figure 15**). The samples were obtained over three days between mid-May and early June (**Table 25**). In Year 3, the sampling effort was repeated to collect five samples within the footprint of the turbines. Sampling was completed at Turbines 3 and 5; however, only two samples were obtained within the footprint of Turbine 1 due to the extensive and deep mussel cover. A total of 12 samples were collected within the footprint of all turbines combined. These diver-collected grab samples were obtained over three days in August-October 2019 (**Table 25**). The sampling effort was spread out over time due to adverse weather conditions.

In Year 3, the sampling effort was further expanded to target the very near-field area surrounding the turbines, i.e., within 30 m of the center of the turbines but outside of the structure (**Figure 8** and **Figure 16**). Divers collected three grab samples at three stations within the very near-field area at each of the three turbines (a total of nine samples per turbine). These samples were collected over four days in October 2019 (**Table 26**).

In addition, divers towed the Lagrangian floating camera system to obtain a camera transect starting from within the turbine footprint and extending up to 90 m from the center of the turbines. In Year 2, camera transects were completed over two days in May-June 2018, to collect imagery along a north-south transect under each turbine structure and across the three distance bands (**Table 27**). In Year 3, the same survey effort was repeated at each of the turbine areas. Diver towed camera transects were obtained on two days in August 2019 (**Table 27**).

Lastly, to provide a comparison between the vessel-based grab samples, collected using the Smith McIntyre grab sampler, and the diver-collected grab samples, three samples using each method were collected. These samples were all collected on the same day in November 2019 (**Table 28**). The results for this comparison are reported in **Section 3.3.2**.

Table 25. Summary of diver-based grab sample collection within the footprint of each of the turbine structures for Year 2 and Year 3.

	Study area	Number of grab samples	Date of grab sample survey
Year 2	Turbine 1	5	8 June 2018
	Turbine 3	5	17 May 2018
	Turbine 5	5	7 June 2018
Year 3	Turbine 1	2	20 August 2019
	Turbine 3	5	5 October 2019
	Turbine 5	5	29 September 2019

Table 26. Summary of diver-based grab sample collection in the very near-field area, i.e., within 30 m of the center of the turbine, for each Turbine in Year 3.

	Study area	No. of stations	No. of replicates	Total samples	Date of grab sample survey
Year 3	Turbine 1	3	3	9	25 and 26 October 2019
	Turbine 3	3	3	9	13 October 2019
	Turbine 5	3	3	9	19 and 25 October 2019

Table 27. Summary of diver-based data collection using the float camera, within the footprint of each turbine structure and extending up to 90 m from the center of the turbine, for Year 2 and Year 3.

	Study area	Number of camera transects	Date of camera survey
Year 2	Turbine 1	1	15 June 2018
	Turbine 3	1	17 May 2018
	Turbine 5	1	15 June 2018
Year 3	Turbine 1	1	2 August 2019
	Turbine 3	1	1 August 2019
	Turbine 5	1	2 August 2019

Table 28. Summary of survey effort for the Smith McIntyre grab sample and diver-based grab sample collection for the purposes of comparison, in Year 3.

Method	Study area	Number of grab samples	Date of grab samples
Vessel	Narragansett Bay	3	9 November 2019
Diver	Narragansett Bay	3	9 November 2019

3.2.2 Particle Size Distribution (PSD) Analysis

Detailed results of the sediment grain size analysis of the diver-collected grab samples within the footprint of each turbine structure studied are presented in **Appendix D**. Owing to the similarities in analyses for Turbines 3 and 5, these turbines are discussed first. Turbine 1, which showed different properties in the particle size distribution, is discussed subsequently. Since the particle size distribution of both the diver and Smith McIntyre vessel-based sample methods were considered similar (**Section 3.3.2.2**), comparisons are made with the vessel-based sampling results reported in **Section 3.1.2**.

The analysis confirmed that sediment characteristics within the footprint of Turbines 3 and 5 in Year 2 were similar to those of the vessel-based grab samples collected in the 30 to 90 m vicinity of the turbine structures. Specifically, all 10 of the samples taken within the footprint of Turbines 3 and 5 in Year 2, were dominated by coarse sand, and the fractions of medium, coarse, and very coarse sand combined accounted for over 90% of the sediment composition (**Table 29**; refer to **Table 7** for sediment analysis of vessel-based grab samples). None of the samples contained clay or silt particles (**Table 29**).

For comparison, the majority of the 110 vessel-based sediment samples collected in Year 1 and Year 2 from Turbines 3 and 5 also were dominated by coarse sand (104 samples), exhibited a combined sand fraction exceeding 90% (110 samples), and had a combined clay and silt fraction of 0% (98 samples). The only exceptions to this description are six samples that were dominated by medium sand and six samples that contained clay and silt particles, but with a contribution of less than 1% to the total sediment composition.

In Year 3, the sediment characteristics within the footprint of Turbines 3 and 5 were similar to Year 2 in that all samples were dominated by coarse sand (**Table 29**). However in Year 3, there was a reduction in the number of samples which had a combined sand fraction exceeding 90% (four samples at both Turbine 3 and 5, respectively) and an increase in the number of samples which had a combined clay and silt contribution exceeding 0% (one at each, Turbine 3 and 5) (**Table 29**). In the very near-field area, surrounding the turbine (<30 m from the center), the dominant sediment type in all samples at Turbine 3 and 5 was also coarse sand (nine of nine samples at both Turbines 3 and 5) with all samples exceeding 90% combined sand fractions and 0% silt and clay particles (**Table 30**). Comparatively, at the study areas surrounding Turbines 3 and 5 (i.e., 30 to 90 m distance from the center), the vessel-based samples recorded 53 of 54 samples (compared to 52 in Year 2) as having a dominant coarse grain size, 53 of 54 samples as having a combined sand fraction exceeding 90%

(compared to 54 of 54 in Year 2) but zero samples in Year 2 and 3 had a clay and silt fraction exceeding 0% (**Table 7**).

Furthermore, the mean fractions of each Wentworth-defined sediment class were comparable for sediment samples collected within the footprint of and in the study area around (i.e., 30 to 90 m) Turbines 3 and 5 (**Table 31**; refer to **Table 8** for sediment analysis of vessel-based grab samples). Specifically, the proportion of fine sand (particles of diameter 150 to 250 µm) of samples from under the structure was 0.3% and 0.0% for Turbines 3 and 5, respectively, which was comparable to the vessel-based samples (mean range = 0.6% to 1.6%). The average contribution of medium sand (particles of diameter 250 to 500 µm) from turbine footprint was 28.8% at Turbine 3 and 23.6% at Turbine 5, similar to the vessel-based samples (mean range = 25.9% to 37.8%). For the coarse sand fraction (particles of diameter 500 to 1,000 µm), the mean proportion was 64.4% and 65.3% for samples collected under Turbines 3 and 5, respectively, and ranged from 50.3 to 61.0% for the vessel-based samples. The very coarse sand fraction mean was 6.6% for Turbine 3 and 11.1% for Turbine 5 for the footprint samples, which falls within mean range of the vessel-based samples (5.7 to 22.1%).

Comparing the samples within the footprint of the Turbines 3 and 5 in Year 3 to those in Year 2 (**Table 31**), it is noted that there was an increase in clay and silt (0.0% in Year 2 increasing to 2.3% in Year 3) and very fine sand (0.0% in Year 2 increasing to 0.7 and 0.4% in Year 3 under Turbine 3 and 5 respectively). The fine sand content remained constant at Turbine 3 (0.3% in Year 2 and 0.4% in Year 3) but increased at Turbine 5 (0.0% in Year 2 increasing to 1.3% in Year 3). The medium sand content in Year 3 increased (Year 2 = 28.8% and 23.6%, Year 3 = 34.8% and 27.1% at Turbines 3 and 5, respectively) and decreased in coarse sand content (Year 2 = 64.4% and 65.3%, Year 3 = 57.7% and 52.6% at Turbines 3 and 5, respectively). This increase in medium sand and decrease in coarse sand content was more pronounced at Turbine 3. The content of very coarse sand decreased under Turbine 3 (Year 2 = 6.6%, Year 3 = 4.2%) and increased under Turbine 5 (Year 2 = 11.1%, Year 3 = 15.3%).

In the very near-field area, surrounding the turbine (<30 m from the center) (**Table 32**), the particle fractions reflected a similar pattern to the sediment composition under Turbines 3 and 5 (**Table 29**) although the finer particles were absent from the samples. There were zero clay and silt particles which is perhaps the strongest contrast. Fine sand in the near-field area were 0.3% and 0.8% at Turbines 3 and 5 respectively. The medium sand content around Turbine 3 was similar (34.1% compared to 34.8% under the turbine) and slightly higher around Turbine 5 (32.5% compared to 27.1% under the turbine). The coarse sand content around Turbine 3 and 5 was 61.2% and 59.5% which is relatively comparable to the under the turbines (57.7 and 62.6%, respectively).

The very coarse sand content at Turbine 3 was similar to that under the turbine (4.5% and 4.2%, respectively) whereas at Turbine 5, the coarse sand content was almost half in comparison (7.2% around the turbine, compared to 15.3% under the turbine). In contrast to Turbines 3 and 5, the sediment samples from Turbine 1 in Year 2 show considerable differences between samples collected within the footprint of the turbine structure and those of the surrounding area (refer to **Table 29** and **Table 31** for analysis diver-based samples and **Table 7** and **Table 8** for analysis of vessel-based samples). Notably, the five samples from under the structure have a substantially higher finer grain size composition. In Year 2, the clay and silt content of the Turbine 1 footprint samples averaged 36.5% (**Table 31**) but was variable among individual samples (combined clay and silt fraction was 24, 25, 34, 28, and 72% for samples 1 through 5, respectively).

Three of the Turbine 1 footprint samples were dominated by medium sand, one by coarse sand, and five by clay and silt (**Table 29**). While this finding is similar to the vessel-based grab samples, which were all dominated by medium sand (n = 41) or coarse sand (n = 14), the distinction is attributed to the average proportion of each sediment class. For example, the average contribution of medium sand for the samples collected under Turbine 1 was 26.1% (**Table 31**), which is nearly half of the 49.6% for the vessel-based samples (same percentage for Year 1 and Year 2, **Table 7**). Similarly, the average proportion of coarse sand was 25.9%, versus 41.6 and 43.4% for vessel-based samples collected Year 1 and Year 2, respectively (**Table 7**). Further, the average proportion of the clay and silt fraction and the very fine sand fraction for samples under the turbine was 36.5 and 4.4%, respectively; the vessel-based samples had an average of 5.7%. Only the fine sand content was comparable between the samples, with a mean average of approximately 6% for all samples.

In Year 3, the samples taken within the footprint of Turbine 1 were higher in clay and silt content than in Year 2. Only two samples (which were similar) were collected at Turbine 1 in Year 3, compared with five in Year 2. The reason for this was that the mussel cover was so dense and deep that it prevented the divers from taking samples in Year 3. The mussel cover at the two sample sites under Turbine 1 was approximately 35 and 50 cm deep. Both samples in Year 3 were dominated by medium sand and had a combined silt and clay content exceeding 0% (**Table 29**).

As stated above, the clay and silt content were variable within the five samples in Year 2 (mean = 36.5%, range 24 to 72%), despite this, the average clay and silt content in Year 3 was still higher with an average of 43.2% (**Table 31**). The average very fine sand content increased by 2.2% (Year 3 = 6.9%), and the fine sand content increased by 4.7% (Year 3 = 10.9%), while the average medium and coarse sand content decreased by 4.3% (21.8%) and 9.3% (16.6%), respectively (**Table 31**). The very coarse sand content remained low (0.5%), reduced by half compared to Year 2. In Year 3, the very near-field samples taken within 30 m of the turbine showed that the average very fine sand and fine sand content were all lower compared to the Turbine 1 footprint. In contrast the average medium sand and coarse sand content increased in this area by 24% and 21.9%, respectively, whereas the coarse sand only increased by 0.1% (**Table 31**).

It is noteworthy, however, that the clay and silt content very near to the turbines (i.e., within 30 m of the center) was notably higher at Turbine 1 (6.9%) than at Turbines 3 and 5 (0.0%) (**Table 32**). The full range of combined clay and silt in the very near-field areas was between 0.0 and 30.2%; the upper range which was driven by the higher clay and silt content in samples surrounding Turbine 1. However, the combined clay and silt content from the footprint of Turbine 1 was much higher (43.2%) than the very nearfield area (6.9%).

When comparing the Year 3 samples taken within the turbine footprint (**Table 31**), with those in the very near-field surrounding area (**Table 32**) and those taken 30 to 90 m from the turbines (**Table 15**), the most dominant feature is the increase in fine particles closer to the turbine. This trend is most prominent at Turbine 1 and particularly for the combined clay and silt content. However, the same trend is apparent, with lesser intensity, for Turbines 3 and 5. This can be seen more clearly in **Figure 53**.

Table 29. Summary of grain size analysis of diver-based sediment samples collected within the footprint of each turbine in Year 2 and Year 3.

	Study area	Total samples	Number of samples for which:			
			Dominant grain size = medium sand	Dominant grain size = coarse sand	Combined sand fraction > 90%	Combined clay and silt > 0%
Year 2	Turbine 1	5	3	1	0	5
	Turbine 3	5	0	5	5	0
	Turbine 5	5	0	5	5	0
Year 3	Turbine 1	2	2	0	0	2
	Turbine 3	5	0	5	4	1
	Turbine 5	5	0	5	4	1
Note: Combined sand fraction is defined as the combination of medium sand, coarse sand, and very coarse sand. Grain size fractions are classified according to the Wentworth scale.						

Table 30. Summary of grain size analysis of diver-based sediment samples collected in the very near-field area, i.e., within 30 m of the center of each turbine in Year 3 only.

	Study area	Total samples	Number of samples for which:			
			Dominant grain size = medium sand	Dominant grain size = coarse sand	Combined sand fraction > 90%	Combined clay and silt > 0%
Year 3	Turbine 1	9	9	0	6	3
	Turbine 3	9	0	9	9	0
	Turbine 5	9	0	9	9	0

Note: Combined sand fraction is defined as the combination of medium sand, coarse sand, and very coarse sand. Grain size fractions are classified according to the Wentworth scale.

Table 31. Mean (and standard error) of each sediment grain size fraction for diver-based sediment samples collected within the footprint of each turbine in Year 2 and Year 3.

	Study area	Sample size (n)	Average fraction of:					
			Clay and silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand
Year 2	Turbine 1	5	36.5% (9.1)	4.4% (0.7)	6.1% (0.7)	26.1% (4.8)	25.9% (4.8)	1.0% (0.3)
	Turbine 3	5	0.0% (0.0)	0.0% (0.0)	0.3% (0.2)	28.8% (4.4)	64.4% (2.9)	6.6% (1.6)
	Turbine 5	5	0.0% (0.0)	0.0% (0.0)	0.0% (0.0)	23.6% (1.5)	65.3% (0.8)	11.1% (0.9)
	Range	-	0 – 72.2%	0 – 7.0%	0 – 8.8%	7.3 – 40.7%	7.9 – 70.2%	0.4 – 14.4%
Year 3	Turbine 1	2	43.2% (2.0)	6.9% (1.0)	10.9% (1.6)	21.8% (2.1)	16.6% (2.6)	0.5% (0.2)
	Turbine 3	5	2.3% (2.3)	0.7% (0.7)	0.4% (0.1)	34.8% (1.1)	57.7% (1.8)	4.2% (0.4)
	Turbine 5	5	2.5% (2.5)	0.4% (0.4)	1.3% (0.4)	27.1% (1.0)	52.6% (2.4)	15.1% (1.6)
	Range	-	0.0% – 45.2%	0.0% – 7.9%	0.1% – 12.5%	19.7% – 37.1%	14.1% – 60.4%	0.4% – 18.9%

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

Table 32. Mean of each sediment grain size fraction for diver-based sediment samples collected in the very near-field area (i.e., within 30 m of the center) of each turbine in Year 2 and Year 3.

	Study area	Sample size (n)	Average fraction of:					
			Clay and silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand
Year 3	Turbine 1	9	6.9% (3.8)	1.1% (0.7)	7.1% (0.6)	45.8% (2.6)	38.5% (2.1)	0.6% (0.1)
	Turbine 3	9	0.0% (0.0)	0.0% (0.0)	0.3% (0.1)	34.1% (1.6)	61.2% (1.2)	4.5% (0.6)
	Turbine 5	9	0.0% (0.0)	0.0% (0.0)	0.8% (0.2)	32.5% (2.1)	59.5% (2.0)	7.2% (1.2)
	Range	-	0.0% – 30.2%	0.0% – 5.6%	0.0% - 9.8%	21.3% – 53.1%	24.5% – 71.0%	0.2% – 12.1%

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

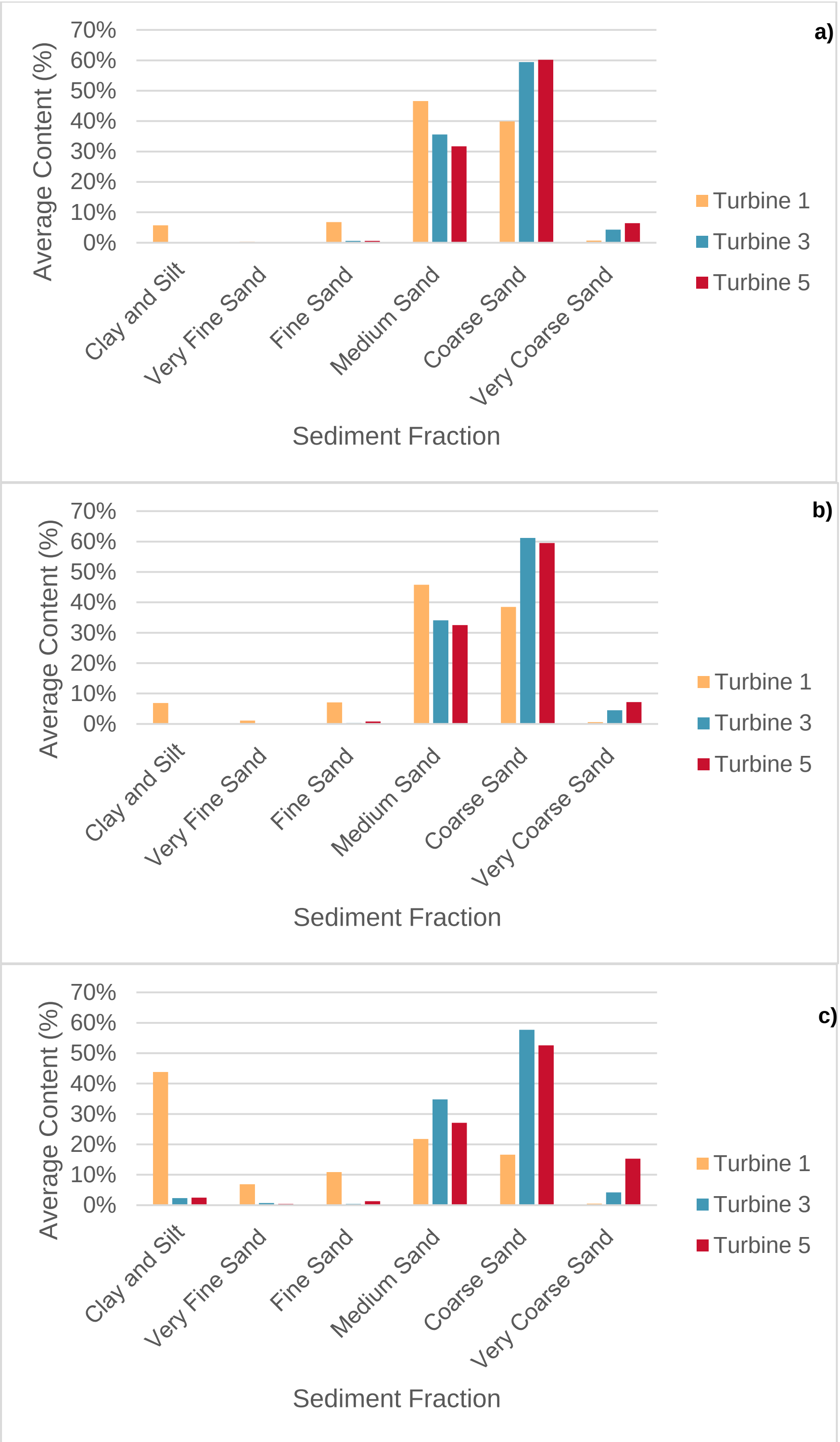


Figure 53. Changes in the average content of sediment fractions for each of the turbines in a) the 30–90 m distance bands (vessel-based sampling, n = 81), b) the very near-field area surrounding the turbines (<30 m diver-based sampling, n = 27) and c) within the footprint of the turbines (diver based sampling, n = 12) in Year 3 (only).

Note: only two samples were collected at Turbine 1, whereas five samples each were collected at Turbines 3 and 5.

3.2.3 Diver-based Seabed Photography Analysis

The Lagrangian floating camera system produced hundreds of images along each of the three diver-towed transects in Year 2 and Year 3. Field survey records for the floating camera deployment are presented in **Appendix C**.

Example imagery from Year 2, for each turbine, is presented in **Figure 54**. The images clearly show the three Turbines vary in the density of blue mussels present on the seafloor within the turbine footprints along a gradient. Specifically, in Year 2 Turbine 1 exhibited extremely dense cover of living mussels and mussel shells. The grate structure on the seafloor was covered in mussels and was not detectable in the images. Conversely, Turbine 5 had very few mussels and shells and the grate structure was not colonized. Turbine 3 was in the middle of this spectrum, although it was much more similar to Turbine 5. Furthermore, the images captured several scavenger species that were attracted to the area due to the presence of mussels, including crabs, sea stars, and snails. Also noted were several species of fish and elasmobranchs, including black sea bass, flounder, spiny dogfish, and winter skate.

In Year 3, the diver photography transects demonstrated very dense mussel cover with a high number of sea stars and crabs (**Figure 55a**). At Turbine 1, the grate was densely encrusted with fauna such as sponges and mussels with sea stars and crabs foraging around it (**Figure 55b, c**). A high frequency of black sea bass were also evident in the photographs. In Year 3, under the Turbine 3 structure was also highly populated with mussels and again, was not as dense as that recorded at Turbine 1, because at Turbine 3, some spaces existed between mussel aggregations (**Figure 55d**). However, there were numerous sea stars and crabs associated with the mussel aggregations at Turbine 3. The structures were observed to be encrusted, mussel growth is estimated to be mature given the degree of encrusting on the mussels and there is again evidence of shell debris and black sea bass (**Figure 55e, f**).

Mussel cover was also evident within the Turbine 5 structure but was more patchy with some areas of seabed unpopulated (**Figure 55g, h**). Turbine 5 grate was evidently encrusted but appeared less diverse but black sea bass were also observed in the photographs. In Year 3, there was still a gradient of denser macrofaunal coverage at Turbine 1, medium cover at Turbine 3 and least coverage at Turbine 5. However, comparing images in **Figure 54** and **Figure 55**, it is evident that there was overall higher macrofaunal cover in Year 3 compared to Year 2.

It is interesting to note from images in Year 2 that it appears the mussels were contained within the footprint of the turbine structures. The data collected, as well as diver observations, suggest mussels were absent even just outside the footprint, including at Turbine 1 in Year 2. However, in Year 3, there is evidence of the mussel growth outside of the turbine structures. Images shown in **Figure 55i-l** demonstrate a range of sizes of live mussel, in aggregations and associated macrofauna captured outside of the Turbine structures during the photography transects.

The concrete mats placed to protect portions of the cable were bare at all of the turbines in Year 2; they were not colonized by mussels or any other organisms, with the exception of encrusting sponges covering small portions (**Figure 54h**). The cable mattresses were not recorded in the footage collected Year 3 images.

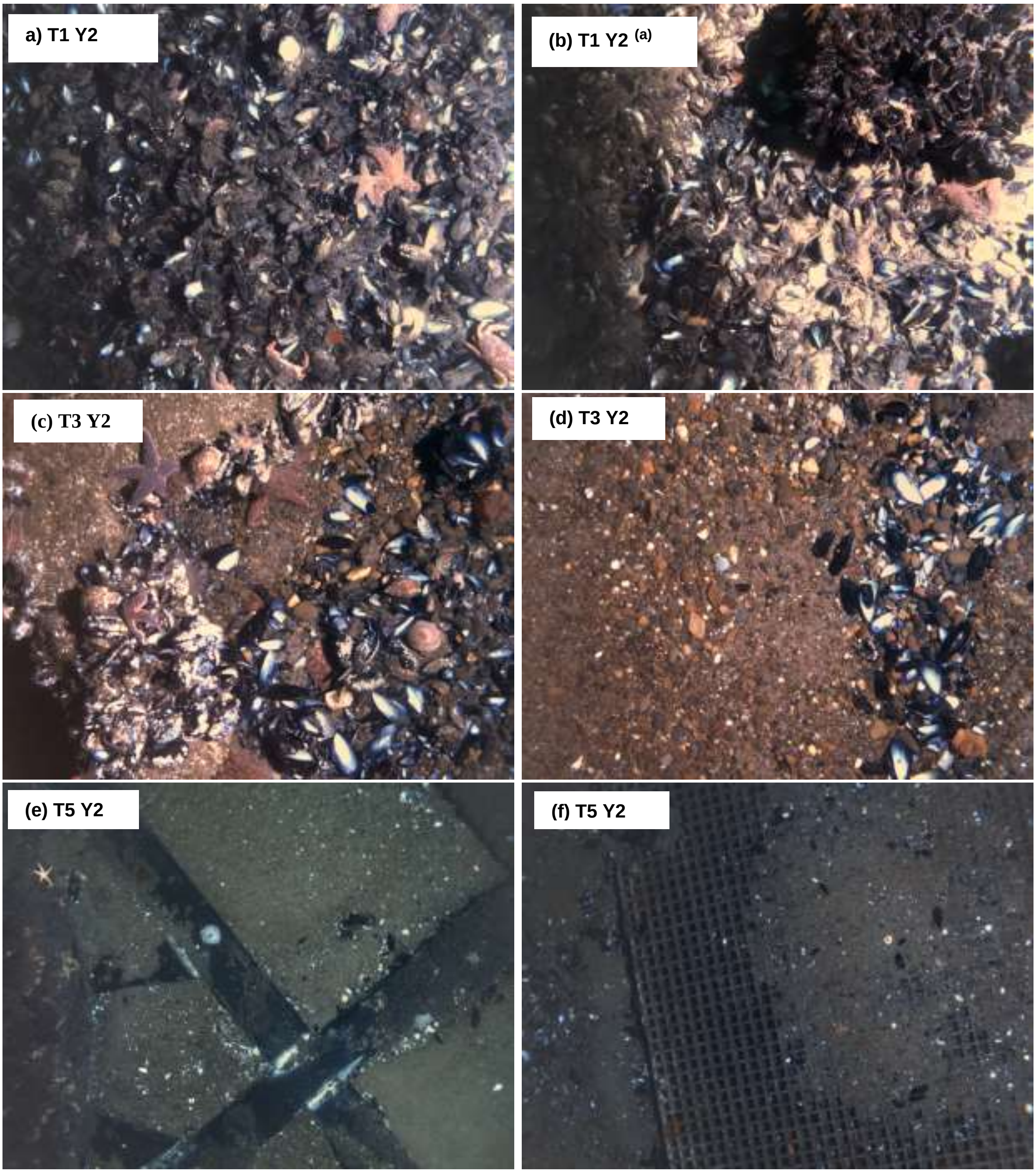


Figure 54a-f. Example images taken within the footprint of the turbine structures by the diver-towed camera system in Year 2.

Note: The images at Turbine 1 (a) and (b) show the dense cover of living mussels and shells at Turbine 1 and the heavy colonization of the grate structure on the seafloor. Image from Turbine 3 (c) and (d) show the partial colonization of the grate structure by mussels and that mussels are present to a much lesser extent. The image at Turbine 5 (e) and (f) show the lack of mussels on the seafloor and that the grate structure is not colonized. Some of the images also show the high density of scavenger species amongst the mussels, including sea stars, crabs, moon snails, which is again highlighted in image (g). Neither mussels or other organisms have colonized the protective concrete mats at any of the turbines, as shown in image (h) and (i) taken at Turbine 1. Note in (i) that the high density of mussels extends towards the edge of the mat (in bottom left corner), but then ceases.

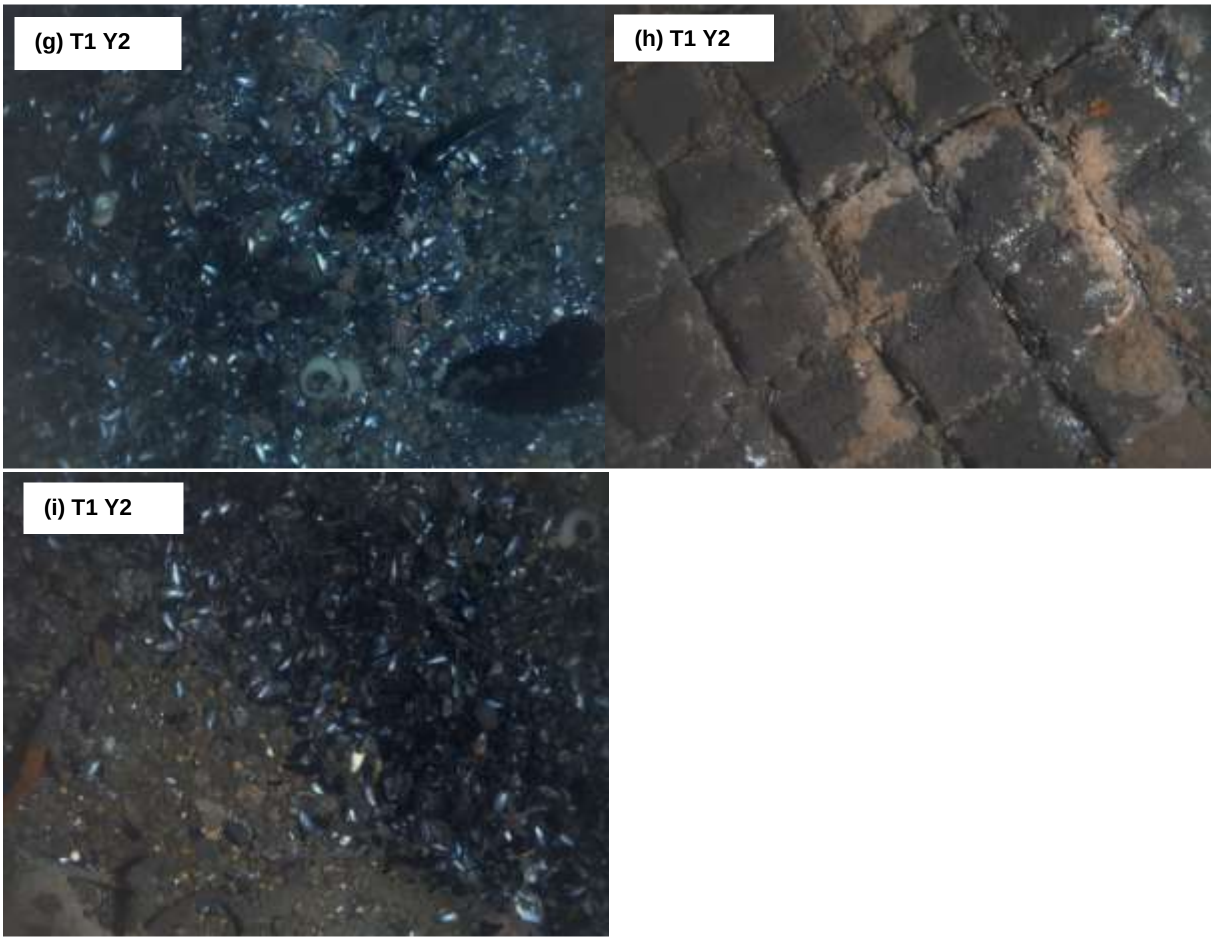


Figure 54g-i. Example images taken within the footprint of the turbine structures by the diver-towed camera system in Year 2.

Note: The images at Turbine 1 (a) and (b) show the dense cover of living mussels and shells at Turbine 1 and the heavy colonization of the grate structure on the seafloor. Image from Turbine 3 (c) and (d) show the partial colonization of the grate structure by mussels and that mussels are present to a much lesser extent. The image at Turbine 5 (e) and (f) show the lack of mussels on the seafloor and that the grate structure is not colonized. Some of the images also show the high density of scavenger species amongst the mussels, including sea stars, crabs, moon snails, which is again highlighted in image (g). Neither mussels or other organisms have colonized the protective concrete mats at any of the turbines, as shown in image (h) and (i) taken at Turbine 1. Note in (i) that the high density of mussels extends towards the edge of the mat (in bottom left corner), but then ceases.

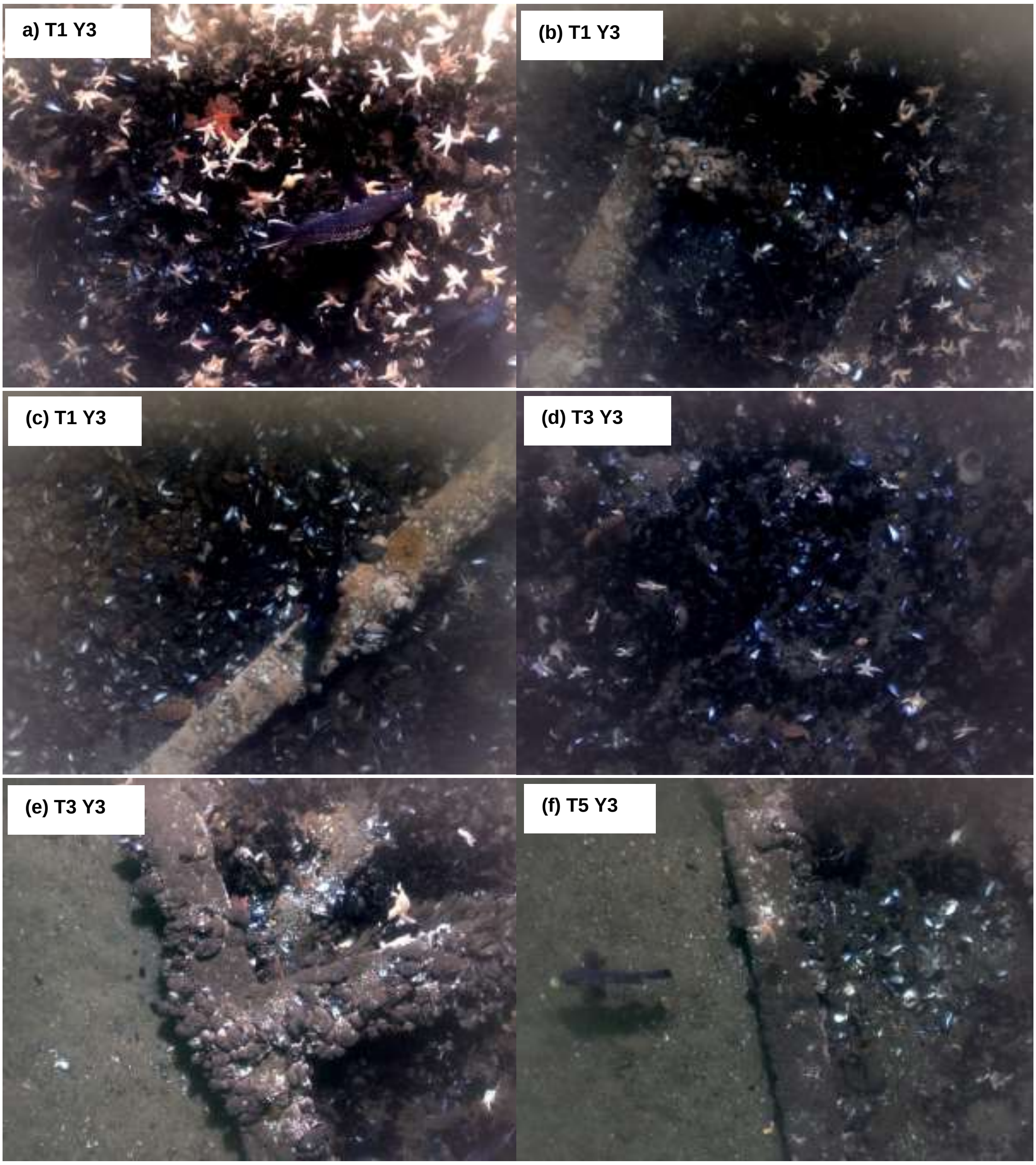


Figure 55a-f. Example images taken within the footprint of the turbine structures by the diver-towed camera system in Year 3.

Note: Image (a) shows very dense mussel coverage and associated fauna at Turbine 1 and the infrastructure visible is shown in (b) and (c) but is also densely covered with mussels an encrusting fauna. Images from Turbine 3 (c), (d) and (e) also show mussel and epifaunal coverage although to a lesser extent that Turbine 1. The images at Turbine 5 (f), (g) and (h) show patchy mussel aggregation but structures are encrusted with epifauna. Some of the images also show the high density of scavenger species amongst the mussels, particularly sea stars and crabs, with numerous blackfish. Images (i) through to (l) demonstrate a variety of sizes of live mussel aggregations recorded outside of the turbine structures during the photography transects, again with associated fauna such as crabs, sponge, sea stars, and black sea bass. Images were in photography transect outside of the structures of: Turbine 1 (i), Turbine 3 (j, k) and Turbine 5 (l).

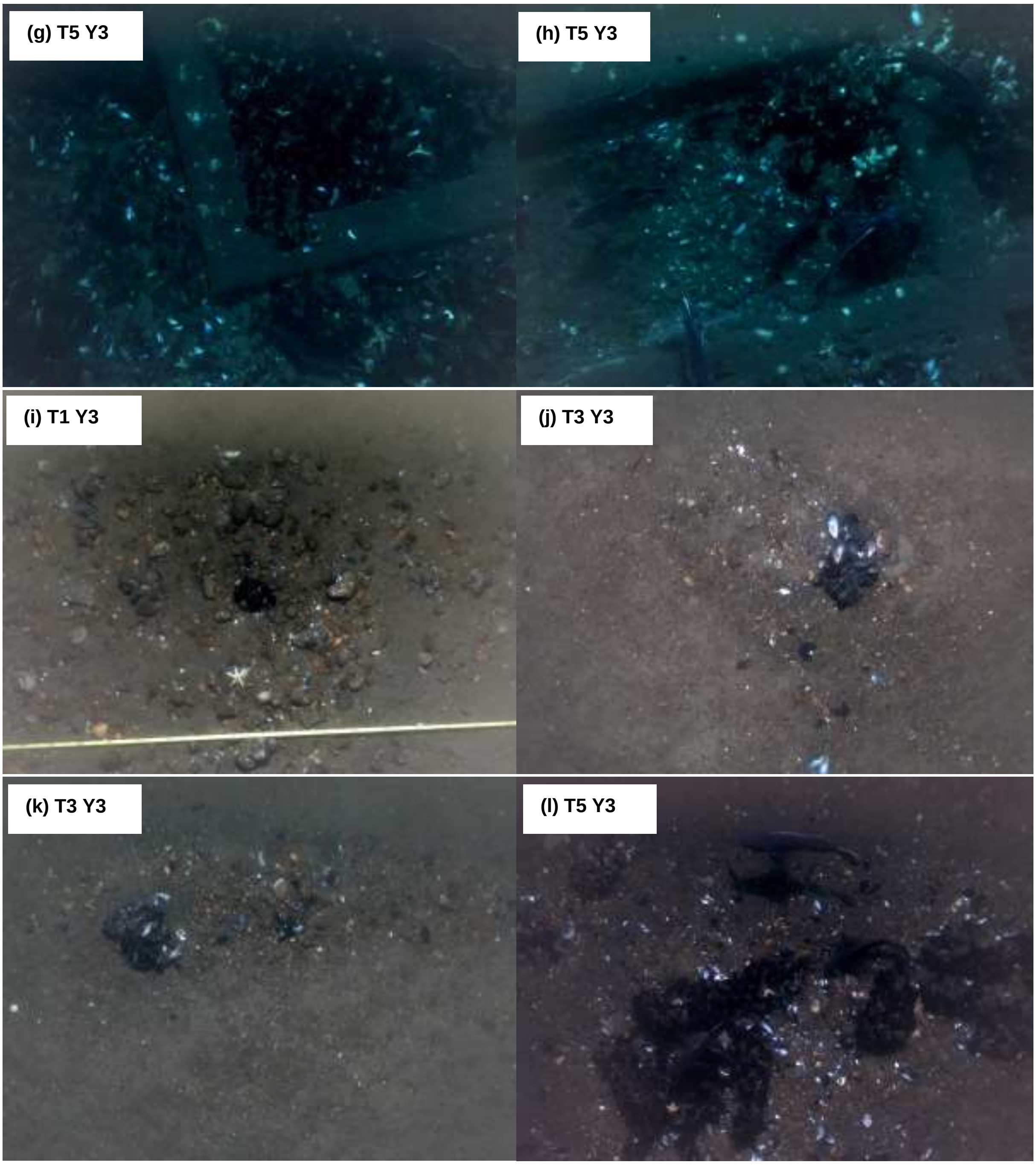


Figure 55g-l. Example images taken within the footprint of the turbine structures by the diver-towed camera system in Year 3.

Note: Image (a) shows very dense mussel coverage and associated fauna at Turbine 1 and the infrastructure visible is shown in (b) and (c) but is also densely covered with mussels an encrusting fauna. Images from Turbine 3 (c), (d) and (e) also show mussel and epifaunal coverage although to a lesser extent that Turbine 1. The images at Turbine 5 (f), (g) and (h) show patchy mussel aggregation but structures are encrusted with epifauna. Some of the images also show the high density of scavenger species amongst the mussels, particularly sea stars and crabs, with numerous blackfish. Images (i) through to (l) demonstrate a variety of sizes of live mussel aggregations recorded outside of the turbine structures during the photography transects, again with associated fauna such as crabs, sponge, sea stars, and black sea bass. Images were in photography transect outside of the structures of: Turbine 1 (i), Turbine 3 (j, k) and Turbine 5 (l).

3.2.4 Sediment Organic Content

The results of the analysis for Total Organic Matter (TOM) and Total Organic Content (TOC) of the samples collected within the footprint of the turbine structures and in the very near-field area around the turbines are presented in **Appendix F** and are summarized in **Figure 56, Figure 57, Table 33,** and **Table 34**. Since the organic content of both the diver and Smith McIntyre sample methods were considered different (**Section 3.3.2.3**), comparisons with the vessel-based sampling methods described in **Section 3.1.5** are omitted.

In Year 2, the levels of TOM and TOC within the footprint of Turbine 1 were substantially higher than those recorded within the footprint of Turbines 3 and 5 (**Table 33**). The average level of TOC for the samples taken within the footprint of Turbine 1 was 2.5%, and the maximum level was 5.4% (**Table 33**). The mean and maximum TOC levels at Turbine 1 were 1.1 and 2.3%, respectively. These levels contrast with those recorded at Turbines 3 and 5 samples, which had lower TOM and TOC levels. Specifically, for Turbine 3 and 5, respectively, mean TOM was 0.5 and 0.3%, mean TOC was 0.2 and 0.1%, and the TOM range was 0.3 to 0.8% and 0 to 0.9%, and TOC range was 0.1% to 0.3 and 0 to 0.4%.

In Year 3, a similar pattern was observed. Although only two samples were obtained from within the footprint of Turbine 1 (due to high mussel density), those samples recorded a much higher TOM and TOC than observed at Turbines 3 and 5 (**Table 33**). Within the footprint of Turbine 1, the mean TOM was 3.1% compared to 0.9 and 0.7% at Turbine 3 and 5, respectively. Similarly, the mean TOC at Turbine 1 was 1.4% compared to 0.4% and 0.3% at Turbines 3 and 5, respectively.

A one-way ANOVA ($\log_{10}$+1 transformed data) demonstrated that both TOM and TOC levels in the Year 2 sediment samples from under Turbine 1 were significantly higher than those recorded in samples collected under Turbines 3 and 5 (p <0.05). A similar difference was noted in Year 3, with the TOM and TOC levels recorded under Turbine 1 being significantly higher than those recorded under Turbine 5 ($F_{(5,22)} = 5.851$, p <0.001) and ($F_{(5,22)} = 5.90$, p <0.001), respectively. In Year 3, the TOM and TOC levels under Turbine 1 and Turbine 3 were not statistically different.

Table 33. Average total organic content and total organic carbon content (and standard error) for samples collected within the footprint of each turbine structure in Year 2 and 3.

		Sample number (n)	Average (s.e.) total organic matter (%)	Average (s.e.) total organic content (%)
Year 2	Turbine 1	5	2.5% (0.7)	1.1% (0.3)
	Turbine 3	5	0.5% (0.1)	0.2% (0.0)
	Turbine 5	5	0.3% (0.2)	0.1% (0.1)
Year 3	Turbine 1	2	3.1% (1.6)	1.4% (0.7)
	Turbine 3	5	0.9% (0.3)	0.4% (0.1)
	Turbine 5	5	0.7% (0.2)	0.3% (0.1)

In Year 3 (only), the area immediately surrounding the turbine (i.e., within 30 m of the center of the turbines but outside of the turbine footprint) was sampled for the first time. The data show that the TOM and TOC was higher in the very near-field area surrounding Turbine 1 compared to Turbines 3 and 5 (**Table 34, Figure 57**).

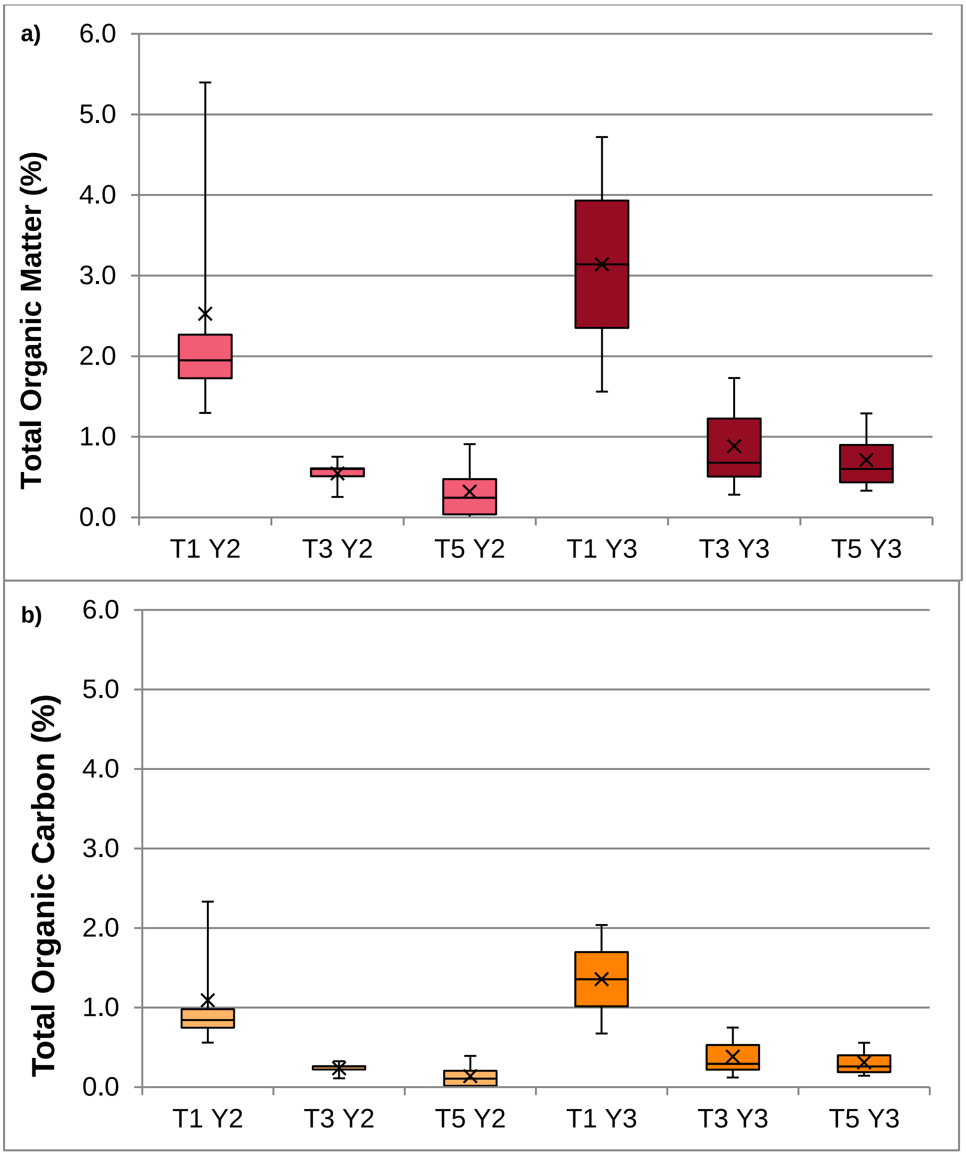


Figure 56. Box plots summarizing the a) TOM and b) TOC content of diver-based sediment samples collected within the footprint of Turbine foundations (Turbine 1, 3 and 5) in Year 2 and Year 3.

The mean TOM around Turbine 1 was 1.9% compared to 0.5 and 0.6% around Turbines 3 and 5, respectively. The mean TOC around Turbine 1 was 0.8% compared to 0.2 and 0.3% around Turbines 3 and 5, respectively. The TOM and TOC at Turbine 1 was more variable than at Turbine 3 and 5 (**Figure 57**). Comparing these figures (**Table 34**) to the figures from underneath the turbines (**Table 33**), the average TOM and TOC was lower in the very near-field area at Turbines 1 and 3 but increased at Turbine 5.

Overall, considering the samples from underneath the turbine (**Table 33**), and the samples in the very near-field area around the turbines (**Table 34**) it can be observed that there is a gradient of increased TOM and TOC with increasing distance from the turbines (**Figure 58**). This trend is most pronounced in the very near-field area to Turbine 1 (R^2 = 0.2219) and Turbine 3 (R^2 = 0.5807) and less obvious at Turbine 5 (R^2 = 0.0453).

Table 34. Average TOM and TOC content (and standard error) for samples collected within the very near-field area (i.e., within 30 m of the center) of each turbine structure in Year 3.

		Average (s.e.) total organic matter (TOM %)	Average (s.e.) total organic carbon (TOC %)
Year 3	Turbine 1	1.9% (1.3)	0.8% (0.6)
	Turbine 3	0.5% (0.1)	0.2% (0.0)
	Turbine 5	0.6% (0.1)	0.3% (0.0)

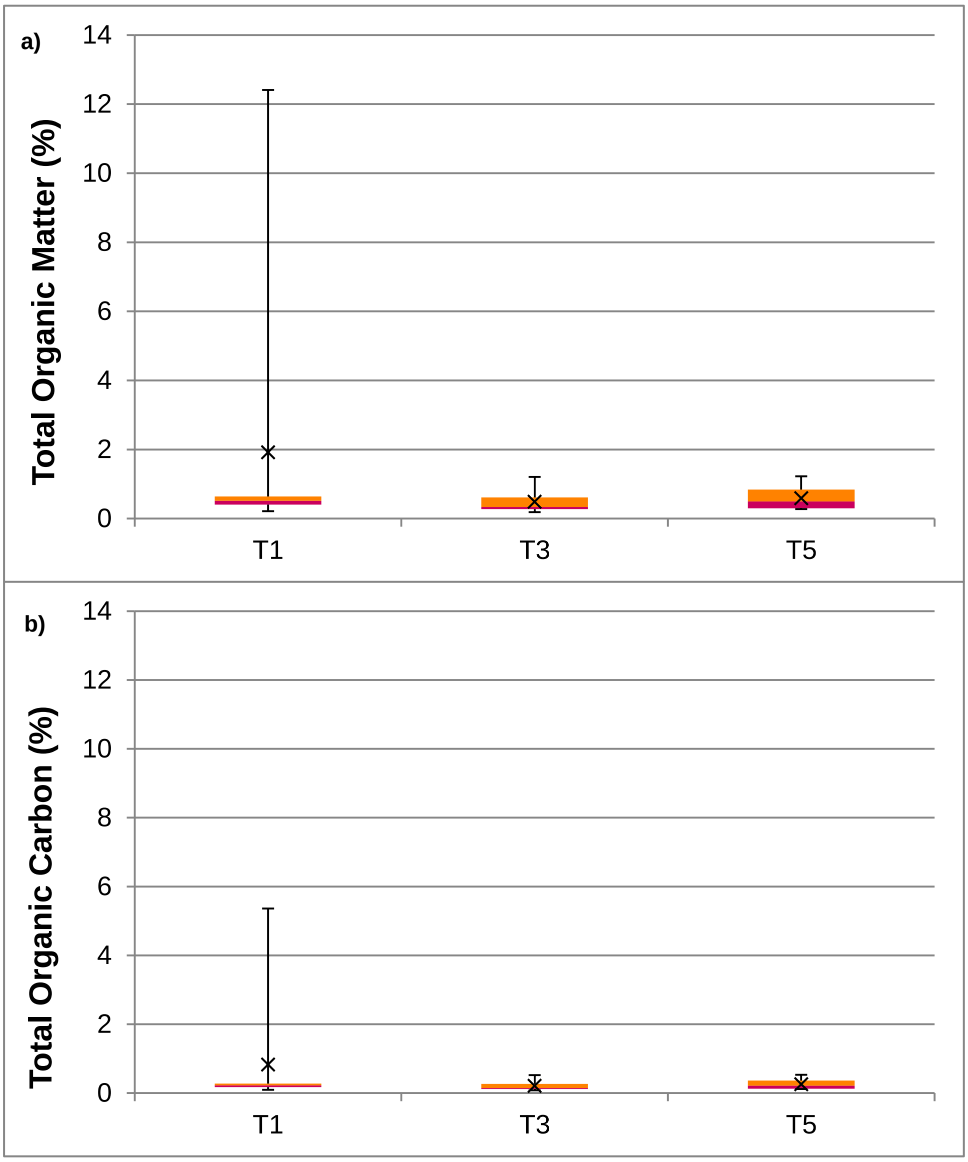


Figure 57. Box plots summarizing the a) TOM and b) TOC content of diver-based sediment samples collected in the very near-field area surrounding Turbines 1, 3 and 5 (i.e., less than 30 m from the center of the turbine) in Year 3 (only).

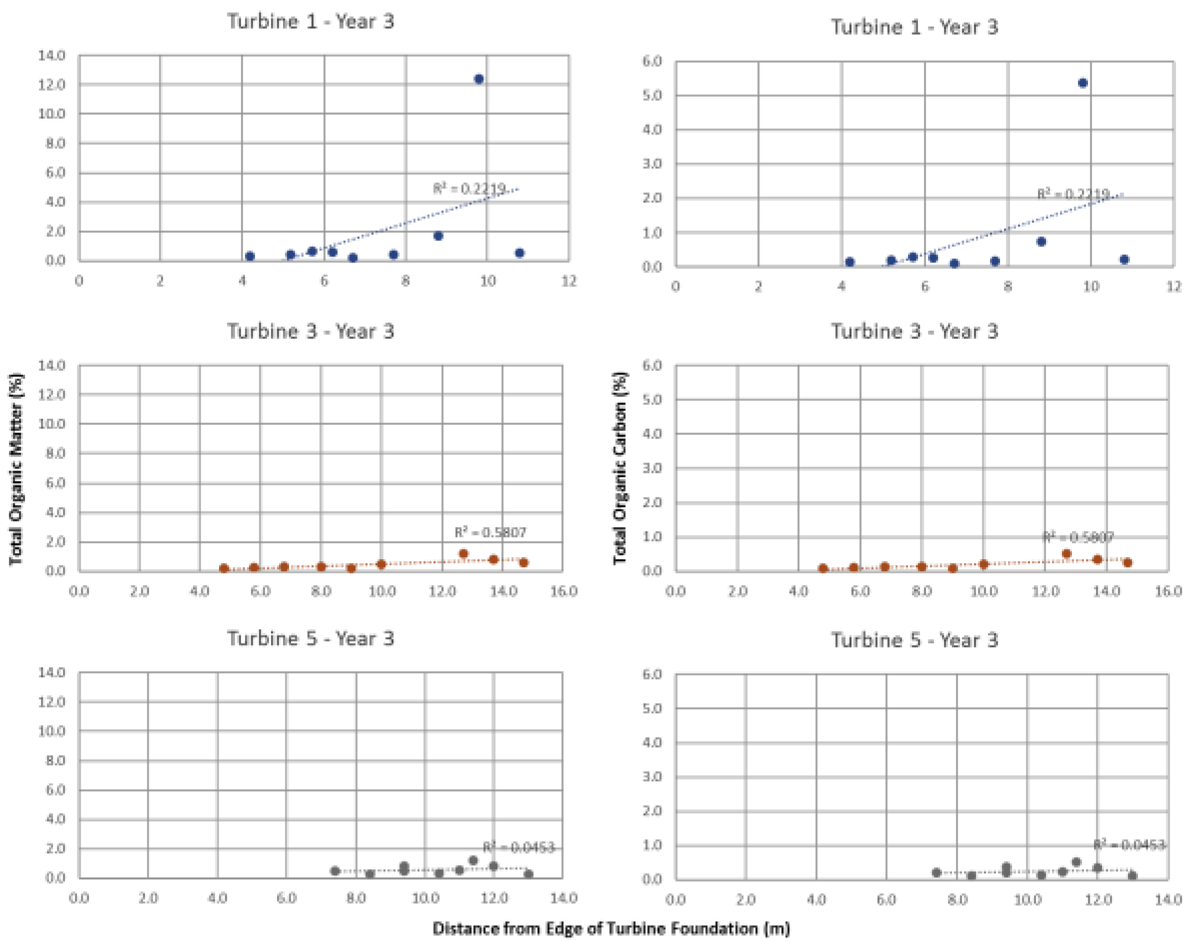


Figure 58. Levels of TOM and TOC in diver-collected sediment samples from the very near-field area, plotted against distance from the edge of each turbine structure (Turbine 1, 3 and 5) at BIWF for Year 3 (only).

3.2.5 Macrofaunal Analysis

A species abundance matrix for the macrofaunal samples collected within the footprint of each turbine structure (Year 2 and Year 3) and the very near-field area (Year 3) is presented in **Appendix G**.

For Year 2 samples, it should be noted that the size of samples collected within a given turbine are comparable, although the sample size amongst turbines varied considerably due to inconsistencies in diver sampling technique (**Table 35**). In Year 3, efforts were made to standardize the sampling strategy by incorporating the use of a quadrat (see **Section 2.3.2.1**).

In Year 2, the smallest samples were collected under Turbine 3 (average weight = 2.4 kilograms [kg], std dev = 1.1), while Turbine 5 had the largest samples (average weight = 16.9 kg, std dev = 1.6). Samples from Turbine 1 fell in the middle of the spectrum (average weight = 10.9 kg, std dev = 2.0). The samples were not standardized (e.g., by weight or volume) in efforts to avoid knowingly introducing error (**Section 1.4.3**). As such, the results presented for Year 2 should be considered relative, rather than direct, descriptions and comparisons. There was less variation between turbines in the average weight of the samples collected in Year 3 (**Table 35**), both within the Turbine footprint (average weight = 6.2 kg, std dev = 3.1) and the very near-field area (average weight = 7.6 kg, std dev = 1.8).

For this reason, the results from Year 2 and Year 3 are reported separately. The Year 2 results are reported in **Section 3.2.5.1**. The Year 3 results are further separated into the findings from samples collected within the footprint of the turbines (**Section 3.2.5.2.**) and the findings from the samples collected in the very near-field area around the turbines (<30 m, **Section 3.2.5.3.**). Each section first reports on the overall results (phyla present, most abundant and most frequently recorded species) and then draws comparisons between the turbines. The biomass of the macrofauna from the Year 3 turbine footprints and the very near-field area is reported in **Section 3.2.5.4**. Lastly, comparisons of macrofaunal characteristics are drawn, where reasonable, between the three different turbine study areas: footprints, very near-field, and 30 to 90 m from the center of the turbines (**Section 3.2.5.5**).

Table 35. Summary of average volumes and weights of all macrofaunal samples collected by divers within the footprint and the very near-field area of each turbine structure in Year 2 and Year 3.

Year	Sample area	Sample metric	Turbine 1	Turbine 3	Turbine 5	All turbines combined
2	Footprint	Average Weight (kg)	10.9	2.4	16.9	10.0
3	Footprint	Average Weight (kg)	6.1	5.8	6.7	6.2
	Very Near-field Area	Average Weight (kg)	8.2	7.7	6.9	7.6
Note: Sample weight is heavily influenced by the concentration of larger sediment particles (i.e., pebble, gravel, and cobbles).						

3.2.5.1 Year 2 Macrofaunal Analysis of Turbine Footprints

3.2.5.1.1 Overall Results – Year 2

A summary of the total species abundance and species richness for the diver-based samples collected in Year 2 within the footprint of the turbines is provided in **Table 36**. A total of 70 macrofaunal species represented by 3,521 individuals were recorded from the 15 grab samples. Considering all samples by phylum, the majority of the macrofauna recovered were nematodes, comprising 49% of the total species abundance, followed by Mollusca, Arthropoda (crustaceans) and Annelida (polychaetes) in similar proportions (20%, 16% and 15%, respectively) (**Figure 59**). Individuals from these four phyla were recovered within all 15 samples. The remaining organisms belonged to the phyla Nemertea, Copepoda, and Platyhelminthes, although in negligible numbers (combined total = 11 individuals). For species richness, organisms were resolved to the species level for three phyla. Of these, annelids contributed 47% to the species richness, and crustaceans and mollusks contributed 31% and 16%, respectively (**Figure 59**).

The most conspicuous species across all the samples in terms of total abundance were nematodes, followed by the blue mussel, *Mytilus edulis* (**Table 37**). Also dominant were the barnacle, *Balanus*; the amphipods, *Unciola irrorata* and *Byblis serrata*; and the polychaetes *Polygordius* spp. and *Lumbrinereis fragilis*. In general, these dominant species were also the most frequently occurring; four were recovered in 14 or all 15 samples (nematodes, *Mytilus edulis*, *Balanus* spp., and *Lumbrinereis fragilis*), and the remaining three were present in 11 samples or fewer (*Polygordius* spp., *Unciola irrorata*, *Byblis serrata).*

Table 36. Summary of species abundance and species richness for all macrofaunal samples collected within the footprint of each turbine structure in Year 2.

	Turbine 1	Turbine 3	Turbine 5	All Turbines combined
Total Species Richness	26	36	50	70
Mean Species Richness	11.4	15.4	23.2	--
Range of Species Richness per Sample	8-16	11-26	17-32	8-32
Total Species Abundance	429	270	2,822	3,521
Total Species Abundance (Nematoda excluded)	349	249	1,200	1,798
Mean Species Abundance	86	54	564	--
Range of Species Abundance per Sample	45-128	29-94	420-716	29-716

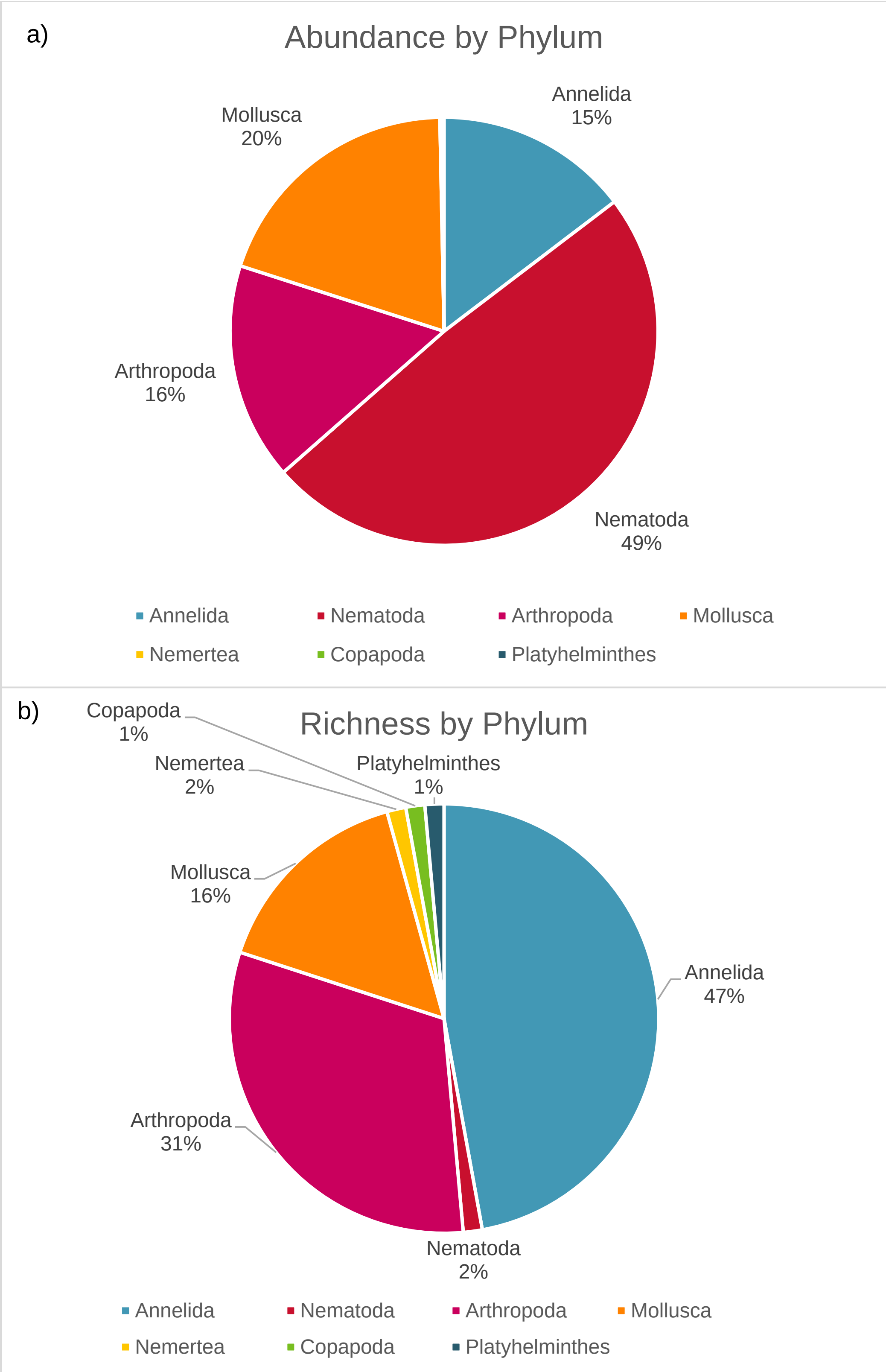


Figure 59. Proportion contribution of macrofauna characterized by phylum to a) total abundance, and b) total species richness for all macrofaunal samples collected within the footprint of each turbine structure (Turbines 1, 3, 5) in Year 2.

Table 37. Most abundant and frequently occurring species for all diver-based samples collected under the structure of each turbine in Year 2. Note: Asterisk denotes species listed as both abundant and frequent.

Species	taxonomic group	total abundance	Occurrence (n=15)
Most abundant (> 100 individuals)			
Nematode*	Nematoda	1721	15
*Mytilus edulis**	Mollusca	668	15
Balanus spp.*	Arthropoda	243	14
*Unciola irrorata**	Arthropoda	159	11
Polygordius spp.*	Annelida	137	10
Byblis serrata	Arthropoda	109	7
*Lumbrinereis fragilis**	Annelida	99	14
Most frequent (> 10 samples)			
Nematode*	Nematoda	1721	15
*Mytilus edulis**	Mollusca	668	15
Balanus spp*	Mollusca	243	14
*Lumbrinereis fragilis**	Annelida	99	14
*Unciola irrorata**	Arthropoda	159	11
Polygordius spp*	Annelida	137	10
Goniadella gracilis	Annelida	25	10

3.2.5.1.2 Comparison of Individual Turbines – Year 2

Macrofaunal patterns of species abundance and richness vary considerably within the footprint of the three turbine structures in Year 2 (**Table 36**). Species abundance was substantially higher at Turbine 5, with a total of 2,822 individuals recovered in the five samples (mean = 564). In contrast, Turbine 1 has total abundance of 429 individuals (mean = 86), and Turbine 3 has 270 individuals (mean = 54). A one way ANOVA confirmed significant differences in species numbers between the three turbine locations ($F_{(2,14)} = 3.8853$, $p = 0.009$) and *post-hoc* Tukey HSD tests highlighted that species numbers at Turbine 5 were significantly higher than those at Turbine 1 ($p < 0.05$). Similarly, there were significant differences in faunal abundance between the three turbines (one-way ANOVA) ($F_{(2,14)} = 3.8853$, $p < 0.001$) with Turbine 5 supporting significantly higher abundances than Turbines 1 and 3 (Tukey HSD $p < 0.05$). This difference is partially attributed to the elevated presence of nematodes at Turbine 5, which accounted for nearly 60% of the total abundance. The variations in sample size at each turbine also likely explains some of the difference, as there is a clear (although non-linear) pattern of increasing abundance with increasing sample size. However, this pattern does not hold true for species richness across the turbines. While total richness is greatest at Turbine 5 (n= 50, mean = 23.2), which has the largest sample size, Turbine 1, with the intermediate sample size, has the lowest richness (n = 26; mean = 11.4). Turbine 3 is approximately in the middle of this range, with a species richness of 36 (mean = 15.4).

The turbines also show some distinction with respect to their dominant species. Barnacles, mussels, and nematodes dominate or co-dominate the five samples collected under Turbine 1. At Turbine 3, barnacles dominate three samples, while *Polygordius* spp. and *Unciola irrorata* each dominate one sample. At Turbine 5, four samples were overwhelmingly dominated by nematodes, followed by mussels for three samples and *B. serrata* for one sample. The fifth sample recorded equal abundances of nematodes and mussels.

ANOSIM results indicate there are differences in community composition between the three turbines ($R = 0.791$; $p = 0.001$). However, again, it should be noted that these statistical results likely also reflect the discrepancy in species abundances because of the variations in sample size across the turbines. As such, nMDS plot and the SIMPER outputs may be considered more useful for interpreting distinctions (**Table 38** and **Figure 60**).

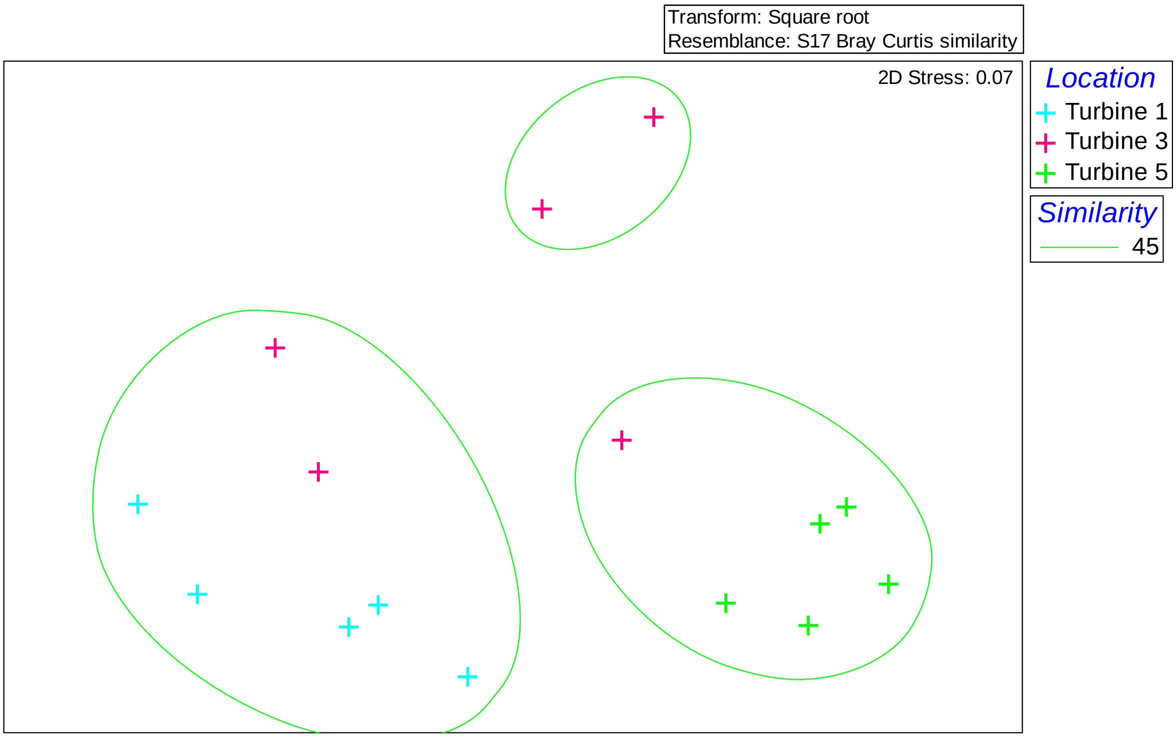


Figure 60. Non-metric MDS plot of diver-based samples collected with the footprint of each turbine in Year 2.

The nMDS plot (**Figure 60**) shows that the samples broadly separate out by turbine, but Turbine 3 had an intermediate community, exhibiting faunal attributes also characteristic of Turbines 1 and 5. Indeed, at the selected similarity level (45%) three discrete sample clusters were apparent. For example, the cluster representing Turbine 1 also contained two samples collected below Turbine 3. Key characterizing species included the blue mussel *Mytilus edulis*, the barnacle *Amphibalanus amphitrite*, nematodes and the polychaete *Lumbrinereis fragilis.* The next largest cluster encompassed all the samples collected below Turbine 5 together with one of the samples collected below Turbine 3. These samples were characterized by a high abundance of nematodes together with mussels, amphipods *U. irrorata* and *B. serrata,* and polychaetes *Pisione* sp. *Polygordius* spp and *L. fragilis*. The third group contained the remaining two samples collected below Turbine 3 and was characterized by comparatively low abundances of polychaetes *Polygordius* spp., *P. caeca*, *G. gracilis* and *L. fragilis*, amphipods, *B. serrata* and barnacles *Balanus amphitrite*.

Examination of species abundance and richness further indicate Turbine 3 was intermediate to Turbines 1 and 5. While the Turbine 3 samples were similar to those of Turbine 5 with regards to macrofaunal community composition, the species at Turbine 3 were found in overall lesser abundances. In particular, Turbine 5 had substantially higher densities of the blue mussel *M. edulis*, the polychaete *Polygordius* spp., and the amphipods *U. irrorata* and *B. serrata*, in addition to nematodes. Turbine 3 was more similar to Turbine 1 with respect to species abundance, both recording relatively low abundance for all species, with a few exceptions. Note that while the samples show Turbine 5 with the highest number of mussels, imagery collected by the divers indicate that mussel abundance was substantially greater at Turbine 1 (**Figure 54b** and **Figure 55**). The discrepancy between the datasets was attributed to the sampling technique. Specifically, at Turbine 1, the divers cleared away, rather than retained, the mussels on the seafloor while collecting the grab sample.

Turbine 1 is conspicuously less similar to Turbine 5 in terms of species composition. For example, two of the species with high abundances in Turbine 5 are not present at all in Turbine 1, namely *Byblis serrata* and *Polygordius* spp. Further, no amphipods were recovered within any of the Turbine

1 samples, with the exception of minor abundances of *Unciola irrorata* (19 individuals). Polychaetes were noticeably absent only at Turbine 1, including *L. acuta*, *Parapionosyllis longicirrata*, and *Pisione* spp., in addition to *Polygordius* spp. Unique to Turbine 1 is the polychaete *Harmothoe* spp., although in relatively minor abundances (20 individuals), and the relatively high abundance of barnacles (130 individuals, versus 76 and 37 at Turbines 3 and 5, respectively).

The SIMPER output also further support macrofaunal community composition changes along a gradient moving from Turbine 1 to 5. The SIMPER output reports that of the six contributing species, two are also listed as contributors for Turbine 1, another two species also contribute to Turbine 5, and the remaining two species are contributors for all three turbines (**Table 38**). The macrofauna composition at Turbine 3 is also more variable, likely due to its intermediate position along the gradient, further reflecting the transition between Turbines 1, 3 and 5. Evidence of this can be seen in the nMDS plot, for which Turbine 3 samples are more loosely scattered on the plot, whereas the samples for Turbines 1 and 5 are shown as more cohesive clusters (**Figure 60**). Additionally, the SIMPER output reports Turbine 3 has the lowest average similarity across its fives samples (44.53%). In comparison, the average similarity for Turbines 1 and 5 was 54.13 and 66.46%, respectively (**Table 38**).

Table 38. SIMPER results showing average similarity and top contributing species (70% cut-off) of diver-based samples collected within the footprint of each turbine in Year 2.

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

3.2.5.2 Year 3 Macrofaunal Analysis of Turbine Footprints

3.2.5.2.1 Overall Results – Year 3 Footprints

A summary of the total species abundance and richness for the diver-based samples collected in Year 3 within the footprint of the turbines in provided in **Table 39**. A total of 78 macrofaunal species represented by 13,247 individuals were recorded from 12 diver grab samples. Only two samples were obtained from the footprint of Turbine 1 due to the high density of mussels making it difficult for divers to collect the samples. The majority of macrofauna were Mollusca, comprising 73% of the total species abundance which was a major increase from Year 2 (**Figure 61**). Annelida and Arthropoda comprised 13% and 9%, respectively, followed by Nematoda (4%) which was a major reduction from the Year 2 abundance (**Figure 59** and **Figure 61**). Specimens from the phyla Cnidaria (1%), Nemertea, Echinodermata, Platyhelminthes and Chordata were also present within the footprint of the turbines but in very low abundances (<0.1% each).

Annelida was the most species rich phylum, comprising 44% of the total species richness. Arthropoda contributed 30% and Mollusca 16% of total species richness while the remaining phyla contributed between 1 and 3% (noting that the Nematoda were not defined to species level). All aforementioned phyla were represented within the footprint of all Turbines apart from the Platyhelminthes which were absent from the Turbine 5 footprint.

In Year 3, *Mytilus edulis* overwhelmingly dominated the samples, with a combined total of 9,112 individuals (**Table 40**), of which 77% occurred within the footprint of Turbine 1. The barnacle, *Balanus* sp. and Nematoda sp. were also dominant (608 and 545, respectively), similar to Year 2. Numerous polychaete species had a high abundance (100 to 400 individuals per species) as did the arthropods *Caprella linearis* (skeleton shrimp) and *Cancer irroratus* (Atlantic rock crab) and mollusks (snails) *Astyris lunata* and *Cotonopsis lafresnay*. The most frequently recorded species were *M. edulis* and *Nematoda* spp. which were present in all 12 samples. Also frequent, found in 11 of 12 samples were the barnacle, *Balanus* sp., the amphipod *Jassa marmorata*, the mollusk *Crepidula fornicata* (slipper snail), and three species of polychaetes, *Captilla* sp., *Phylldoce maculata*, *L. fragilis.* Two species were present in 10 of 12 samples, the polychaetes *H. extenuata* and *Gyptis vittata*.

Table 39. Summary of species abundance and species richness for all macrofaunal samples collected within the footprint of each turbine structure in Year 3.

	Turbine 1	Turbine 3	Turbine 5	All turbines combined
Total Species Richness	40	49	56	78
Mean Species Richness	34.5	30.8	24.6	28.8
Range of Species Richness per Sample	32-37	26-36	17-34	17-37
Total Species Abundance	7,915	3,691	1,641	13,247
Total Species Abundance (Nematoda excluded)	7,811	3,459	1,432	12,702
Mean Species Abundance	3,957.5	738.2	328.2	1,103.9
Range of Species Abundance per Sample	3,036-4,879	391-1,191	142-571	142-4,879
Mean Diversity (H’)	0.630	2.051	1.958	1.775
Mean Richness (d)	4.053	4.580	4.199	4.333
Mean Eveness (J’)	0.179	0.600	0.608	0.533
Mean Dominance (1-ʎ)	0.218	0.751	0.709	0.645

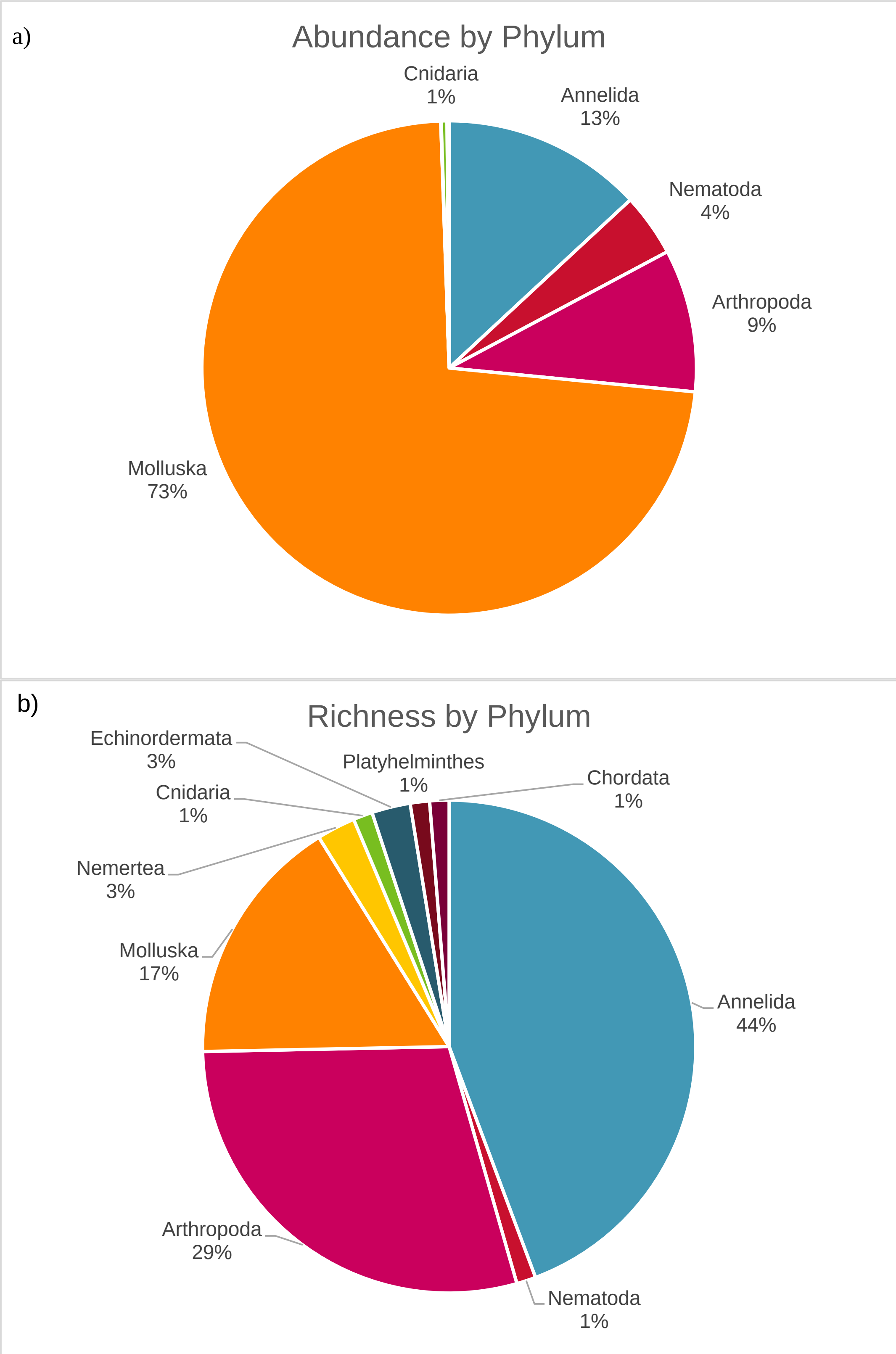


Figure 61. Proportion contribution of macrofauna characterized by phylum to a) total abundance, and b) total species richness for all macrofaunal samples collected within the footprint of each turbine structure (Turbines 1, 3, 5) in Year 2.

Table 40. Most abundant and frequently occurring species for all diver-based samples collected from within the footprint of each turbine in Year 3. Note: Asterisk denotes species listed as both abundant and frequent.

Species	Taxonomic group	Total abundance	Occurrence (n = 12)
Most abundant (> 100 individuals)			
*Mytilus edulis**	Mollusca	9112	12
Balanus spp.*	Arthropoda	608	11
Nematoda spp.*	Nematoda	545	12
Polygordius spp.	Annelida	387	6
*Harmothoe extenuata**	Annelida	353	10
*Crepidula fornicata**	Mollusca	271	11
Lepidonotus squamata	Annelida	271	8
Capitella sp.*	Annelida	235	11
Caprella linearis	Arthropoda	203	9
Astyris lunata	Mollusca	118	7
*Phyllodoce maculata**	Annelida	113	11
Cancer irroratus	Arthropoda	110	7
Cotonopsis lafresnayi	Mollusca	107	5
Most frequent (> 10 samples)			
*Mytilus edulis**	Mollusca	9112	12
Nematoda spp.*	Nematoda	545	12
Balanus spp.*	Arthropoda	608	11
*Crepidula fornicata**	Mollusca	271	11
Capitella sp.*	Annelida	235	11
*Phyllodoce maculata**	Annelida	113	11
Jassa marmorata	Arthropoda	72	11
Lumbrineris fragilis	Annelida	50	11
*Harmothoe extenuata**	Annelida	353	10
Gyptis vittata	Annelida	44	10

3.2.5.2.2 Comparison of Individual Turbines – Year 3 Footprints

Similar to Year 2, macrofaunal patterns of species abundance and richness varied considerably within the footprint of the three turbine structures in Year 3 (**Table 39, Figure 62**). In Year 3, species abundance within the footprint of Turbine 1 far exceeds that of the others despite the lower sample number (n = 2, compared to n = 5). Turbine 1 had a total species abundance of 7,915 (mean = 3,957.5) whereas the total species abundance for Turbine 3 was 3,691 (mean = 738.2) and 1,641 for Turbine 5 (mean = 328.2). Where the discrepancy in Year 2 was attributed to the high nematode abundance, this was not a feature in the Year 3 samples. There was however still a strong gradient in species richness with Turbine 5 being the lowest with the broadest range, Turbine 1 being the highest and Turbine 3 being in the middle (**Figure 62**). The opposite gradient is true for species abundance, (i.e. Turbine 1 had the greatest abundance and Turbine 5 the least).

Mean values for Margalef's richness were broadly comparable across the three turbine sites varying between 4.052 (Turbine 1) to 4.199 (Turbine 5) to 4.580 (Turbine 3). However, the mean value for Shannon Weiner diversity (H') was markedly lower at Turbine 1 (0.630) compared to those at Turbine 3 (2.051) and Turbine 5 (1.958) despite the comparatively higher numbers of species and abundance present. Similarly, the mean values for Pielou's eveness and Simpson's dominance were distinctly lower at Turbine 1 (0.179 and 0.218 respectively) compared to those at Turbine 3 (0.600 and 0.751, respectively) and Turbine 5 (0.608 and 0.709 respectively).

For the Year 3 macrofaunal data, a one-way ANOVA confirmed differences in the species abundance between the three turbines ($F_{(2, 4)} = 24.08$, $p = 0.005$) with the footprint of Turbine 1 being significantly greater in abundance than that of Turbines 3 and 5 which were similar (**Figure 62**). There was, however, no significant differences in species richness between the turbine footprints ($p > 0.05$).

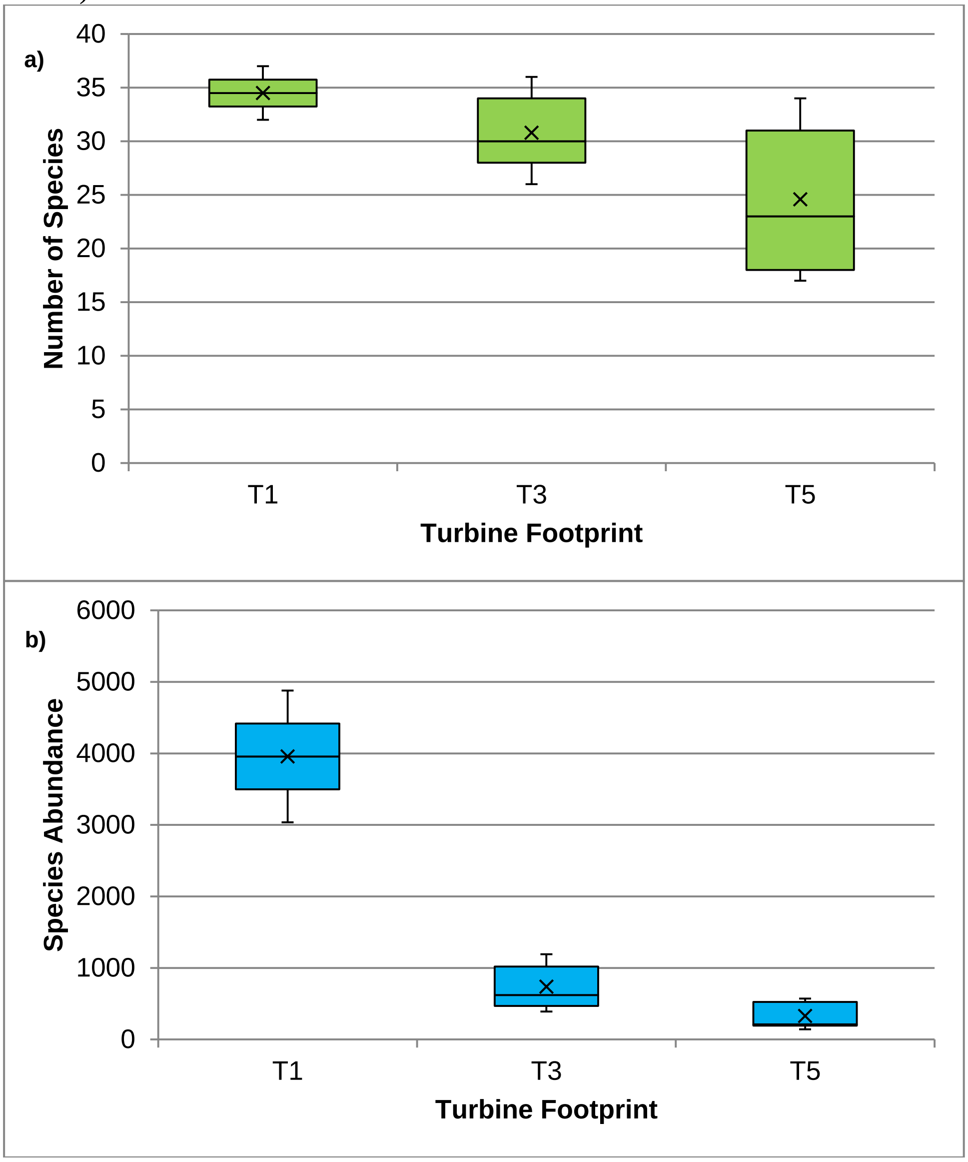


Figure 62. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of a) the number of species and b) the number of individuals within the footprint of each turbine (T1, T3, T5) in Year 3.

For all footprint samples combined, 69% of the total abundance was contributed by *M. edulis*, though the contribution varied for each Turbine individually (Turbine 1 = 89%, Turbine 3 = 46%, Turbine 5 = 22%). *M. edulis* clearly dominated at Turbine 1 (7,045 individuals, n = 2) and also at Turbine 3 (1,714, n = 5) but co-dominated with *Polygordius* sp. at Turbine 5, both in lower numbers (386 *Polygordius* sp. individuals and 353 *M. edulis* individuals). *Balanus* sp. was in the top five most dominant species at Turbines 1 and 3 but not Turbine 5. The remainder of the top most abundant species at Turbines 3 and 5 were polychaetes. Only the scaleworm *Harmothoe extenuata* was common to both Turbines 1 and 3 in excess of 100 individuals. However, this may have been a function of the lower sampling at Turbine 1.

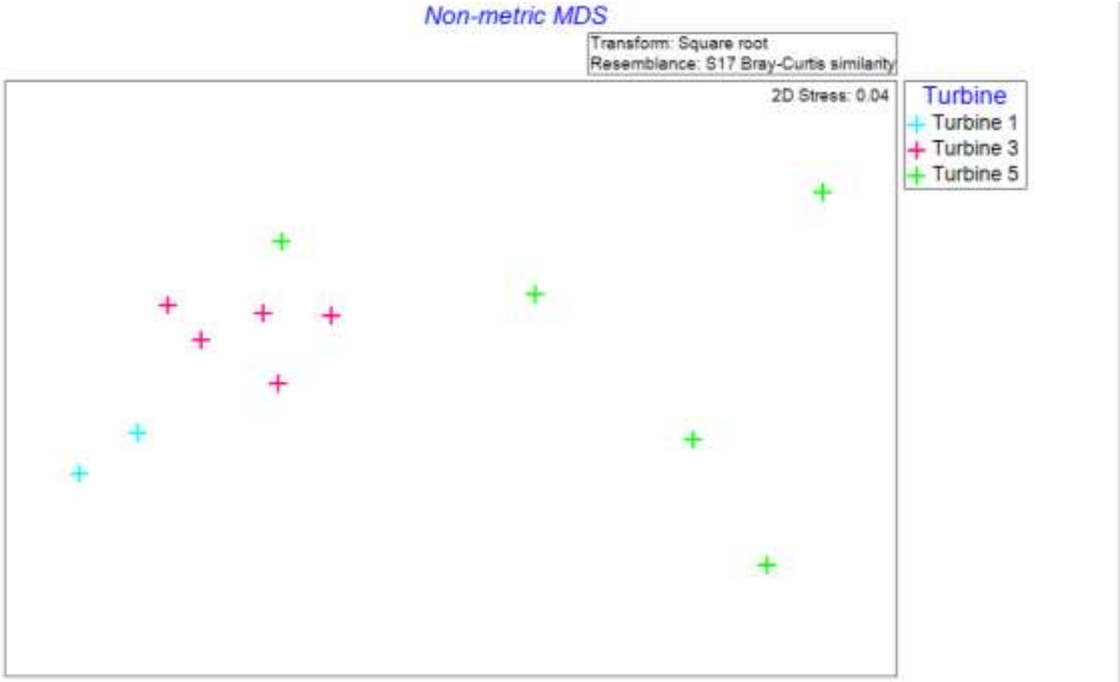


Figure 63. Non-metric MDS plot of diver-based samples collected with the footprint of each turbine in Year 3.

The nMDS plot of Year 3 data demonstrates distinction in the macrofaunal communities between the footprint of each turbine (**Figure 63**). The two Turbine 1 samples cluster together with an average similarity of 75.4% (**Figure 63**, **Table 41**). Turbine 3 samples plot as a cohesive cluster and have an average similarity of 66.5%. Turbine 5 samples are more disperse and have an average similarity of 41.2%. In general, samples separate out according to their respective turbines, with the exception of one sample from Turbine 5 that plots in close vicinity of the Turbine 3 sample cluster. When considering all turbine footprints together, the average macrofaunal similarity reported by SIMPER was 44.3% (**Table 41**). *M. edulis* contributed the most to the average similarity for all turbines individually and combined (**Table 41**). The dissimilarity was highest between Turbine 1 and 5 (71.93%) and lowest between Turbine 1 and 3 (47.18%), with Turbines 3 and 5 falling in the middle of the spectrum (61.45%). Similar to Year 2, these nMDS plot and SIMPER results for the Year 3 samples indicate macrofaunal community composition changes along a gradient following the geographic spacing of the turbines from Turbine 1 to 3 and 5, and that Turbine 3 is intermediate to Turbines 1 and 5. This gradient pattern continues to be apparent when examining the species that contribute the most of the average similarity at Turbine 3 (**Table 41**). Of the ten species, two are unique to Turbine 3, two are listed for all three turbines, three are also listed for Turbine 1, and three are also listed for Turbine 5.

Table 41. SIMPER results showing average similarity and top contributing species (70% cut-off) of diver-based samples collected within the footprint of each turbine structure in Year 3.

	Average similarity (%)	Contributing species (70% cut-off)
Turbine 1	75.44%	*Mytilus edulis* (45.89%)
		Harmothoe extenuata (5.99%)
		Capitella sp. (5.86%)
		Caprella linearis (4.43%)
		Balanus spp. (4.33%)
		Lepidonotus squamatus (3.38%)
		Urticina felina (3.00%)
Turbine 3	66.54%	*Mytilus edulis* (21.90%)
		Balanus spp. (9.04%)
		Lepidonotus squamatus (7.26%)
		Harmothoe extenuata (7.22%)
		Crepidula fornicata (7.18%)
		Nematoda spp. (5.84)
		Capitella sp. (3.02%)
		Lumbrinereis fragilis (3.01%)
		Jassa marmorata (2.90%)
		Phyllodoce maculata (2.90%)
Turbine 5	41.23%	*Mytilus edulis* (18.45%)
		Nematoda spp. (17.44%)
		Polygordius spp. (7.35%)
		Pisione sp. (6.65%)
		Neanthes arenaceodentata (5.75%)
		Phyllodoce maculate (5.46%)
		Capitella sp. (5.10%)
		Jassa marmorata (3.91%)
All combined	44.3%	*Mytilus edulis* (23.84%)
		Nematoda spp. (10.86%)
		Balanus spp. (7.33%)
		Harmothoe extenuata (5.61%)
		Capitella sp. (5.12%)
		Crepidula fornicata (4.79%)
		Phyllodoce maculata (4.70%)
		Lepidonotus squamatus (3.85%)
		Jassa marmorata (3.79%)
		Lumbrineris fragilis (3.30%)

3.2.5.3 Year 3 Macrofaunal Analysis of the Very Near-Field Area (VNF)

3.2.5.3.1 Overall Results – Year 3 VNF

In Year 3, a total of 109 macrofaunal species represented by 11,308 individuals were recorded from the diver-collected grab samples from the very near-field areas surrounding Turbines 1, 3, and 5 (n = 9 at each turbine, 27 total) (**Table 42**). The majority of macrofauna were Nematoda, comprising 57% of the total species abundance (**Figure 64**). Annelida and Arthropoda comprised 21% and 20% respectively, followed by Mollusca (2%) (**Figure 64**). Specimens from the phyla Nemertea, Cnidaria, Echinodermata, Platyhelminthes and Chordata were also present but in very low abundances (<0.1% each).

Nematoda were not identified to species level but of the phyla that were, Annelida comprised 48% of the total species richness, followed by Arthropoda (28%) and Mollusca (15%). The remaining phyla contributed less than 2% each. Most of the aforementioned phyla were represented within the very near-field area surrounding all of the Turbines sampled, apart from the Cnidaria which were absent from the Turbine 3 samples, and Chordata and Platyhelminthes which were only present in the Turbine 1 samples.

Nematodes were the most abundant species in the very near-field area (6,400 individuals) and were the only species to be present in all 27 samples (**Table 43**). The barnacle, *Balanus* sp. was the second most abundant (1,891 individuals) but was only present in 13 of a possible 27 samples. Of the remaining nine most abundant species (>100), seven were annelids (*Pisione* sp., *Polygrodius* spp., *Lumbrinereis actuta*, *Goniadella gracillis*, *Polycirrus eximus*, *Parapionosyllis longiciratta* and *Parougia caeca*) which occurred in 16-24 of the samples. The bivalve *Mytilus edulis* and amphipod *Unciola irrorata* were also on the top most abundant list (and most frequent).

Table 42. Summary of species abundance and species richness for all macrofaunal samples collected within the very near-field area to each turbine structure (Turbine 1, 3, 5) in Year 3.

	Turbine 1	Turbine 3	Turbine 5	All turbines combined
Total Species Richness	74	70	52	109
Mean Species Richness	21.9	25.1	21.5	22.9
Range of Species Richness per Sample	18-35	14-42	18-29	14-42
Total Species Abundance	2,998	2,596	5,714	11,308
Total Species Abundance (Nematoda excluded)	2,567	1,277	1,064	4,908
Mean Species Abundance	333.1	288.4	634.9	418.8
Range of Species Abundance per Sample	100-706	89-464	171-1,568	89-1,568
Mean Diversity (H’)	1.521	1.939	1.154	1.538
Mean Richness (d)	3.682	4.295	3.355	3.777
Mean Eveness (J’)	0.501	0.611	0.377	0.496
Mean Dominance (1-ʎ)	0.588	0.711	0.433	0.577

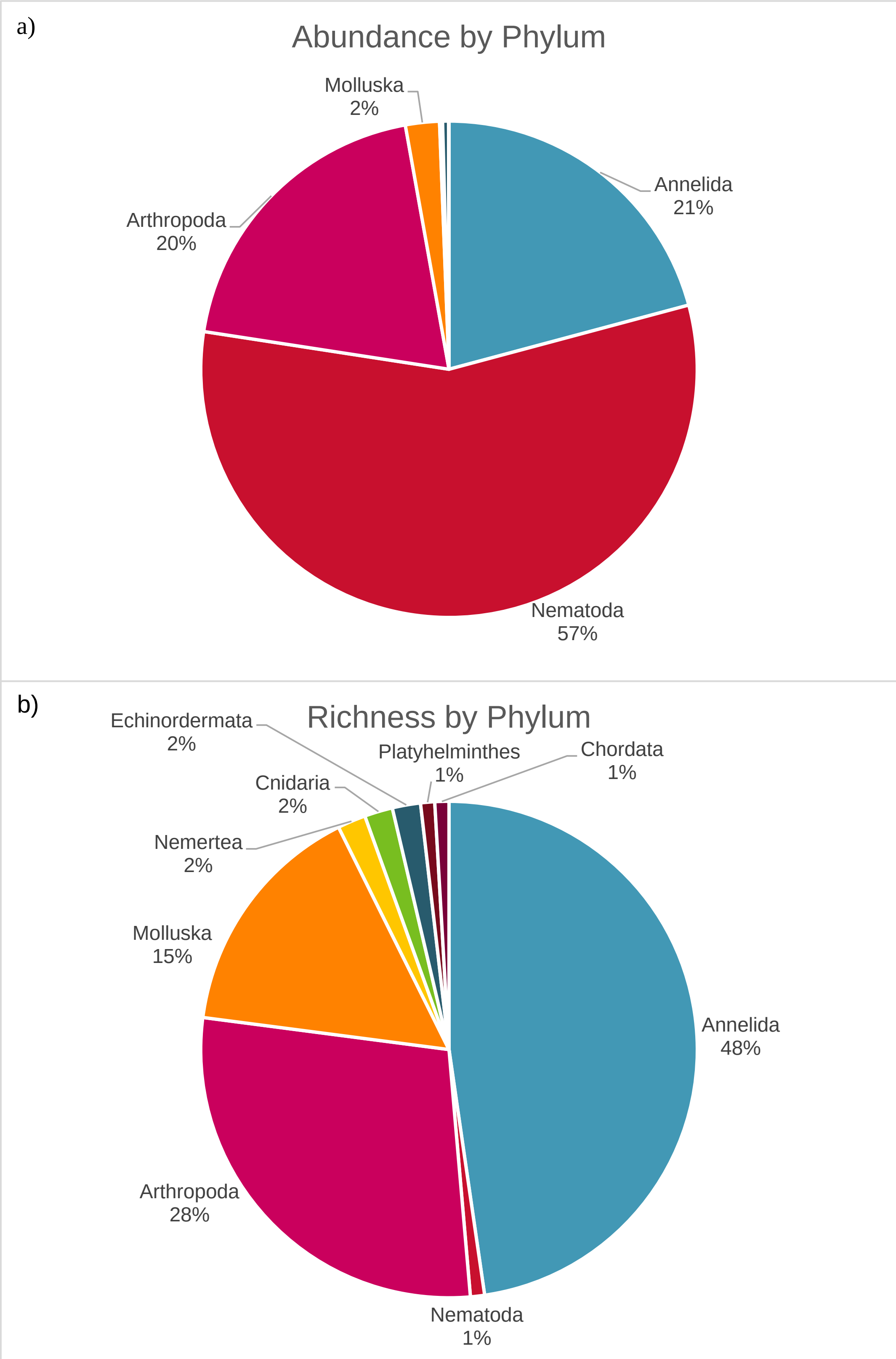


Figure 64. Proportion contribution of macrofauna characterized by phylum to a) total abundance, and b) total species richness for all macrofaunal samples collected in the very near-field areas to each turbine structure (Turbines 1, 3, 5) in Year 3.

Table 43. Most abundant and frequently occurring species for all diver-based samples collected from the very near-field area to each turbine structure (Turbine 1, 3, 5) in Year 3.

Species	Taxonomic group	Total abundance	Occurrence (n = 27)
Most abundant (> 100 individuals)			
Nematoda spp.*	Nematoda	6,400	27
Balanus spp.	Arthropoda	1,891	13
Pisione sp.	Annelida	595	18
Polygordius spp.*	Annelida	374	23
*Lumbrineris acuta**	Annelida	242	23
*Goniadella gracilis**	Annelida	230	24
Polycirrus eximius	Annelida	168	18
*Unciola irrorata**	Arthropoda	150	24
*Mytilus edulis**	Mollusca	123	20
Parapionosyllis longicirrata	Annelida	105	17
Parougia caeca	Annelida	105	16
Most frequent (> 20 samples)			
Nematoda spp.*	Nematoda	6,400	27
Polygordius spp.*	Annelida	374	24
*Goniadella gracilis**	Annelida	230	24
*Unciola irrorata**	Arthropoda	150	24
*Lumbrinereis acuta**	Annelida	242	23
Lumbrinereis fragilis	Annelida	59	21
*Mytilus edulis**	Mollusca	123	20
Note: Asterisk denotes species listed as both abundant and frequent.			

3.2.5.3.2 Comparison of Individual Turbines – Year 3 VNF

The patterns of macrofaunal species abundance and richness within the very near-field area around the turbines are summarized in **Table 42** and **Figure 64**.

The total species abundance within the very near-field area of Turbine 1 (2,998 individuals, n = 9 per turbine) was most similar to Turbine 3 (2,596 individuals) whereas Turbine 5 was substantially higher (5,714 individuals) (**Table 42**). The total species richness followed the opposite trend with Turbine 5 being lowest (52 species) and Turbine 1 and 3 being more similar with 74 and 70 species respectively.

Mean values for all diversity indices (**Table 42**) within the very near field were broadly comparable with the highest mean values exhibited at Turbine 3 and lowest values occurring at Turbine 5. Samples collected around Turbine 1 exhibited intermediate mean values for diversity measures. Values for diversity (H’) and Margalef’s richness (d) varied little ranging between 1.939 and 4.295 respectively (Turbine 3) to 1.154 and 3.355 respectively (Turbine 5). Mean values for eveness (J) and dominance were also similar within the very field for all the turbines ranging between 0.611 and 0.711 respectively (Turbine 3) to 0.377 and 0.433 respectively (Turbine 5).

Comparing the macrofauna collected within very near-field areas, between turbines using a one way ANOVA confirmed there were no significant differences in the mean species abundance ($p > 0.05$) or mean species richness ($p > 0.05$). The mean species abundance ranged between 288.4 and 634.9 with the broadest range evident at Turbine 5 (**Figure 65** and **Table 42**). The mean species richness was relatively similar and ranged between 21.5 and 25.1 across the three turbine areas (**Figure 65**).

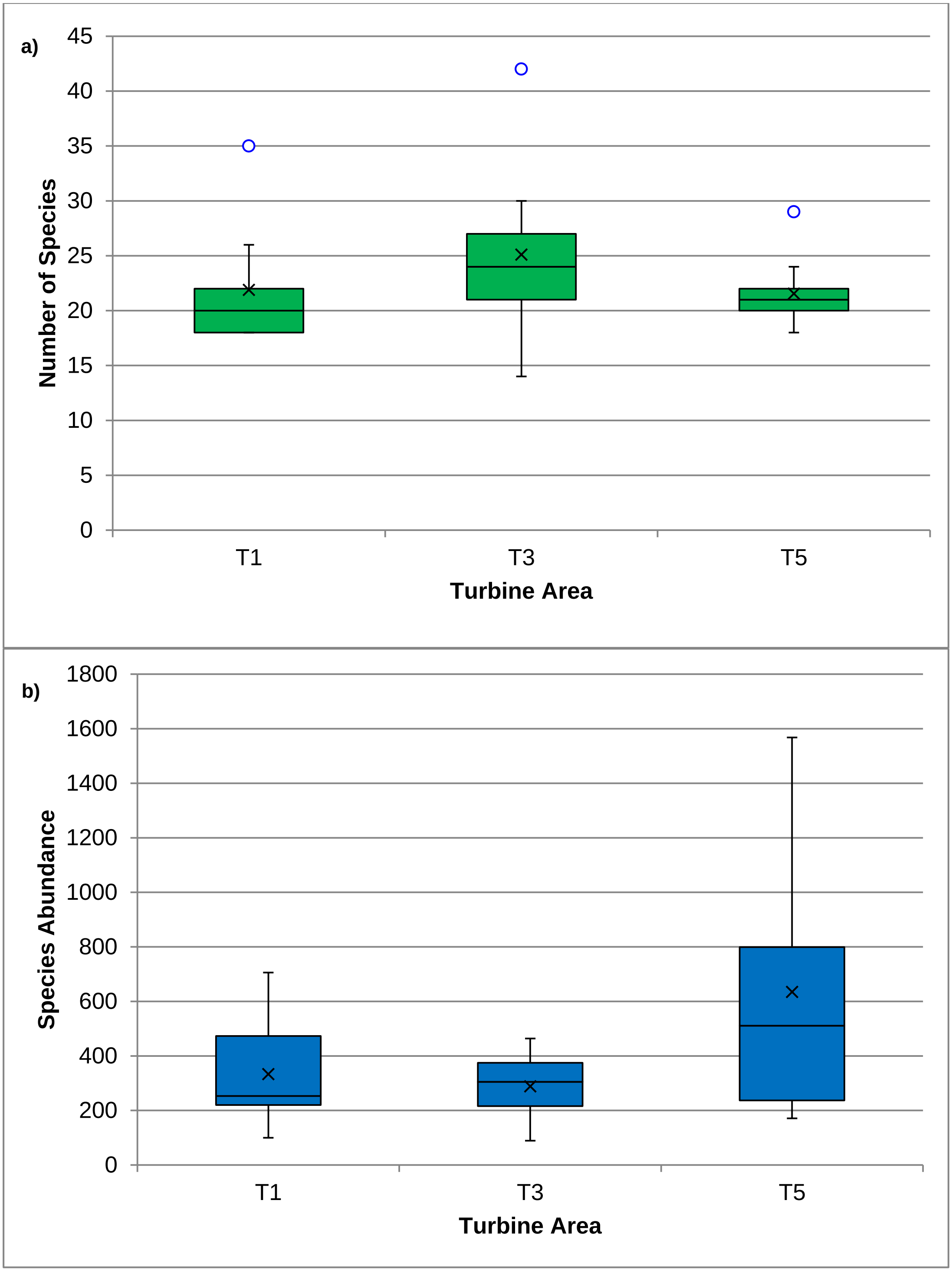


Figure 65. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of a) the number of species and b) the number of individuals sampled in the very near-field area surrounding each turbine (T1, T3, T5) in Year 3.

Closer inspection of the most abundant and most frequent species recorded in the very near-field area highlights further differences between turbines. Around Turbine 1, the most dominant species was *Balanus* spp. (1,877 individuals) and nematodes (431 individuals) which were recorded in all nine samples. The next most frequent species around Turbine 1, present in seven of nine samples were the amphipod *U. irrorata* (76 individuals), and the polychaetes *G. gracilis* (80 individuals), and *L. fragilis* (17 individuals). Comparatively, nematodes dominated in the area surrounding Turbine 3 (1,319 individuals) together with four species of polychaetes (*Pisione* sp. (307), *Polygordius* spp. (176), *G. gracilis* (108), *L. acuta* (101 individuals), all of which were present in all nine samples. Also present in all samples around Turbine 3 but less frequent were the amphipod *U. irrorata* (57 individuals), the polychaete *P. eximius* (54 individuals) and the bivalve *M. edulis* (52 individuals). The area surrounding Turbine 5, similar to Turbine 3, was dominated by nematodes (4,650 individuals, all nine samples), followed by polychaetes common to the other turbines areas including *Pisione* sp., *P. eximius*, *L. acuta*, *Polygordioius* spp., and *Parougia caeca*, which were also present in all samples (70 to 300 individuals per species).

As noted, *M. edulis* were recovered in all nine samples collected at Turbine 3, and were relatively abundant (52 individuals in total, n = 9). Comparatively, *M. edulis* had a similar total abundance at Turbine 1, although it was only recovered in five samples (50 individuals). At Turbine 5, *M. edulis* were present in 6 samples, but with the lowest total abundance (21 individuals).

The nMDS plot for the very near-field areas demonstrates that the samples from Turbine 1 were more variable in macrofaunal species composition whereas samples around Turbines 3 and 5 were more similar and form a more cohesive cluster (**Figure 66**). The SIMPER analysis supports that the Turbine 1 samples were most variable in macrofaunal composition with the lowest similarity of the three turbines (46.24%, **Table 44**). Turbines 3 and 5 samples had comparable similarity of 58.54% 60.83% respectively. Overall, the very near-field area had a similarity of 42.78%. The dissimilarity was strongest between Turbine 1 and 5 (74.91%), followed by Turbine 1 and 3 (68.02%) and lastly Turbines 3 and 5 (45.2%).

The SIMPER analysis identified *Balanus* sp. as the top contributing species at Turbine 1, followed by nematodes, two polychaetes (*Polygordius* sp. and *G. gracilis*) and the amphipod *U. irrorata* (**Table 44**). The top contributing species at both Turbine 3 and 5 were nematodes and *Pisione* sp. although the contributions varied. The majority of the remaining top contributing species at Turbine 3 or 5 were also listed for at least one other turbine but only nematodes and *Polygordius* spp. was present at all three (**Table 44**). Also, as seen within the footprint datasets for Years 2 and 3 (**Table 38**, **Table 41**), Turbine 3 is intermediate to Turbines 1 and 5, with two of the six contributing species also listed for Turbine 1, two also listed for Turbine 5, and the remaining two listed for all three turbines (**Table 44**).

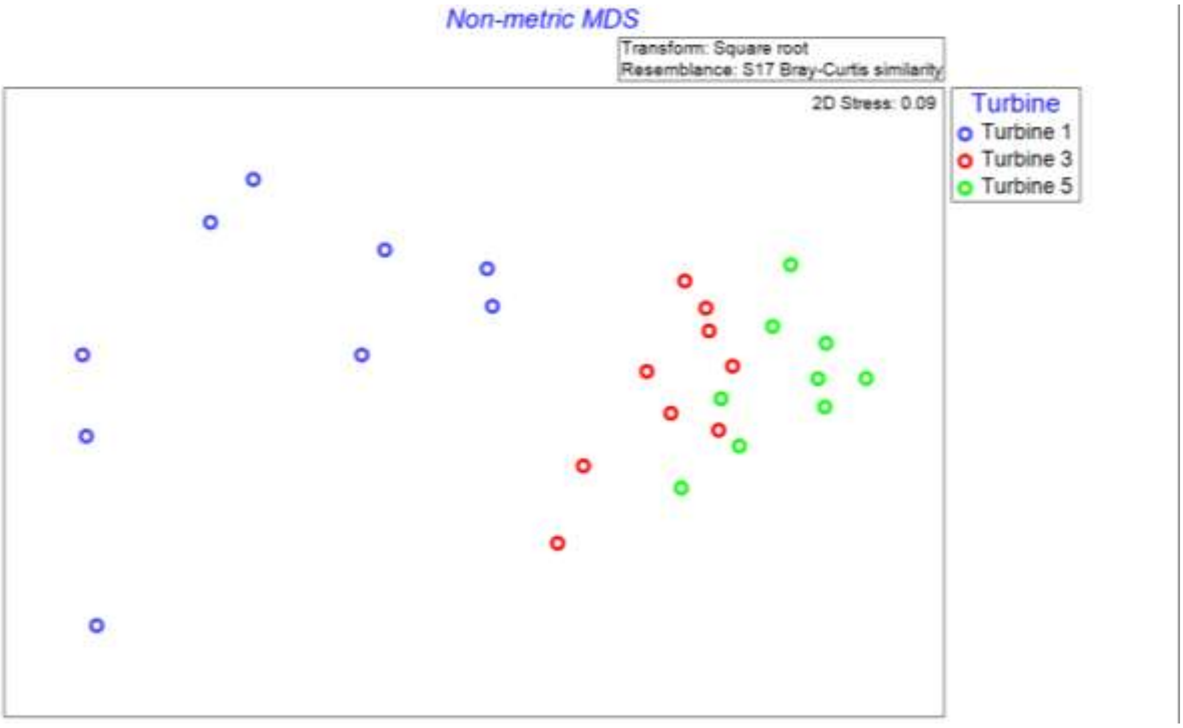


Figure 66. Non-metric MDS plot of diver-based samples collected in the very near-field area around each turbine in Year 3.

Table 44. SIMPER results showing average similarity and top contributing species (70% cut-off) of diver-based samples collected in the very near-field area around the turbine structures (Turbines 1, 3 and 5) in Year 3.

	Average similarity (%)	Contributing species (70% cut-off)
Turbine 1	46.24%	*Balanus* sp. (36.42%)
		Nematoda spp. (21.57%)
		Polygordius spp. (5.34%)
		Goniadella gracilis (5.28%)
		Unciola irrorata (3.91%)
Turbine 3	58.45%	*Nematoda* spp. (28.24%)
		Pisione sp. (15.65%)
		Polygordius spp. (8.90%)
		Goniadella gracilis (7.04%)
		Lumbrinereis acuta (7.24%)
		Unciola irrorata (5.69%)
Turbine 5	60.83%	*Nematoda* spp. (38.18%)
		Pisione sp. (11.79%)
		Lumbrinereis acuta (8.05%)
		Polycirrus eximius (6.70%)
		Parougia caeca (4.67%)
		Polygordius spp. (4.43%)
All combined	42.78%	*Nematoda* spp. (34.19%)
		Pisione sp., (8.33%)
		Polygordius spp. (7.88%)
		Lumbrinereis acuta (7.24%)
		Goniadella gracilis (6.90%)
		Balanus spp. (4.93%)
		Unciola irrorate (4.91%)

3.2.5.4 Comparison of Biomass within Turbine Areas in Year 3

Biomass is a key measure in the determination of enrichment effects and was introduced in Year 3. While this dataset did not permit the assessment of null hypotheses, a descriptive account for the Year 3 data is provided. This section reports on the wet and dry biomass of macrofauna from samples taken within the turbine footprint and in the very near-field area. The data are detailed in **Appendix I.**

3.2.5.4.1 Turbine Footprint Macrofaunal Biomass

Overall, when combining the dry biomass of the footprint samples across all three turbines (n = 12), the Arthropoda contributes the highest biomass (total = 148.9 g, average per sample = 12.4 g), followed by the Annelida (total = 8.8 g, average per sample = 0.7 g). The other phyla were present in comparably low total biomass (< 1.0 g each).

The dry biomass of Arthropoda was highest at Turbine 3 with a total of 101.1 g (average = 20.2 g, std dev = 18.5, n = 5), followed by Turbine 1 with a total of 25.2 g (average 12.6 g, std dev = 13.4, n = 2) and lowest at Turbine 5 with a total of 22.6 g (average = 4.5 g, std dev = 8.1, n = 5). It is notable however that only two samples were collected at Turbine 1 and so the total contribution would have been higher if all five samples had been collected. The dry biomass contribution of Annelida per turbine was more equal at Turbines 1 and 3, approximating an average of 1.0 g each, but was comparably lower at Turbine 5 with an average of 0.3 g.

The total wet biomass of Mollusca for all three turbine footprints (n = 12) combined was 13,259.9 g (average = 1,105.0 g). The greatest contribution of average wet biomass by Mollusca was recorded at Turbine 1 (total = 3,894.9 g, average = 1,947.5 g, n = 2). The Turbine 1 average was similar to Turbine 3 having an average of 1,730.0 g (total = 8,650.2 g, n = 5). Turbine 5 was substantially lower with an average of 143.0 g (total = 714.8 g, n = 5).

Of the total wet Mollusca biomass, 99% was contributed by the mussel *M. edulis*. The average wet biomass contributed by *M. edulis* at Turbine 1 was 1944.6 g (std dev = 143.4), at Turbine 3 was 1710.2 g (std dev = 429.8) and Turbine 5 was 136.1 g (std dev = 235.6). Although Turbine 5 was much lower in average *M. edulis* biomass, the distribution was more variable within the turbine footprint. Mussels were only present in four of five samples and the biomass of the central sample was 545.6 g from large mussels alone (>30 mm). Large mussels consistently contributed the greatest proportion of average mussel biomass across all turbine footprints (93 to 97%). The average contribution by medium mussels (5 to 300 mm) and juveniles (1 to 5 mm) was highest at Turbine 1, with 37.8 g (1.9% of T1 total) and 18.8 g (1.0%), respectively.

The total dry and wet biomass measurements were consistent across all samples and therefore can be compared between the footprint of each turbine sampled (**Figure 67**). A Welch's test confirmed that the total biomass within the footprint of Turbine 1 and Turbine 3 were significantly greater than that recorded within the footprint of Turbine 5 ($F_{(2, 6)} = 27.7$, $p < 0.001$).

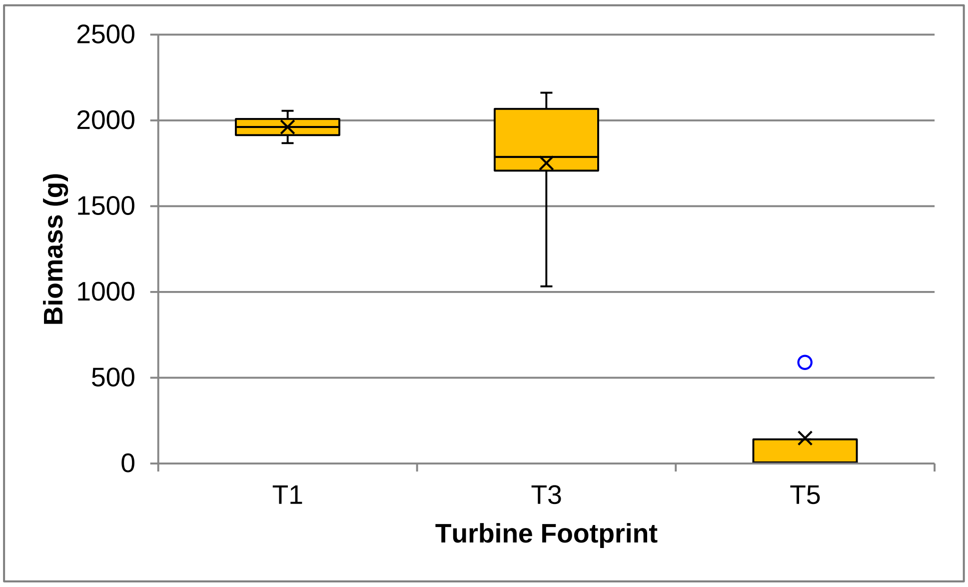


Figure 67. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of the total biomass (all phyla, wet and dry biomass combined) for diver-collected samples collected within the footprint of Turbines 1, 3 and 5 in Year 3.

3.2.5.4.2 Very Near-field Area Macrofaunal Biomass

Within the very near-field area, considering all three turbine samples together (n = 27), the highest contribution of wet biomass was from the Arthropoda with a total = 114.9 g (average = 4.3 g) followed by the Annelida with a total of 3.5 g (average = 0.1 g) and the Chordata with a total of 1.7 g (average = 0.8 g). The other phyla were present but in very low biomass (0.001 to 0.04 g).

The total biomass of Arthropoda was predominantly from the very near-field area around Turbine 1 with a total of 102.9 g (average = 11.4 g). Comparatively, the total biomass of Arthropoda in the very near-field area of Turbine 3 was much lower at 11.9 g (average 1.3 g) and lower again around Turbine 5 with a total of 0.2 g (average = 0.02 g). The total biomass of Annelida around Turbine 1 was 1.4 g (average = 0.2 g) and comparable around Turbine 3 and Turbine 5 both with a total biomass of 1.1 g (average = 0.1 g). The total biomass of the Chordata was contributed from the Turbine 1 samples.

The total wet biomass of Mollusca for all samples combined (n = 27) was 940.8 g (average = 37.6 g). Again, Turbine 1 had the greatest contribution with a total of 616.7 g (average = 77.1 g) followed by Turbine 3 with a total of 322 g (average 35.8 g) and the lowest was Turbine 5 with a total of 1.7 g (average = 0.2 g). Notably, *M. edulis* contributed 99% of the total Mollusca biomass at Turbines 1 and 3, but, conversely, the species contributed less than 1% in samples around Turbine 5.

The total dry and wet biomass measurements were consistent across all samples and therefore can be compared between the very near-field areas for each turbine sampled (**Figure 68**). A Kruskal-Wallis test confirmed that the total biomass in the very-nearfield of Turbine 1 was significantly greater than that recorded around Turbine 5 (Chi square = 12.09, p <0.001, df = 2).

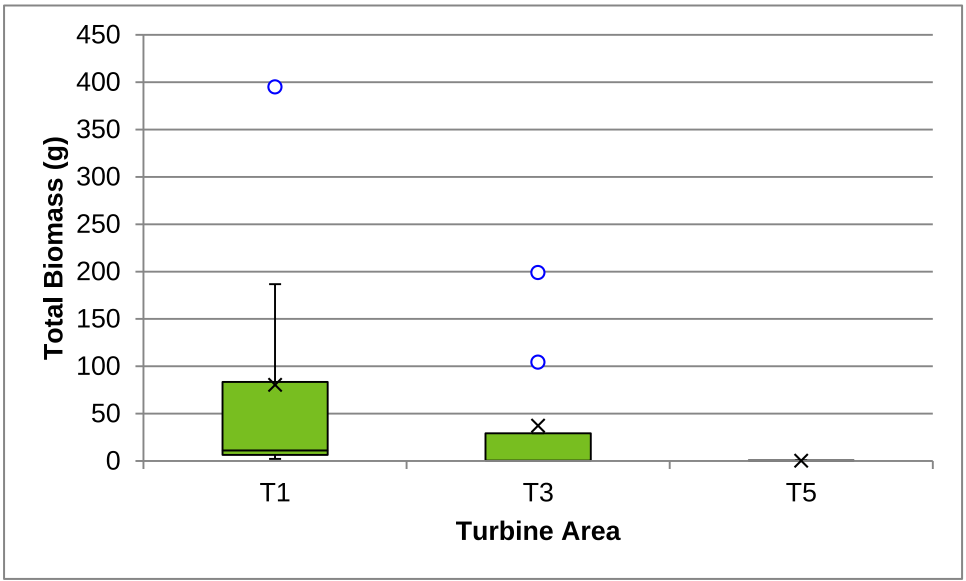


Figure 68. Box and whisker plots showing the mean, median, 1st and 3rd quartiles and data range of the total biomass (all phyla, dry and wet biomass) for diver-collected samples collected within the very near-field area around Turbines 1, 3 and 5 in Year 3.

3.2.5.5 Comparison of Macrofauna Across all Sampled Areas

Based on the grab sample method comparison (**Section 3.3.2**), it is reasonable to draw some comparisons between samples taken within the different study areas, i.e., the footprints, the very near-field areas, and the vessel-based sampling targeting the 30-90 m area from the center point of the turbines (**Section 3.1.6.4**). The variation in sampling regime between these study areas does not allow for statistical comparisons. However, descriptive comparison can be made with respect to total species abundance by phyla, mean species richness, mean species abundance, mean biomass and macrofaunal species composition similarities. This section focuses on Year 2 and Year 3 data.

Considering the total species abundance by phyla, the two areas sampled in Year 2 were dominated by the Nematoda (30 to 90 m areas = 68%, footprint areas = 49%) (**Figure 29** and **Figure 59**). The turbine footprints were comparably more diverse than the 30 to 90 m area in Year 2 and had almost even contributions of Mollusca, Arthropoda, and Annelida (15% to 20%, **Figure 59**). In Year 3, Mollusca within the turbine footprints increased to 73% (**Figure 61**), whereas the 30-90 m area was dominated by Annelida (50%, **Figure 29**, and the newly added very near-field areas were dominated by Nematoda (57%, **Figure 64**). The Year 3 turbine footprints and very near-field areas both had the Arthropoda and Annelida as the next most dominant phyla (**Figure 61** and **Figure 64**).

In Year 2, the most abundant species within the turbine footprints were nematodes and *M. edulis* (**Table 37**). Nematodes were also listed as the most abundant species in the 30 to 90 m area (**Table 13**) but were accompanied by a variety of polychaetes but *M. edulis* did not feature. In Year 3, the turbine footprints were again dominated by *M. edulis*, followed by *Balanus* spp. and nematodes which were also the most frequently recorded species (**Table 40**). In Year 3, nematodes and *Balanus* spp.

were also most abundant in the very near-field area (top two, **Table 43**) and in the 30 to 90 m area (top three, **Table 21**). Although *M. edulis* was not the top, most abundant species, it did feature ninth in the very-near-field area (**Table 43**) and fourth in the 30 to 90 m area (**Table 21**).

The SIMPER reported average similarity between samples taken within the footprint of the turbines was between 40% and 44% for both Year 2 (**Table 38**) and Year 3 (**Table 41**) and was 43% for samples in the very near-field area in Year 3 (**Table 44**). In Year 3, the macrofaunal similarity was higher (by >20%) within the footprints of Turbine 1 and 3 compared to the very near-field area but the opposite trend occurred at Turbine 5 (**Table 38** and **Table 41**). The macrofaunal similarity in the 30 to 90 m area varied between 39 and 70% (**Table 18**) and Turbines 3 and 5 were consistently higher in the macrofaunal similarity that Turbine 1 in both Year 2 and Year 3.

According to SIMPER analyses, the top contributing species within the footprint of the turbines in Year 2 were *M. edulis* and *Balanus* sp. for Turbine 1 and Turbine 3, and nematodes and *M. edulis* for Turbine 5 (**Table 38**). In Year 3, the top contributing species within the footprint of Turbine 1 had changed to *M. edulis* and *H. extenuatea,* although *Balanus* spp., still contributed to a lesser degree. The footprint of Turbine 3 and Turbine 5 remained dominated by the same species in Year 3 although *M. edulis* had increased its contribution and become the top contributing species within the footprint for all three turbines. Within the very near-field area in Year 3, the top contributing species around Turbine 1 was *Balanus* sp. and nematodes whereas around Turbine 3 and 5, nematodes and the polychaete *Pisione* sp., were the top contributors (**Table 41**). In Year 3, nematodes, *Balanus* sp. and *M. edulis* were also top contributing species in the 30 to 90 m area around Turbine 1, but only nematodes and *Pisione* sp. were common to Turbines 3 and 5, which also had *P. eximius* listed as a top contributing species (**Table 21**).

Drawing upon the Year 3 data (**Table 39** and **Table 42**), the areas within the footprints of the foundations consistently supported a slightly higher species richness compared to sampled areas within the very near field. Mean values for Margalef's richness within foundation footprints ranged between 4.053 and 4.580 and exceeded those within the very near field which ranged between 3.355 and 4.295. Mean diversity was similarly higher within the footprints of the foundations compared to the very near field with the exception of Turbine 1 were the mean diversity was elevated in the very near field compared to the foundation footprint despite the greater numbers of species and abundance directly below Turbine 1.

Within each area studied (the turbine footprint, the very near-field area and the 30 to 90 m area), there is a gradient in species composition which reflects the geographic spatial position of Turbines 1 through 3 and 5 (**Figure 43, Figure 60, Figure 63,** and **Figure 66**). This gradient also is observed in the abundance of organisms, particularly for *M. edulis,* observed within the footprint of the turbines which existed in Year 2 and was more pronounced in Year 3. However, the degree of macrofaunal similarity and dissimilarity is variable between turbines and across years for each area (**Table 21, Table 38, Table 41,** and **Table 44**).

The biomass of macrofauna by phyla was only recorded in Year 3; however, it demonstrates relatively similar proportions of biomass of Arthropoda and Annelida in the turbine footprint and very nearfield areas (**Section 3.2.5.4**). In contrast, the biomass in the 30 to 90 m area was characterized by smaller proportions of Annelida, Chordata and Arthropoda (**Section 3.1.6.6**). The total wet biomass of Mollusca is more informative. Despite the lower sample number within the turbine footprints, there was approximately 13 kg of Mollusca recorded, 99% of which was *M. edulis* (n = 12). Comparably, approximately 1 kg of *M. edulis* was recorded in the very near-field area of which 98% was *M. edulis* (n = 27). In Year 3, mussel biomass was recorded within the turbine footprint and very near-field area for all turbines. In the 30 to 90 m area, 93% of the contribution to Mollusca around Turbine 1, was from *M. edulis* equaling 0.7 kg (n =27) (**Section 3.1.6.6**).

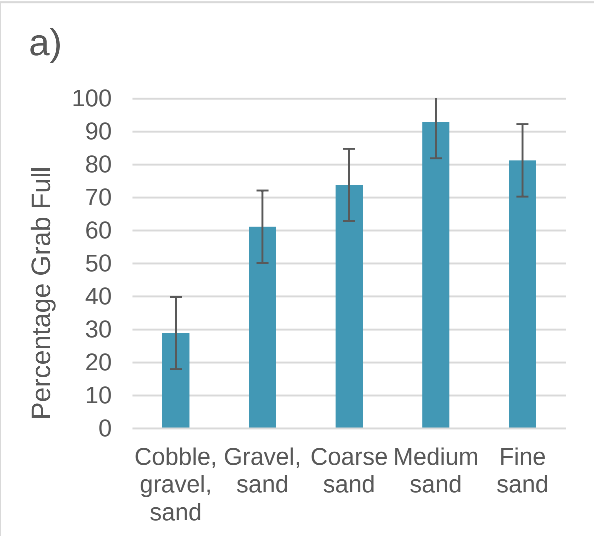
Overall, the main spatial distinction is that dense mussels were present in the samples collected within the turbine footprint but showed a lower presence in the surrounding areas. In Year 2, this appeared to be a feature solely associated with footprint of the turbine foundation at Turbine 1, although in Year 3 there was an increased density of *M. edulis* and *Balanus* sp. within the turbine footprint and in the broader area (very near-field area and 30 to 90 m area). Year 3 also found increased mussel abundance within the footprints of Turbines 3 and 5, and the very near-field area of Turbine 3, suggesting that they may be following the same trend as Turbine 1, but at a slower temporal pace.

3.3 Grab Sample Method Evaluation

3.3.1 Smith McIntyre Grab Sample Performance

It was observed that the performance of the Smith McIntyre grab sampler differed depending on the substrate type. Qualitative data were extracted from the Year 1 survey record (**Appendix B**). **Figure 69 (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.

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 small (on average only ⅓ full) compared with those collected at the other two turbine locations (on average ¾ full). In practice throughout the three year study, volume inconsistencies were limited by ensuring that a reasonable sample volume was obtained while in the field (i.e., 1/8th of bucket) and if not, the sample was repeated. The same Smith McIntyre grab sampler was used throughout the three year study. The grab sampler had surface area of 0.06 m^2 and therefore provides a standardized sample area. The area rather than the volume of a grab sample is far more informative since the macrofauna targeted by this research method typically live in the top 5 to 10 cm of sediment (Mackie et al. 2007).



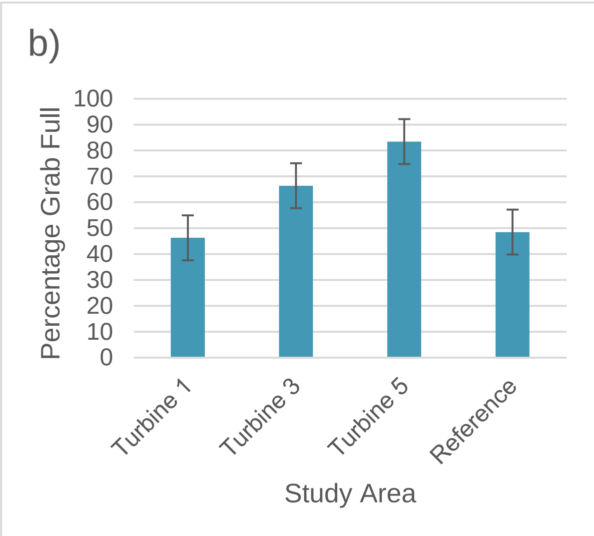


Figure 69. Summary of size of Year 1 vessel-based grab samples collected from a) different substrates at BIWF and b) different Turbine locations.

3.3.2 Grab Sample Method Comparison

Throughout this multi-year study there were two methods of grab sampling employed; vessel-based grab samples which used a Smith McIntyre grab sampler and diver-based grab samples where divers manually obtained a grab sample. These methods are fully described in **Section 2.3.1.1** and **Section 2.3.2.1**. To determine if these two methods of obtaining grab samples were equivalent, both methods were executed in Narragansett Bay in Year 3. Three samples were collected using each method, side by side. The results show that the samples from each method were comparable for the mass of the sample and the sediment grain size composition, macrofauna characteristics but not for the organic content analysis. It is acknowledged that the samples size was small and without additional data, caution should be exercised in comparisons made between the two methods. Data supporting these conclusions are presented later.

3.3.2.1 Sample mass

Grab samples obtained by divers were between 1.6 and 3.3 kg (mean = 2.6, std dev = 0.9) and samples obtained by the Smith McIntyre Grab sampler were between 2.0 and 4.1 kg (mean = 2.9, std dev = 1.1). Therefore, the grab samples obtained by the Smith McIntyre sampler were higher in their range of mass, however when comparing between each sample set, the difference ranged from -0.5 to 1.2 kg (mean = 0.3, std dev = 0.8) indicating that the sample size and performance was variable. Two sample t-tests indicated that the mass of the samples obtained by each method were not statistically different ($t = -0.414$, $p > 0.05$).

3.3.2.2 Particle Size Distribution

The diver-collected and Smith McIntyre samples were in agreement in that both methods indicate that the dominant grain size was medium sand in all samples and all samples had a measurable combined clay and silt content (**Table 45**). The average sediment fraction percentages for each method are reported in **Table 46** and shown in **Figure 70**. In general, there is agreement for the pattern of proportions in that the medium sand is most dominant, followed by fine sand, coarse sand and lastly very fine sand; both methods show these proportionally (**Figure 70**).

Statistically, two sample t-tests for each sediment fraction confirms that the sediment composition obtained from the two methods were not significantly different ($p > 0.05$). It is apparent that the diver method (D) averages were higher than the Smith McIntyre method (SM) for the three finer sediment fractions; clay and silt (D = 29.3%, SM = 18.5%), very fine sand (D = 8.4%, SM = 7.4%) and fine sand (D = 22.7%, SM = 22.1%) whereas, the Smith McIntyre methods returned higher averages for medium (D = 26.9%, SM = 33.5%) and coarse sand (D = 12.4%, SM = 18.3%) (**Table 46**). Overall, the strongest differences in mean percentage fractions of sediment were found between the clay and silt (difference of 10.8%), the medium sand (difference of 6.6%) and the coarse sand (difference of 5.8%). Comparatively, the sampling methods were more similar for the very fine sand, fine sand and very coarse sand, each with a difference between 0.1% and 1.0%. Overall, the sediment compositions obtained by each method can be considered similar.

Table 45. Summary of grain size analysis of diver-based sediment samples and samples collected using the Smith McIntyre sampler, in Narragansett Bay in Year 3.

	Sample type	Total samples	Number of samples for which:			
			Dominant grain size = medium sand	Dominant grain size = coarse sand	Combined sand fraction > 90%	Combined clay and silt > 0%
Year 3	Diver	3	3	0	0	3
	Smith McIntyre	3	3	0	0	3

Table 46. Mean of each sediment grain size fraction for diver-based sediment samples and samples collected using the Smith McIntyre sampler, in Narragansett Bay in Year 3.

	Study area	Average fraction of:					
		Clay and silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand
Average	Diver	29.3%	8.4%	22.7%	26.9%	12.4%	0.1%
	Smith McIntyre	18.5%	7.4%	22.1%	33.5%	18.3%	0.2%
Range	Diver	27.5% – 31.6%	5.5% – 10.1%	10.1% – 30.2%	25.15 – 29.93	5.4% – 22.5%	0.0% - 0.3%
	Smith McIntyre	5.0% – 36.7%	1.7% – 12.6%	15.9% – 27.7%	20.0% – 46.0%	3.0% - 31.1%	0.0% - 0.4%
Note: The range of each grain size fraction within the full study area is also provided. Grain size fractions are classified according to the Wentworth scale.							

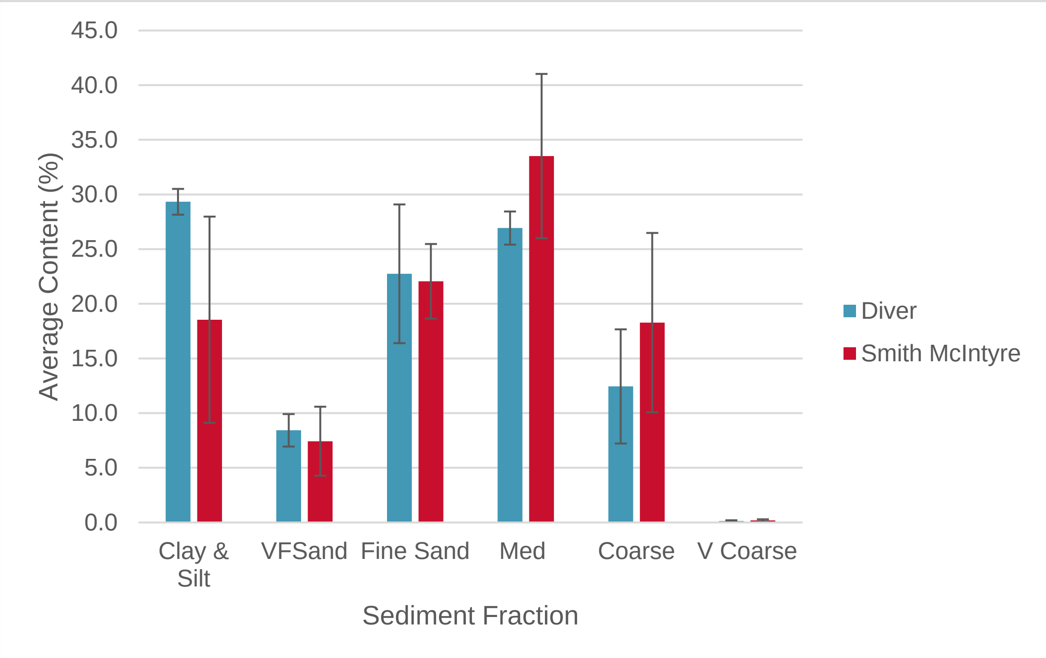


Figure 70. Mean percentage content (with standard error bars) of each sediment grain size fraction for diver-based sediment samples and samples collected using the Smith McIntyre sampler, in Narragansett Bay in Year 3.

3.3.2.3 Sediment Organic Content

The diver and Smith McIntyre collected grab samples were different in the reported average levels and ranges of TOM and TOC content (**Table 47**). A two-sample t-test confirmed that the TOM and TOC reported by each method, were significantly different (TOM: t = 2.77, p = 0.024, TOC: t = 2.77, p = 0.024).

The diver samples had an average TOM of 2.3% and TOC of 1.0% while the Smith McIntyre samples had an average TOM of 1.4% and TOC of 0.6% (**Table 47**). That is a difference of 0.9% in the average TOM and 0.4% in the average TOC. The range of TOM and TOC was significantly higher for the diver collected samples, with no overlap in range for the two methods (**Table 47**). The ratios of average TOM to average TOC were proportionally similar though with the TOC being approximately 60% of the TOM value.

Table 47. Average total organic matter and total organic carbon content (and standard errors) for samples collected by each sample method in Narragansett Bay in Year 3.

		Average total organic matter (%)	Average total organic carbon (%)
Average	Diver	2.3% (0.1)	1.0 (0.1)
	Smith McIntyre	1.4% (0.2)	0.6 (0.1)
Range	Diver	2.0% – 2.4%	0.9% – 1.1%
	Smith McIntyre	1.1% – 1.8%	0.5% – 0.8%

3.3.2.4 Macrofaunal Analysis

The two methods, Smith McIntyre (SM) and diver-collected (D) grab samples produced variable results, which may be indicative of the small-scale macrofaunal variability in the area of Narragansett Bay sampled and/or the low sample number for comparison.

The abundance by phylum were relatively similar but the diver collected samples had a larger contribution of Annelida which comprise 51% of the total abundance compared to 39% for the Smith McIntyre sample method (**Figure 71**). The species richness by each method was more distinctly variable. The dominant phyla collected by the Smith McIntyre methods were Annelida (43%), Arthropoda (31%) and Mollusca (18%). Comparatively, the species richness for the diver collected samples were dominated by Nematoda (46%), followed by Annelida (24%) and Arthropoda (21%).

Variability was also indicated by the range of species abundance, range of species richness and range of biomass from each method (**Table 48**). The macrofaunal data collected by the two methods were however, similar in mean species richness, mean species abundance and mean biomass. A series of t-tests confirmed there were no statistical differences ($p > 0.05$) between these mean macrofaunal properties and therefore the two methods can be considered comparable in these ways.

Table 48. Summary of species abundance and species richness for all macrofaunal samples diver-based samples and samples collected using the Smith McIntyre sampler, in Narragansett Bay in Year 3.

	Diver	Smith McIntyre
Total Species Richness	37	54
Mean Species Richness	19.3	27.7
Range of Species Richness per Sample	9 – 27	17 – 42
Total Species Abundance	274	353
Mean Species Abundance	91.3	117.7
Range of Species Abundance per Sample	25 – 133	45 – 206
Total Biomass (g)	262.5	866.7
Mean Biomass (g)	87.5	288.9
Range in Biomass (g) per sample	28.8 – 201.8	1.1 – 453.4

In terms of species composition, the nMDS plot shows that the first two samples of each method group very closely together but the third is more dissimilar (**Figure 72**). The SIMPER analysis indicated that the diver samples had a similarity of 34.48% and the Smith McIntyre samples a similarity of 40.55% which is relatively comparable (**Table 49**). The dissimilarity in species composition between the two methods was 55.05%. The top two contributing species for each method were the same for each method, namely the annelid *Spiochaetioterus oulatus* and the mollusk *Tritia trivittata* (**Table 49**). An additional two species were also common in both methods, *Glycera Americana* and *Pagurus annulipes* (**Table 49**).

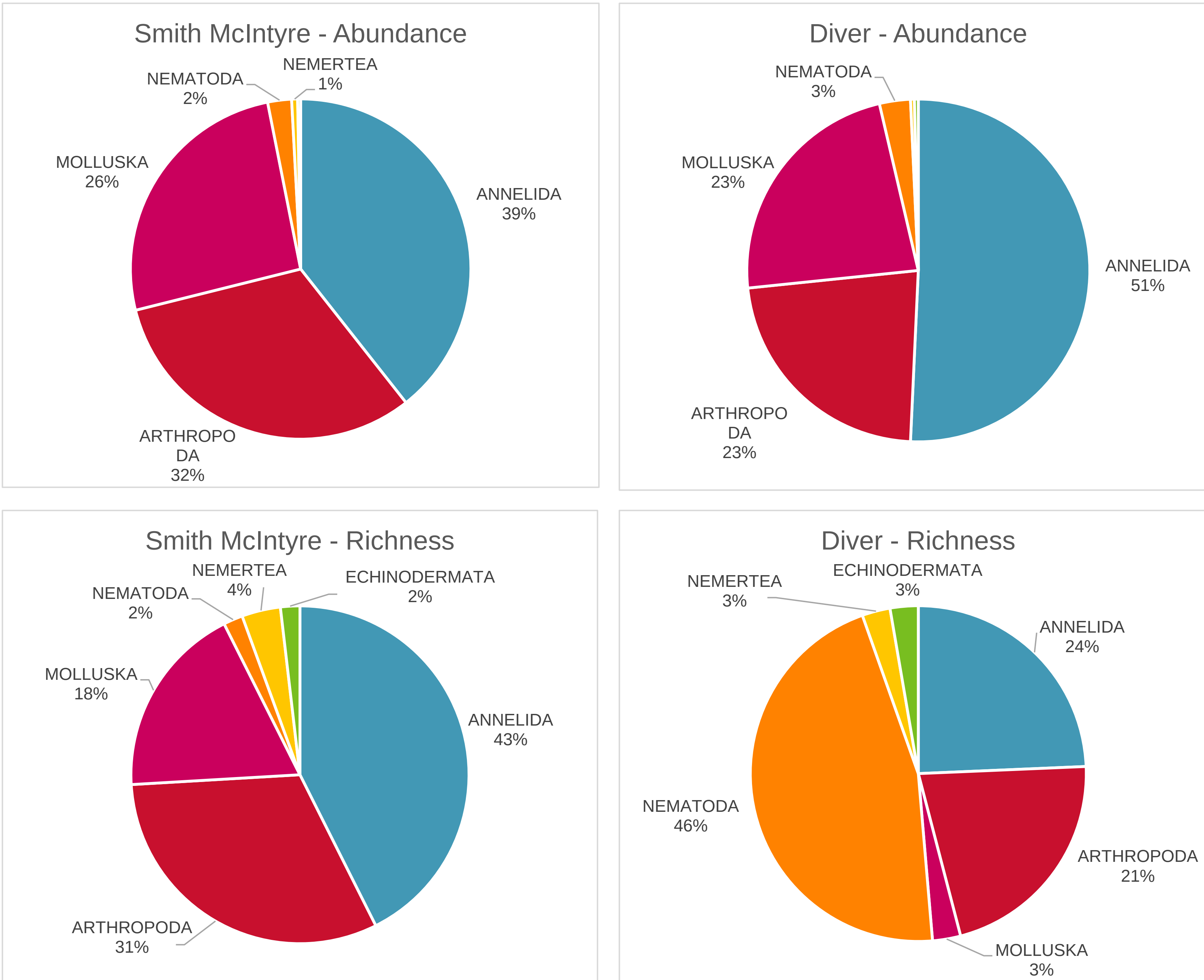


Figure 71. Proportion contribution of macrofauna identified from two grab sample methods, the Smith McIntyre grab sampler and diver-collected grab samples from Narraganset Bay, characterized by phylum, to the total abundance and total species richness.

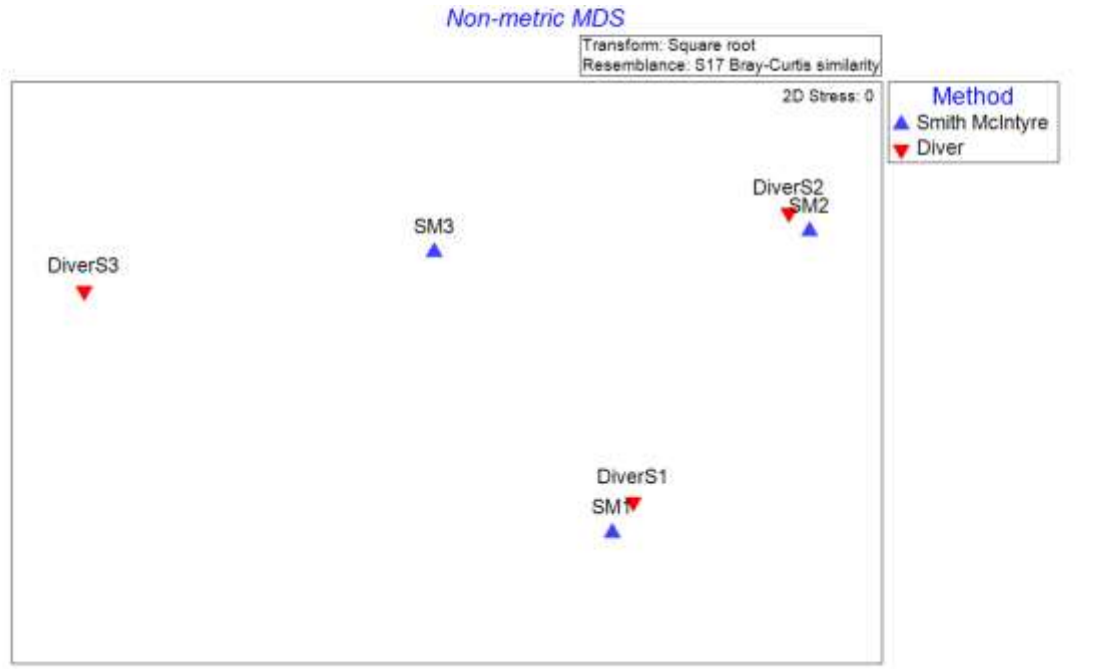


Figure 72. An nMDS plot showing the macrofaunal composition (dis)similarity between the Smith McIntyre and diver collected grab sample methods, compared in Narraganset Bay in Year 3.

Table 49. SIMPER results showing average similarity and top contributing species (70% cut-off) of the diver-based samples and samples collected using the Smith McIntyre sampler, in Narragansett Bay in Year 3.

Method	Average Similarity (%)	Contributing Species (70% cut-off)	Phyla
Smith McIntyre	40.55%	*Spiochaetioterus oculatus* (13.70%)*	Annelida
		Tritia trivittata (10.80%)*	Mollusca
		Nephtys picta (10.44%)	Annelida
		Glycera americana (9.76%)*	Annelida
		Nematoda spp. (6.69%)	Nematoda
		Pagaurus annulipes (6.31%)*	Arthropoda
		Maldanidae spp. (6.31%)	Annelida
		Grandidierella sp. (5.63%)	Arthropoda
		Lyonsia hyaline (5.63%)	Mollusca
Diver	34.8%	*Spiochaetioterus oculatus* (22.89%)*	Annelida
		Tritia trivittata (14.48%)*	Mollusca
		Crepidula fornicata (11.37%)	Mollusca
		Glycera americana (10.48%)*	Annelida
		Ampelisca vadorum (5.80%)	Arthropoda
		Caulleriella venefica (4.64%)	Annelida
		Pagurus annulipes (3.79%)*	Arthropoda
An asterisk denotes species common to top contributing species for both methods.			

3.4 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 Components were integrated to classify biotopes for the turbine study areas within the 30 m – 90 m distance bands. As such, biotopes reflect the relationship between macrofaunal communities and associated geological characteristics within the defined map units. While comparisons of the biotopes developed for this BIWF study and the OSAMP study are insightful, it is acknowledged that the BIWF study was conducted at a very site-specific scale, whereas the OSAMP study was conducted at a regional scale.

3.4.1 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* spp. and *Polycirrus* spp. 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, *Lumbrinereis hebes* was not identified, but *Lumbrinereis acuta* was. Moreover, *Lumbrinereis. acuta* was found in high abundances in areas where *Lumbrinereis hebes* was previously identified. 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. Although taking a conservative approach, identification at the genus level is used for biotope classification.

Furthermore, nematodes were not enumerated in the OSAMP dataset, although they were in the BIWF dataset. In Year 1 and Year 2, 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 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.

3.4.2 Biotope Classification

Biotopes within the three turbine study areas were classified according to CMECS (**Figure 73, Figure 74, Figure 75, Table 43, Table 50, Table 51,** and **Table 52**). 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 (dominant species with respect to abundance) 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 biotopes in both Year 1 and Year 2 are defined by polychaetes in depositional environments containing coarse sand. In Year 3, polychaetes continue to define the biotopes at Turbines 3 and 5. However, barnacles (*Balanus* spp.) and juvenile blue mussels (*Mytilus edulis*) now co-dominate the biotope at Turbine 1.

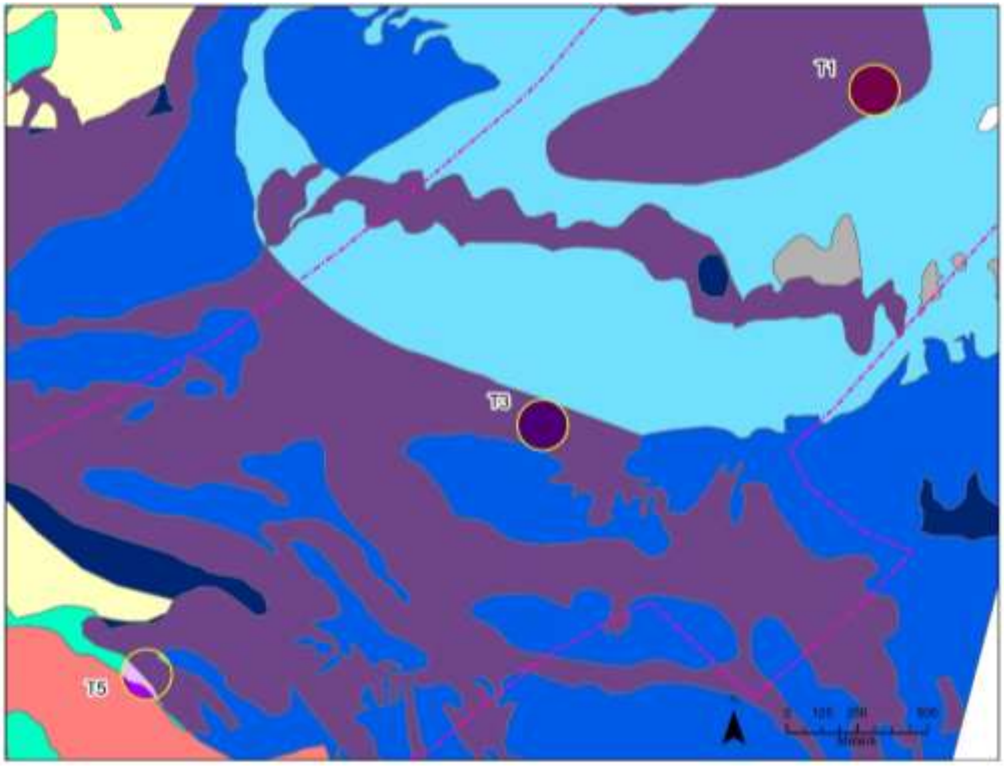
For the first two sampling years, the Turbine 1 study area was characterized by polychaetes in an environment of coarse sand with small dunes within a glacial alluvial fan. The primary distinction is the change in dominant species. In Year 1, the polychaete, *Sabellaria vulgaris,* was dominant, which also contributed 5.22% to the overall biotope similarity. In Year 2, the polychaete, *Polygordius* spp., was dominant and contributed 15.41% to the overall similarity. It should be noted that *Polygordius* spp. was also one of the most dominant species in Year 1 and contributed 11.54% to the overall similarity. The change in the biotope classification between Year 1 and Year 2 is attributed to the highly localized and patchy distribution of *Sabellaria vulgaris* and relocation of the sampling sites between years, rather than a result of the turbine structure.

In Year 3, the biological aspect of the biotope classification changes, as *Balanus* spp. and juvenile *Mytilus edulis* come to dominate the area. Although, the third dominant species is *Polygordius* spp. (defined Year 2 biotope), followed by other polychaete species. Aside from *Balanus* spp. and juvenile *Mytilus edulis*, all of the species most responsible for the biotope similarity in Year 3 are polychaetes and were also identified as most responsible in Year 1 and/or Year 2. These results suggest that *Balanus* spp. and juvenile *Mytilus edulis* are present in addition to the macrofaunal community that existed in Years 1 and 2, i.e., they had not yet, caused a shift in macrofaunal community composition in Year 1 and Year 2 throughout the biotope as a whole. However, as a reminder, biotope classifications represent the average condition within a given area because they are defined by combining all samples collected within the area. In this case, further examination of the invidual sample sites was warranted to further examine if and how macrofaunal community composition had changed.

Within the Turbine 3 study area *Polycirrus* spp. was the dominant species across all samples in Years 1, 2 and 3. The biotope is classified as "*Polycirrus* spp. in coarse sand with small dunes within glacial alluvial fan." In Year 3, eight species are the most responsible for biotope similarity, seven of which also are listed in Year 1 and/or Year 2. These results indicate the macrofaunal community at Turbine 3 has been stable over the three sampling years.

Turbine 5 was investigated according to the three biotope units used in the OSAMP study. All biotopes are characterized by polychaetes in Years 1, 2, and 3. All of the biotopes within Turbine 5 are now dominated exclusively by *Polycirrus* spp. The classification of one of the three biotopes stayed the same for all years: "*Polycirrus* spp. in pebble, gravel, and coarse sand within moraine shelf." The biotope classified in Years 1 and 2 as "*Polygordius* spp. in coarse sand with small dunes / sand waves within moraine shelf" changed to be dominated by *Polycirrus* spp. in Year 3. The remaining biotope has a depositional environment classification of "coarse sand with small dunes within glacial alluvial fan." Within this biotope, the biological component was classified in Year 1 by *Polycirrus* spp. and*Lumbrinereis* spp., in Year 2 by *Parapionosyllis longicirrata*, *Polycirrus* spp., and *Pision*e spp., and in Year 3 by "*Polycirrus* spp." The majority of the species that are responsible for the overall similarity in the Year 3 biotopes are also listed in Year 1 and/or Year 2, including the species that have defined the biotopes. The changes in the biotopes over the years appears to be based on variations in abundances of the characterizing polychaete species, rather than the species themselves, indicating some consistency in macrofaunal community composition over time.

Statistical analysis shows there is a significant relationship between the geological depositional environments and the associated macrofaunal community assemblages within each biotope area for all three years (ANOSIM R: Year 1 = 0.413, Year 2 = 0.412, Year 3 = 0.388; $p = 0.001$). However, in Year 3, the strength of the relationship is slightly reduced as the study area becomes more complex.The species that dominate the epifouling community present on and within the turbine structures nowcolonize the seafloor adjacent to the turbines. This influence of epifouling species on the benthic macrofaunal community assemblages is particularly evident at Turbine 1, now dominated by barnacles and blue mussels.



Biotope Classification

Study Areas

Turbine Study Areas

BIWF Study Area

Turbine 1

Sabellaria vulgaris in coarse sand with small dunes within glacial alluvial fan

Turbine 3

Polycirrus sp in coarse sand with small dunes within glacial alluvial fan

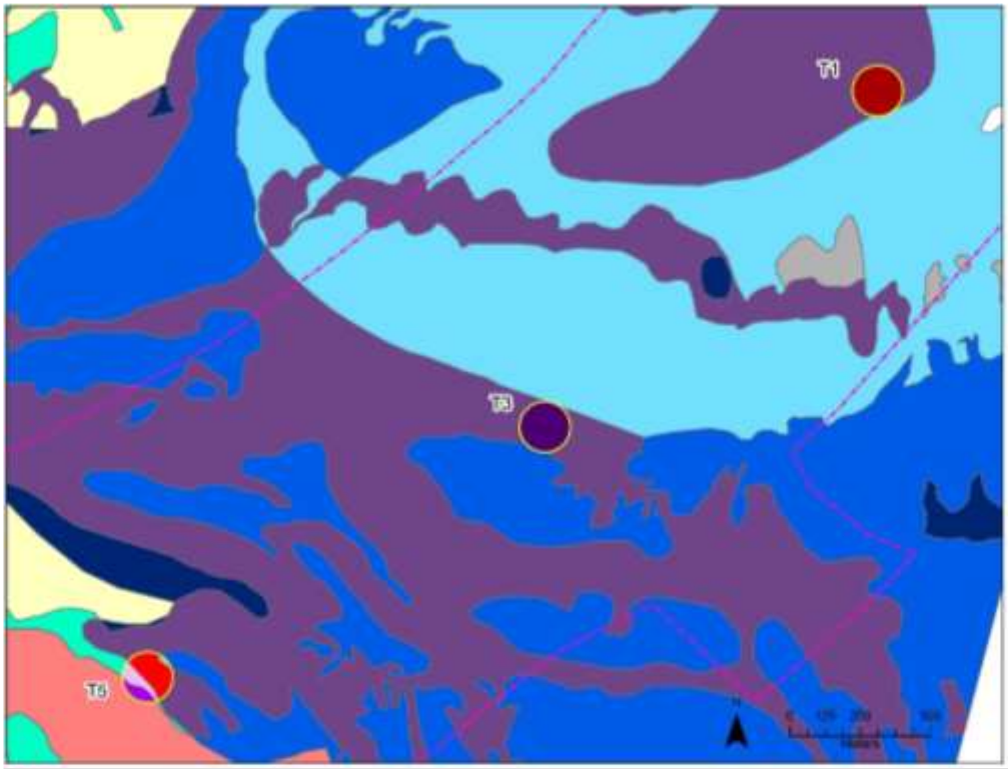
Turbine 5

Polycirrus sp. / Lumbrineries 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
Undefined

OSAMP (From LaFrance et al., 2014)

B. serrata in boulder gravel concentration within glacial alluvial fan
B. serrata in pebble, gravel, and coarse sand within glacial alluvial fan
B. serrata in sheet sand within glacial alluvial fan
J. falcata in boulder gravel concentration within moraine shelf
Corophium spp. in pebble, gravel, and coarse sand within moraine shelf
Pisione sp. in coarse sand with small dunes and sand waves within moraine shelf
Polycirrus sp. / Lumbrinereis sp. in coarse sand with small dunes within glacial alluvial fan
Undefined

Figure 73. Biotope classification map of the turbine areas within the BIWF study area for Year 1.



Biotope Classification

Study Areas
Turbine Study Areas

BIWF Study Area

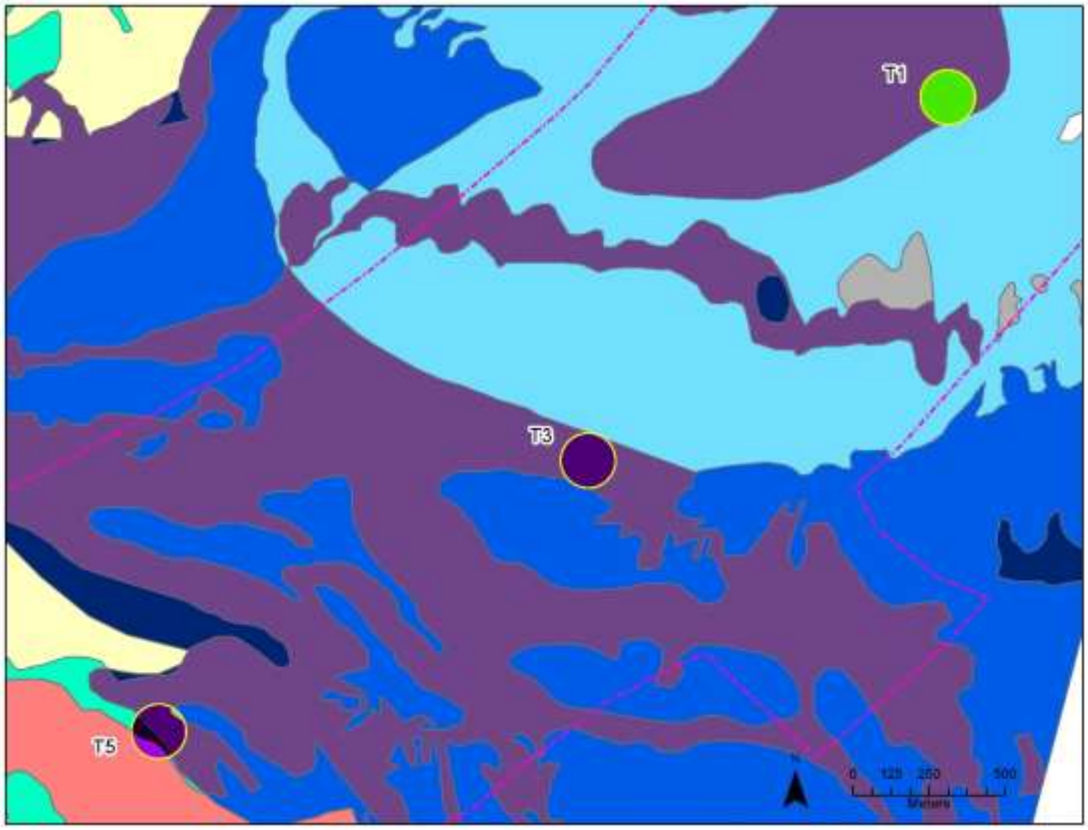
Turbine 1
Polygordius spp. in coarse sand with small dunes within glacial alluvial fan

Turbine 3
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan

Turbine 5
P. longicirrata / Polycirrus sp. / Pisione 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
Undefined

OSAMP (From LaFrance et al., 2014)
B. serrata in boulder gravel concentration within glacial alluvial fan
B. serrata in pebble, gravel, and coarse sand within glacial alluvial fan
B. serrata in sheet sand within glacial alluvial fan
J. falcata in boulder gravel concentration within moraine shelf
Corophium spp. in pebble, gravel, and coarse sand within moraine shelf
Pisione sp. in coarse sand with small dunes and sand waves within moraine shelf
Polycirrus sp. / Lumbrinereis sp. in coarse sand with small dunes within glacial alluvial fan
Undefined

Figure 74. Biotope classification map of the turbine areas within the BIWF study area for Year 2.



Biotope Classification

Study Areas
Turbine Study Areas

BIWF Study Area

Turbine 1
Balanus spp. and Mytilus edulis (juveniles) in coarse sand with small dunes within glacial alluvial fan

Turbine 3
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan

Turbine 5
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan
Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf environment
Polycirrus sp. in coarse sand with small dunes / sand waves within moraine shelf environment
Undefined

OSAMP (From LaFrance et al., 2014)
B. serrata in boulder gravel concentration within glacial alluvial fan
B. serrata in pebble, gravel, and coarse sand within glacial alluvial fan
B. serrata in sheet sand within glacial alluvial fan
J. falcata in boulder gravel concentration within moraine shelf
Corophium spp. in pebble, gravel, and coarse sand within moraine shelf
Pisione sp. in coarse sand with small dunes and sand waves within moraine shelf
Polycirrus sp. / Lumbrinereis sp. in coarse sand with small dunes within glacial alluvial fan
Undefined

Figure 75. Biotope classification map of the turbine areas within the BIWF study area for Year 3.

Table 50. Description of CMECS classification of BIWF biotopes with turbine areas for Year 1.

Year 1 CMECS classification of BIWF Biotopes	Dominant species across all samples within biotope (# individuals)	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)*	38.91%	*Nematoda (20.45%)*
	Nematoda (262)		*Goniadella gracilis (12.33%)*
			Polygordius spp. *(11.54%)*
			Nephtys bucera (8.85%)
			Unciola irrorata (6.82%)
			Lumbrinereis acuta (6.15%)
			Sabellaria vulgaris (5.22%)
Turbine 3			
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan	*Nematoda (1,344)*	62.49%	*Nematoda (14.20%)*
	Polycirrus sp. *(847)*		*Polycirrus* sp. *(12.46%)*
			Pisione sp. *(11.05%)*
			Lumbrinereis acuta (10.37%)
			Polygordius spp. *(10.14%)*
			Goniadella gracilis (6.21%)
			Aricidea cerrutii (5.59%)

Table 50. Continued.

Year 1 CMECS classification of BIWF biotopes	Sample stations within biotope (# samples)	Dominant species across all samples within biotope	Overall biotope similarity	Species most responsible for biotope similarity (% contribution)
Turbine 5				
Polycirrus sp. / *Lumbrinereis* sp. in coarse sand with small dunes within glacial alluvial fan	2, 3, 4, 5 (12)	*Nematoda (717)*	52.37%	*Nematoda (25.28%)*
		Lumbrinereis acuta (193)		*Lumbrinereis acuta (11.43%)*
		Polycirrus sp.*(175)*		*Goniadella gracilis (10.14%)*
				Polygordius spp. *(9.75%)*
				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)*	55.90%	*Polycirrus* sp. *(25.09%)*
		Nematoda (442)		*Nematoda (18.00%)*
				Polygordius spp. *(16.32%)*
				Pisione sp. *(13.64%)*
Polygordius spp. in coarse sand with small dunes / sand waves within moraine shelf	1, 9 (5)	*Polygordius* spp. *(526)*	58.74%	*Nematoda (19.68%)*
		Nematoda (342)		*Polygordius* spp. *(19.40%)*
				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. Color coding: Yellow cells are polychaetes; green cells are amphipods; grey cells are nematodes, which were excluded in biotope classification.

Table 51. Description of CMECS classification of BIWF biotopes with turbine areas for Year 2.

Year 2 CMECS classification of BIWF biotopes	Dominant species across all samples within biotope (# individuals)	Overall biotope similarity	Species most responsible for biotope similarity (% contribution)
Turbine 1			
Polygordius spp. in coarse sand with small dunes within glacial alluvial fan	*Nematoda (2,840)*	55.33%	*Nematoda (27.53%)*
	Polygordius spp. *(541)*		*Polygordius* spp. *(15.41%)*
			Goniadella gracilis (11.20%)
			Lumbrinereis acuta (7.42%)
			Parapionosyllis longicirrata (6.58%)
			Exogone hebes (4.87%)
Turbine 3			
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan	*Nematoda (16,214)*	69.95%	*Nematoda (33.77%)*
	Polycirrus sp. *(838)*		*Polygordius* spp. *(6.74%)*
			Polycirrus sp. *(6.62%)*
			Parapionosyllis longicirrata (6.17%)
			Pisione sp. *(6.13%)*
			Lumbrinereis acuta (6.05%)

Year 2 CMECS classification of BIWF biotopes	Sample stations within biotope (# samples)	Dominant species across all samples within biotope	Overall biotope similarity	Species most responsible for biotope similarity (% contribution)
Turbine 5				
P. longicirrata, *Polycirrus* sp., *Pisione* sp. in coarse sand with small dunes within glacial alluvial fan	2, 4, 6, 9 (12)	*Nematoda (4,514)*	65.07%	*Nematoda (22.37%)*
		Parapionosyllis longicirrata (371)		*Pisione* sp. *(10.14%)*
		Polycirrus sp. *(331)*		*Polycirrus* sp. *(9.74%)*

Year 2 CMECS classification of BIWF biotopes	Sample stations within biotope (# samples)	Dominant species across all samples within biotope	Overall biotope similarity	Species most responsible for biotope similarity (% contribution)
Turbine 5				
		Pisione sp. *(322)*		*Polygordius* spp. *(8.44%)*
				Lumbrinereis acuta (7.07%)
				Parapionosyllis longicirrata (6.40%)
Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf	3, 5, 8 (7)	*Nematoda (2,470)*	69.68%	*Nematoda (31.61%)*
		Polycirrus sp. *(267)*		*Polycirrus* sp. *(9.78%)*
				Pisione sp. *(8.29%)*
				Parapionosyllis longicirrata (7.58%)
				Parougia caeca (6.69%)
				Polygordius spp. *(5.90%)*
				Sphaerosyllis erinaceus (5.25%)
Polygordius spp. in coarse sand with small dunes / sand waves within moraine shelf	1, 3, 5, 7 (8)	*Nematoda (3,990)*	69.17%	*Nematoda (30.02%)*
		Polygordius spp. *(410)*		*Pisione* sp. *(9.65%)*
				Polycirrus sp. *(8.35%)*
				Polygordius spp. *(7.33%)*
				Lumbrinereis acuta (6.51%)
				Parougia caeca (6.04%)
				Parapionosyllis longicirrata (5.74%)
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. Color-coding: Yellow cells are polychaetes; grey cells are nematodes, which were excluded in biotope classification.				

Table 52. Description of CMECS classification of BIWF biotopes with turbine areas for Year 3.

Year 3 CMECS classification of BIWF biotopes	Dominant species across all samples within biotope (# individuals)	Overall biotope similarity	Species most responsible for biotope similarity (% contribution)
Turbine 1			
Balanus spp. and *Mytilus edulis* (juveniles) in coarse sand with small dunes within glacial alluvial fan	*Balanus* spp. *(6,318)*	44.20%	*Nematoda (15.03%)*
	Mytilus edulis (juveniles) *(5,283)*		*Balanus* spp. *(12.70%)*
			Polygordius spp. *(11.67%)*
			Mytilus edulis (juveniles) *(9.24%)*
			Goniadella gracilis (6.60%)
			Nephtys spp. *(5.39%)*
			Lumbrinereis acuta (5.17%)
			Exogone spp. *(3.62%)*
			Parapionosyllis longicirrata (3.53%)
Turbine 3			
Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan	*Nematoda (3,367)*	64.60%	*Nematoda (18.94%)*
	Polycirrus sp. *(3,073)*		*Polycirrus* sp. *(18.02%)*
			Polygordius spp. *(9.23%)*
			Pisione sp. *(8.91%)*
			Lumbrinereis acuta (6.17%)
			Dorvilleidae spp. *(4.77%)*
			Parapionosyllis longicirrata (3.76%)
			Aricidea cerrutii (3.65%)

<table>
<tr><th>Year 3
CMECS classification of BIWF biotopes</th><th>Sample stations within biotope
(# samples)</th><th>Dominant species across all samples within biotope</th><th>Overall biotope similarity</th><th>Species most responsible for biotope similarity
(% contribution)</th></tr>
<tr><td colspan="5">Turbine 5</td></tr>
<tr><td rowspan="6">Polycirrus sp. in coarse sand with small dunes within glacial alluvial fan</td><td rowspan="6">1, 3, 7, 8
(11)</td><td>Polycirrus sp.
(1,670)</td><td rowspan="6">62.84%</td><td>Polycirrus sp.
(25.17%)</td></tr>
<tr><td rowspan="5"></td><td>Nematoda
(16.22%)</td></tr>
<tr><td>Pisione sp.
(12.69%)</td></tr>
<tr><td>Dorvilleidae spp.
(6.14%)</td></tr>
<tr><td>Lumbrinereis acuta
(5.95%)</td></tr>
<tr><td>Polygordius spp.
(4.46%)</td></tr>
<tr><td rowspan="7">Polycirrus sp. in pebble, gravel, and coarse sand within moraine shelf</td><td rowspan="7">2, 5, 6
(7)</td><td>Polycirrus sp.
(1,718)</td><td rowspan="7">68.22%</td><td>Polycirrus sp.
(28.56%)</td></tr>
<tr><td rowspan="6"></td><td>Nematoda
(14.28%)</td></tr>
<tr><td>Pisione sp.
(11.09%)</td></tr>
<tr><td>Parapionosyllis longicirrata
(5.53%)</td></tr>
<tr><td>Mytilus edulis
(juveniles)
(5.09%)</td></tr>
<tr><td>Lumbrinereis acuta
(4.82%)</td></tr>
<tr><td>Polygordius spp.
(4.69%)</td></tr>
<tr><td rowspan="6">Polycirrus sp. in coarse sand with small dunes / sand waves within moraine shelf</td><td rowspan="6">2, 4, 8, 9
(9)</td><td>Polycirrus sp.
(1,480)</td><td rowspan="6">61.94%</td><td>Polycirrus sp.
(25.67%)</td></tr>
<tr><td rowspan="5"></td><td>Pisione sp.
(13.84%)</td></tr>
<tr><td>Nematoda
(11.70%)</td></tr>
<tr><td>Dorvilleidae spp.
(7.75%)</td></tr>
<tr><td>Lumbrinereis acuta
(7.71%)</td></tr>
<tr><td>Polygordius spp.
(5.18%)</td></tr>
<tr><td colspan="5">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. Color coding: Yellow cells are polychaetes; red cells are bivalves; blue cells are crustaceans; grey cells are nematodes, which were excluded in biotope classification.</td></tr>
</table>

3.5 Epifaunal Sampling Results

This section presents results from analyses of biota samples collected from selected turbine foundations by divers. Survey records are provided in **Appendix J**. Key data and results from the epifaunal sample analyses are summarized in **Appendix K**. Video footage from the epifaunal surveys is provided in an electronic format on the accompanying external hard drives.

3.5.1 Survey effort

With increasing interest on the potential artificial reef effect of turbines, a preliminary look at epifaunal growth on one turbine was undertaken in Year 2. Efforts were expanded to determine the epifaunal communities growing on three turbine foundations in Year 3 allowing analyses to determine if there were differences in species presence and percent cover between the turbines. The sampling strategy in each year was a combination of video transects and epifaunal scrape samples.

Video transects were collected to determine epifaunal species and percent cover on the turbine structures, summarized in **Table 53**. Divers completed video transects along the depth gradient of the southern leg of the turbines on both the leeward and current side. In Year 2, video transect data were analysed from Turbine 1 only, collected in June 2018, and in Year 3, video transects were analysed from Turbines 1, 3 and 5, collected in August 2019.

Table 53. Summary of survey effort to collect video transect data of the southern leg of turbine structures in Year 2 and Year 3.

	Study area	Number of video transects	Side of leg sampled	Date of survey
Year 2	Turbine 1	1	Leeward	8 June 2018
		1	Current	
	Turbine 3	1*	Leeward	
		1*	Current	
	Turbine 5	1*	Leeward	
		1*	Current	
Year 3	Turbine 1	1	Leeward	19 August 2019
		1	Current	
	Turbine 3	1	Leeward	
		1	Current	
	Turbine 5	1	Leeward	
		1	Current	
* Note: video data was collected but not analysed.				

Divers also collected epifaunal scrape samples to identify and enumerate the species growing on the turbine foundations; the survey effort is summarized in **Table 3**. In Year 2, divers collected a total of ten scrape samples from only the leeward side of the southern leg of Turbine 1, in August 2018. In Year 3, divers collected 27 epifaunal scrape samples from both the leeward and current side of Turbine 1 only, in September 2019 (total of 54 samples). Of the 27 samples from each side of the turbine leg, all were used in an assessment of epifaunal thickness, mass and subsequent estimates of drag forces (**Section 3.6**); and 15 were used to determine the epifaunal species and percent cover on the southern leg of Turbine 1 (**Section 3.5.3**).

Table 54. Summary of survey effort to collect epifaunal scrape samples from the southern leg of the turbine structures in Year 2 and Year 3.

	Study area	Number of scrape samples*	Side of leg sampled	Date of survey
Year 2	Turbine 1	10	Leeward	16 August 2018
	Turbine 3	-	-	-
	Turbine 5	-	-	-
Year 3	Turbine 1	27	Leeward	28 September 2019
		27	Current	27 September 2019
	Turbine 3	-		
	Turbine 5	-		
* Note: In Year 3, 27 samples were collected of which, only 15 were used for the biological analyses but all 27 were used for the assessment of epifaunal mass, thickness and estimates of drag force (Section 3.6).				

3.5.2 Turbine Epifaunal Video Analyses

3.5.2.1 Year 2

Video analysis indicated that 94.8% of the average epifaunal cover on the Turbine 1 southern leg was dominated by the blue mussel *Mytilus edulis* and associated epibionts (considered as one complex) (**Figure 76**). All species present on the structure and identifiable from the video are listed in **Table 55**. The dominant, almost monoculture of mussels was intermittently fouled with numerous species hydroids (see **Table 55** for species), barnacles (*Balanus* sp.) and at shallower depths both red (*Spyridia* sp., *Polysiphonia* sp.) and brown (*Scytosiphon* sp.) macroalgae. Other species found colonizing the turbine leg included anemones (*Metridium senile*) and sea stars (*Asterias forbesi*). Sponges (*Microciona prolifera*, *Haliclona loosanoffi*) were less common although they were observed at depth along the leg base.

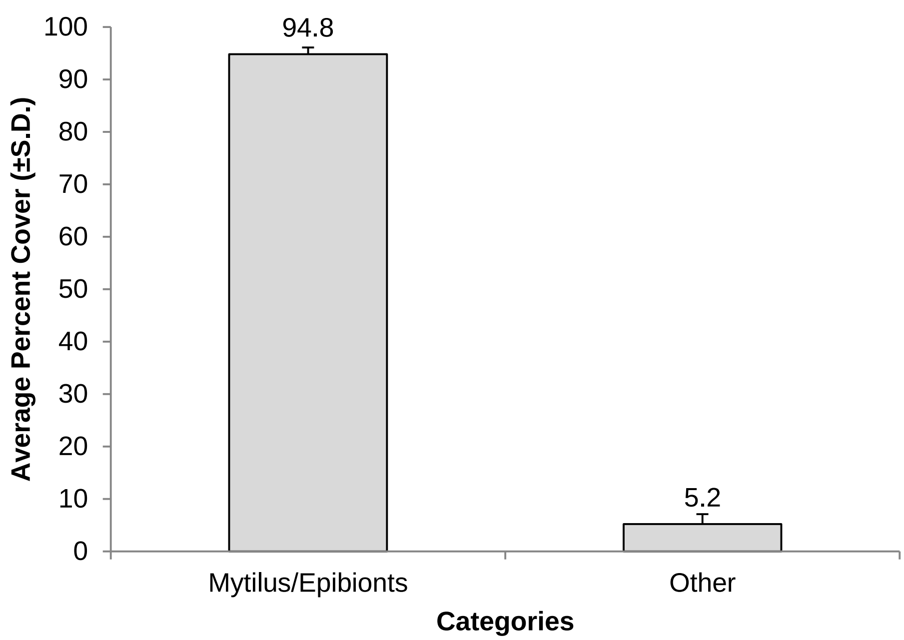


Figure 76. Average percent cover of organisms ((i) *Mytilus*/Epibiont complex and (ii) Other species) colonizing the southern leg of Turbine 1 as determined from video analysis in Year 2.

Table 55. The average percent cover (± standard deviation) of colonizing species and the number of mobile species present in photo stops from 15 minutes of continuous video footage of the southern leg of Turbine 1 in Year 2.

Taxon	Average percent cover
Mollusca	66.8 (±3.01)
Mytilus edulis	
Hydrozoa	19.8 (±2.75)
Tubularia sp.	
Obelia geniculata	
Bugula turrita	
Eudendrium spp.	
Campanularia spp.	
Clytia spp.	
Macroalgae	
Rhodophyta	3.2 (±0.51)
Spyridia sp.	
Polysiphonia sp.	
Phaeophyta	
Scytosiphon sp.	
Crustaceans	5 (±2.99)
Balanus sp.	
Other sessile species	
Anthozoa	1.8 (±0.48)
Metridium senile	
Porifera	2.4 (±0.89)
Microciona prolifera	
Haliclona loosanoffi	
Mobile Species Present	**Number Counts**
Echinodermata	
Asterias forbesi	4
Osteichthyes	
Tautogolabrus adspersus	35
Centroprisitic stiata	8

Figure 77 shows the percentage cover of all sessile species catalogued from the video transects from Turbine 1 in Year 2. A t-test demonstrated no significant differences in mussel or the percentage cover of other species on the leeward or current side of the structure (p >0.05). Fish counted directly from video footage from Turbine 1 in Year 2 demonstrate that small cunners (*Tautogolabrus adspersus*) were most common (n = 35) and black sea bass (*Centroprisitic stiata*) were present (n = 8) at depth.

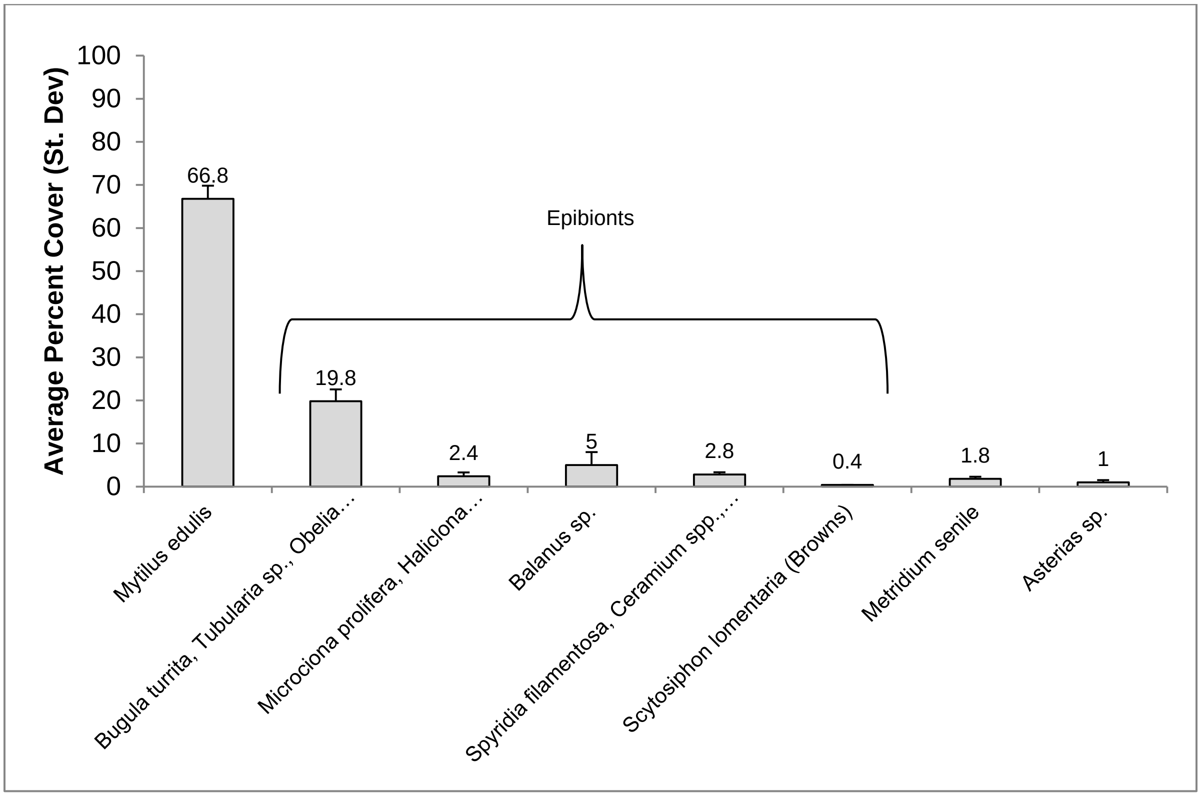


Figure 77. The average percent cover (± standard deviation) of sessile taxa from video analysis for the southern leg of Turbine 1 in Year 2 (current and leeward side combined).

3.5.2.2 Year 3

All species present on the structure and identifiable from the videos in Year 3 are detailed in **Table 56**. For comparison within the Year 3 sampling effort, **Table 56** also scores how common epifauna recorded from the epifaunal scrape samples were; the results of which are reported in **Section 3.5.3**. The dominant, almost monoculture of mussels was intermittently fouled with numerous hydroid species (**Table 55**), barnacles (*Balanus* sp.), anemones and at shallower depths both red and green macroalgae. Other common invertebrates, attached directly to the structure rather than on mussels, including anemones (*Metridium senile*), the invasive carpet tunicate (*Didemnum vexillum),* sponges (*Cliona celata*), which were present on the video but not in the specimen counts (**Section 3.5.3.2**), and corals (*Astrangia poculata*), which were less common although appeared with increasing depth along the turbine legs close to the base (i.e., only the lower 3 m of turbine leg). Sea stars (*Asterias forbesi*) were recorded infrequently on the structures (n = 6) but observed feeding on mussels on the horizontal substrates at depth for all turbines. No observations of squid eggs were recorded from the turbine foundations, but the video footage was collected outside of the squid spawning season.

Table 56. A summary of species present in video transects and epifaunal scrape samples taken from the southern leg of from turbines on both the leeward and current sides.

	Video footage: average percent cover		Scrape samples
	Turbines 1, 3 and 5		Turbine 1 only
Taxon	**Current side**	**Leeward side**	**Common**
Mollusca	72.67 (±2.69)	67.73 (±2.29)	--
Mytilus edulis	--	--	XXXX
Crepidula plana	--	--	XXX
Hydrozoa	6.87 (±1.43)	11.0 (±1.87)	XXX
Tubularia sp.	--	--	--
Obelia geniculata	--	--	--
Bugula turrita	--	--	--
Eudendrium spp.	--	--	--
Campanularia spp.	--	--	--
Clytia spp.	--	--	--
Encrusting Bryozoan	0.27(±0.19)	0	
Membranipora membranacea	--	--	X
Macroalgae	5.93(±0.51)	4.07(±2.56)	--
Chlorophyta	--	--	--
Ulva sp.	--	--	X
Rhodophyta	--	--	--
Polysiphonia sp.	--	--	X
Crustaceans	3 (±3.16)	0.86 (±0.48)	--
Balanus sp.	--	--	XXX
Other sessile species			
Anthozoa	6.73 (±0.89)	6.73 (±0.87)	--
Metridium senile	--	--	XX
Astrangia poculata	--	--	--
Tunicate	4.53 (±1.10)	9.6 (±1.50)	
Didemnum vexillum	--	--	X
Mobile species present	**Number counts**	**Number counts**	
Echinodermata	--	--	--
Asterias forbesi	5*	1*	--
Polychaeta	--	--	--
Neries sp.	--	--	XXX
Mollusca	--	--	--
Urosalpinx cinerea	--	1	X
Osteichthyes	--	--	--
Tautogolabrus adspersus	1	--	--
Centropristis stiata	100+ at base	100+ at base	--

*Many were observed in the area on the horizontal substrate around the turbines feeding on mussels.

Note: Average percent cover (± standard deviation) of all species present in photo stops for each side is provided for the video footage and the species present in epifaunal scrape sample collected from Turbine 1 (only) with occurrence in all samples examined (X = >25%, XX = <26% + >50%, XXX = >51%+ <75%, XXXX = >76%).

Figure 78 demonstrates the average percentage cover of all *Mytilus*/Epibiont complexes and other organisms, by turbine number and location of video transect (i.e., current or leeward side) in Year 3.

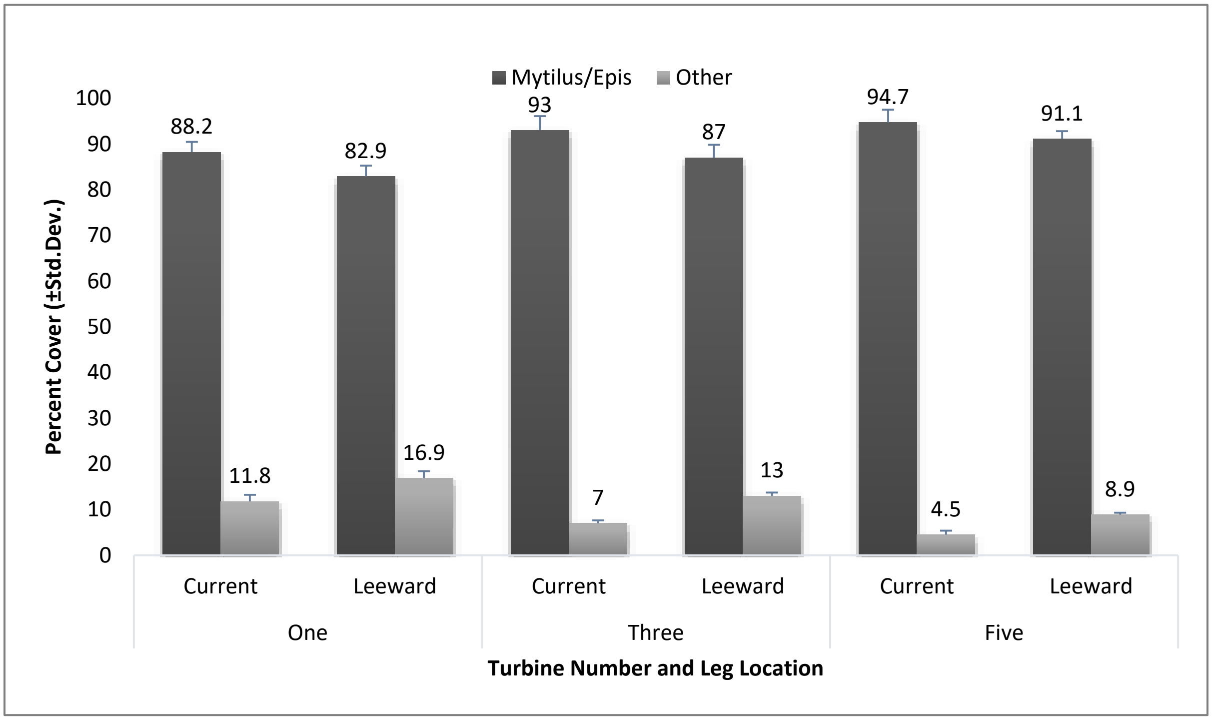


Figure 78. Average percent cover of organisms ((i) *Mytilus*/Epibiont complex and (ii) other species) from three Turbines (1, 3, and 5) and two video transect locations (current and leeward side of the turbine legs) in Year 3.

The results of the two-way ANOVA demonstrate a significant difference between the turbine and location of transect on the percentage cover for both *Mytilus*/epibiont complexes (Turbine: $F_{(2, 293)} = 10.881$, $p < 0.001$; Location: $F_{(1, 293)} = 6.193$, $p = 0.13$) and other species (Turbine: $F_{(2, 294)} = 11.154$, $p < 0.001$; Location: $F_{(1, 294)} = 7.309$, $p = 0.007$) but not for the interaction of turbine and location ($p < 0.05$). Tukey post-hoc tests demonstrated that for both dependent variables ('*Mytilus*/epibionts' and 'Other species' percentage cover) that Turbine 1 differed from Turbines 3 and 5, but Turbines 3 and 5 were similar.

Given the makeup of the epibiont community, the average percent cover of just *M. edulis* (epibionts separated for visual analysis of videos) collected in Year 2 of sampling in 2018 was plotted for comparison with the average percent cover for each turbine examined in Year 3 of sampling in 2019 (**Figure 79**). Noting that Turbine 1 was the only turbine sampled in both years for the video analysis, Turbine 1 exhibited a slight decrease in *M. edulis* cover (66.8% in Year 2 to 61.1% in Year 3) with a corresponding increase in 'Epibiont/Other' species cover (33.2% in Year 2 to 38.9% in Year 3).

However, t-tests demonstrated no statistically significant differences between 2018 (Year 2) and 2019 (Year 3) in mussel or percent cover of other species on the leeward or current side of Turbine 1 ($t = 1.31$, $p = 0.09$). The average percent cover of *M. edulis* alone and for other species (epibionts included) for each turbine is demonstrated in **Figure 80**.

From the video recordings of both sides of the turbine legs (diver descent and ascent), records of fish presence were noted. During footage obtained from both the descent (current) and ascent (leeward), small cunner (*Tautogolabrus adspersus*) fish were recorded but were rare (n = 1). However, at the base and grate area of each turbine, the black sea bass (*C. stiata*) dominated the fish present and were too numerous to count (estimates in the hundreds). It also was noted that sea stars (*Asterias forbesi)* were more common on the grate near the turbine structure (feeding on mussels) than on the turbine structures. On the final day of dive survey, partial boat debris (e.g., paneling from a small boat hull) was observed around Turbine 1, but no footage was obtained.

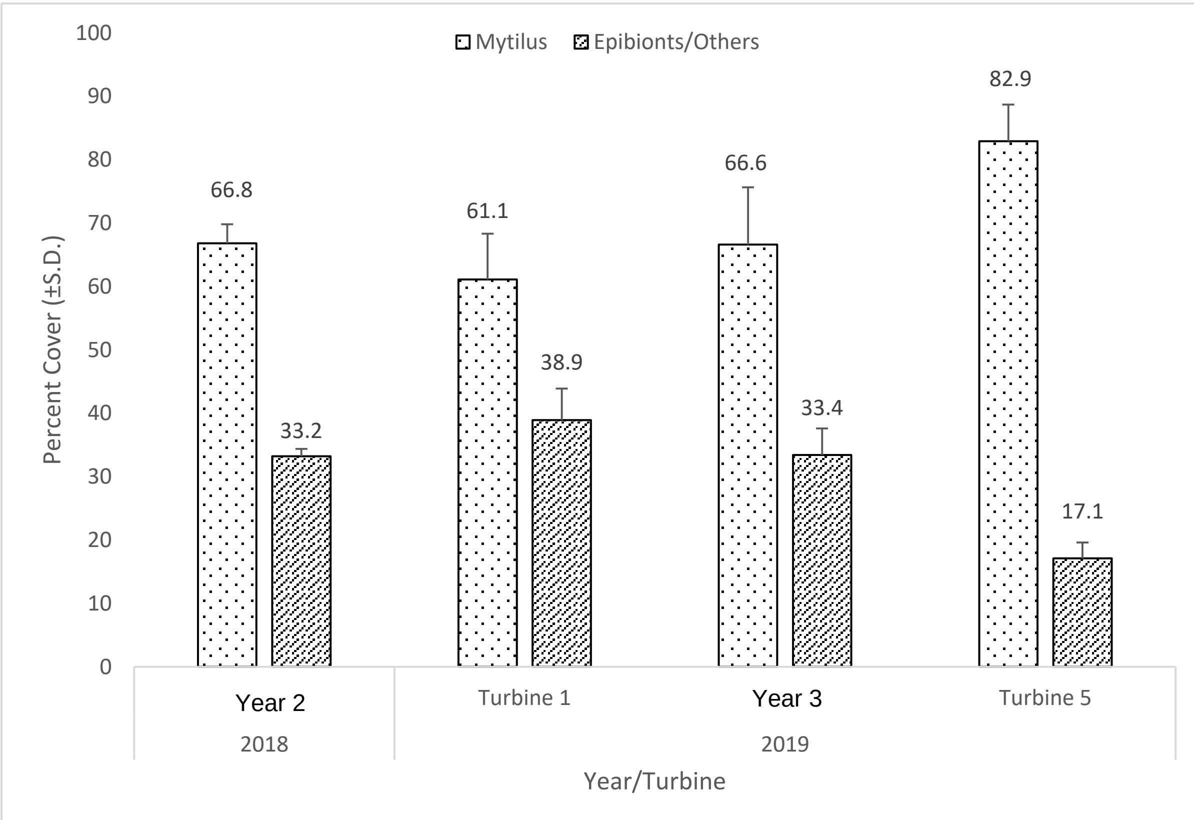


Figure 79. Average percent cover of (i) Mytilus edulis and (ii) Epibionts/other species identified from video footage of Turbine 1 in Year 2 and Turbine 1, 3 and 5 in Year 3.

Although black sea bass (*C. stiata)* dominated the video footage analyzed, more information from the fish inhabiting the turbine areas was obtained from the scientific divers, although they agreed that black sea bass (*C. stiata*) were very common around the base of the turbines. Divers reported the presence of Atlantic striped bass (*Morone sacatilis*) schooling frequently at the base of the turbines, bluefish (*Pomatomus saltatrix*) less frequently but observed in midwater around the turbines, scup (*Stenotomus chrysops*) seen frequently at the base of the structures, dogfish (*Squalus acanthias*) occasionally, in schools. In addition, divers reported frequently seeing rock gunnels (*Pholis gunnellus*) darting in and out of mussels present under and on the turbine structures. A monkfish (*Lophius americanus*) also had taken residence at one of the turbines and was observed on numerous dives. Fish species observed by scientific divers during surveys are detailed in **Appendix J**. Additionally, images of fish observed within the project area captured by the Langrangian photography transects are detailed in **Section 3.1.4** and **3.2.3**.

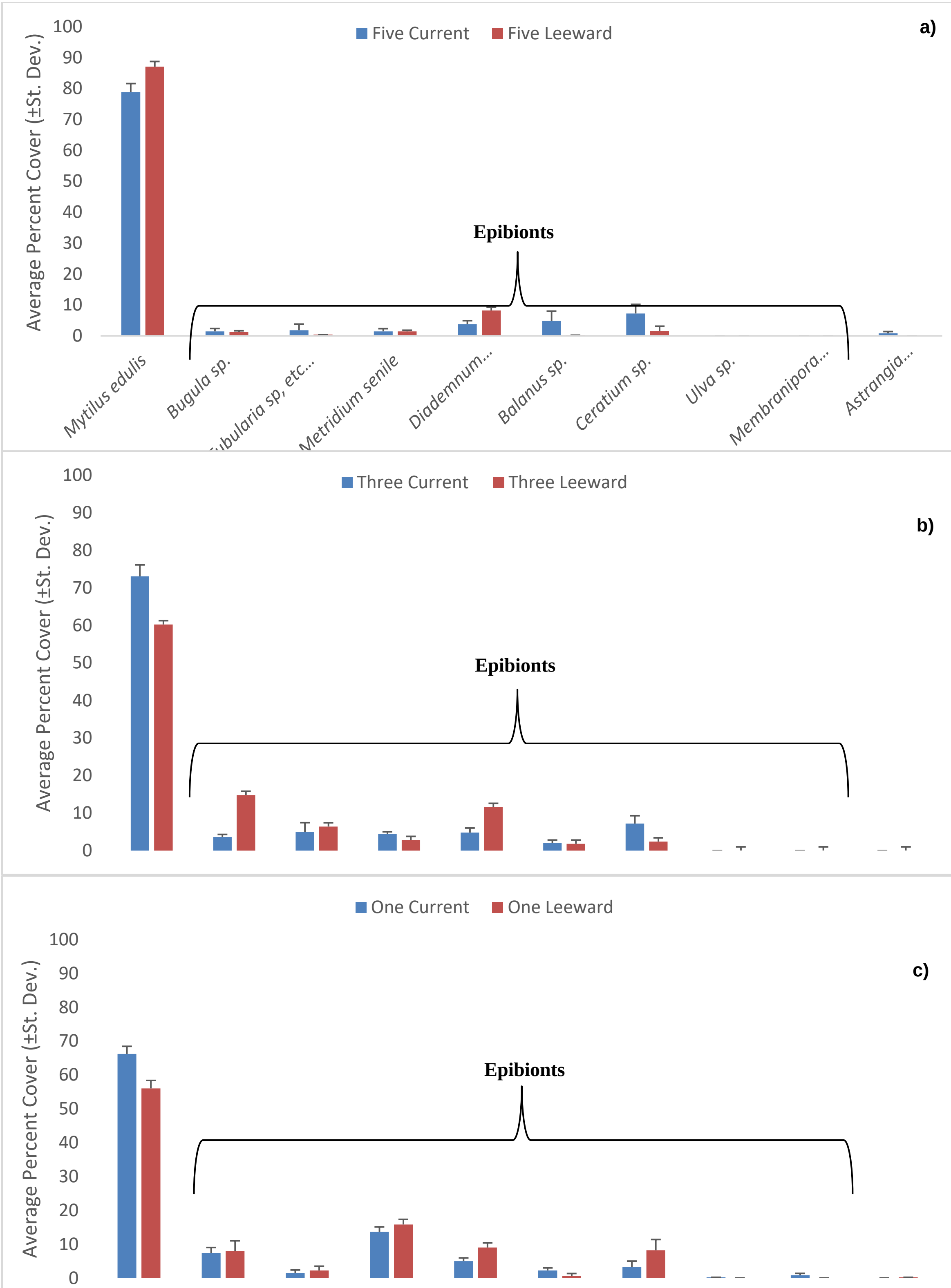


Figure 80. Average percent cover (± standard deviation) of all taxon from video analyses for a) Turbine 1, b) Turbine 3, and c) Turbine 5 (current or leeward side) in Year 3.

3.5.3 Turbine Leg Epifauna Specimen Collections

3.5.3.1 Year 2

Consistent with results from the video analysis, specimen collections from 10 areas on the southern leg of Turbine 1 in Year 2 demonstrated dominance by the blue mussel *M. edulis* and associated epibionts. The total biomass of each sample (mussels and all epibionts) is shown in **Figure 81**. The density of mussels (*M. edulis*) is show in **Figure 82** and the average length of mussels measured is shown in **Figure 83**. The intertidal area exhibited the largest density of smaller mussels (**Figure 82** and **Figure 83**).

Results of one way ANOVAs demonstrate that average mussel length ($F = 63.21$, $p < 0.001$) and density varied significantly ($F = 97.81$, $p < 0.001$) between some depths with fewer larger mussels on the grate base, leg base and 28 m depth and more abundant smaller mussels at shallower depths. Size frequency diagrams of all mussels per collection area are shown in **Figure 84**.

Unlike the video analysis, epifaunal scrape samples could be examined thoroughly allowing polychaetes (*Nereis* sp.) to be identified (n = 7 total from all samples). Unlike the video analyses, there was no evidence of anemones, sponges, or sea stars from the specimen collections and similarly, no pea crabs were encountered. Macroalgae was however, found in both the samples from the intertidal and from just below the waterline. Most collections at all depths contained barnacles (*Balanus* sp.).

Photographs taken in the laboratory of samples collected at different depths are shown in **Appendix L.** Examples of specimens identified from the scrapings are identified in photographs extracted from the video footage are also presented in **Appendix L**.

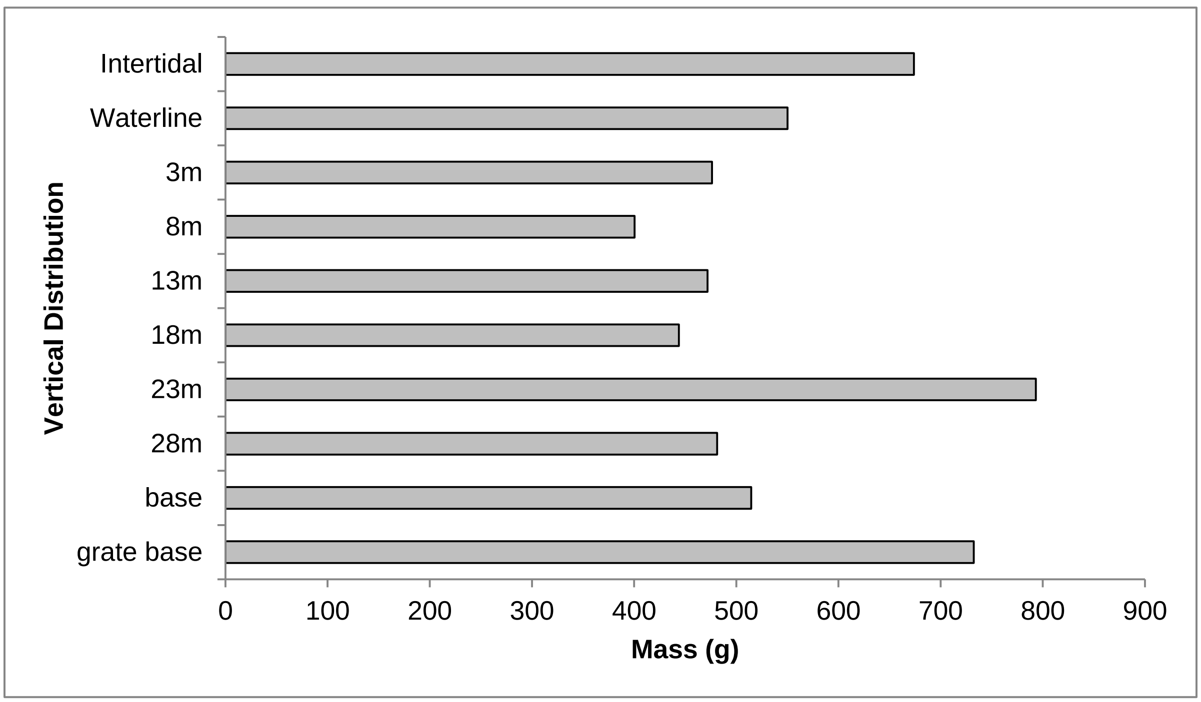


Figure 81. Biomass of all epifauna collected from each scrape sample from the leeward side of the southern leg of Turbine 1 in Year 2.

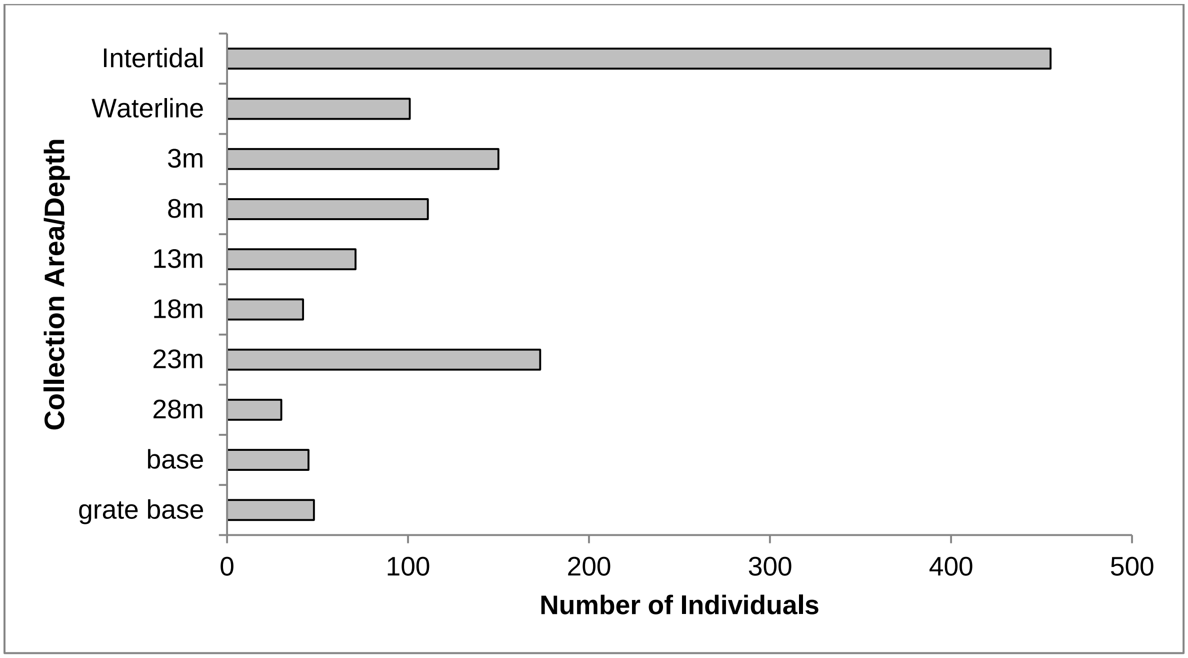


Figure 82. Density of mussels from each scrape sample (0.01 m^2) collected from the leeward side of the southern leg of Turbine 1 in Year 2.

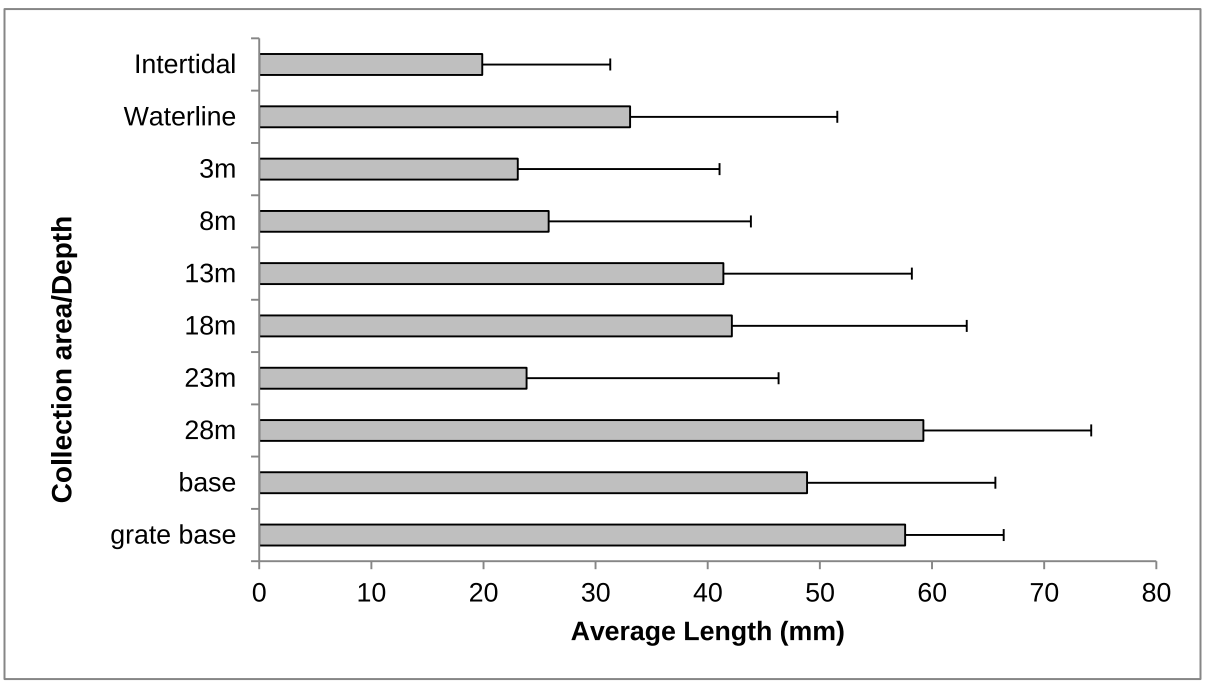


Figure 83. Average length of all mussels (mm, +st. dev) collected from each scrape sample from the leeward side of the southern leg of Turbine 1 in Year 2.

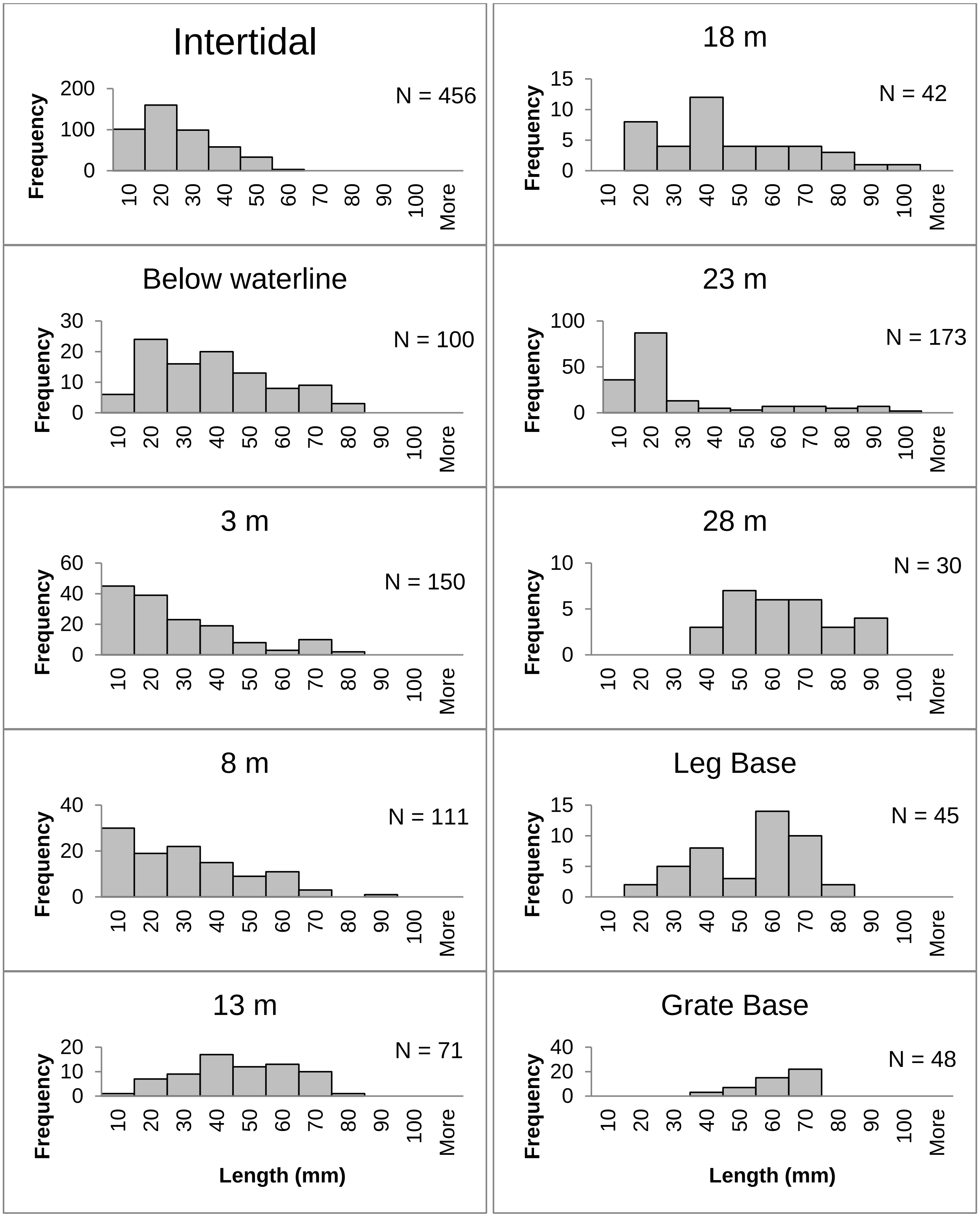


Figure 84. Size frequency distributions of the length (mm) of mussels, *Mytilus edulis,* collected from each scrape sample from the southern leg of Turbine 1 in Year 2.

3.5.3.2 Year 3

In Year 3, consistent with results from the video analyses, epifaunal specimen collections from 15 approximately similar depths on both the leeward and current side of the Turbine 1 southern leg, demonstrate a dominance of the blue mussel *M. edulis* and associated epibionts. In Year 3, scrape samples had an average percent cover by *M. edulis* and associated epibionts of 89% with only 11% cover by other species.

Common organisms for all epifaunal samples, from the Turbine 1 southern leg, are reported in **Table 56** beside the epifauna recorded from the video analyses of turbine legs (Turbines 1, 3, and 5). The most common organism found in the epifaunal scrape samples was the blue mussel *M. edulis* which was covered in multiple epibionts. The most common fauna, found in >76% of samples included hydroids, barnacles and polychaetes; found in >51% and <75% of samples included anemones; found in >26% and <50% of samples included macroalgae, tunicates and snails. Additionally, no pea-crabs, which are common to mussel beds, were found in the turbine leg epifaunal specimen collections.

The average biomass of current and leeward samples from all depths (combined) were not significantly different (Independent Samples T-test; $t = 0.99$, $p = 0.33$) and each sample collection (mussels and all epibionts and other species, i.e., the full sample) is demonstrated in **Figure 85**. Because there was only one sample from each depth, on each side, trends of biomass with depth were not assessed.

The waterline area and samples from 2, 5 and 10 m exhibited a high density of mussels (**Figure 86**) which are identified as small mussels in **Figure 87** and **Figure 88**. The average length of mussels for all depths and both collection locations (leeward and current side) is demonstrated in **Figure 87**, and size frequency diagrams of all mussels per collection area are demonstrated in **Figure 88**. Based on the results of a two-way ANOVA on log transformed data, mussel length did not differ between locations sampled (leeward or current) but was significantly different by depth ($F = 30.36$, $p < 0.001$) and depth by location interaction ($F = 10.86$, $p < 0.001$) with fewer larger mussels at the deeper depths and more abundant smaller mussels at shallower depths.

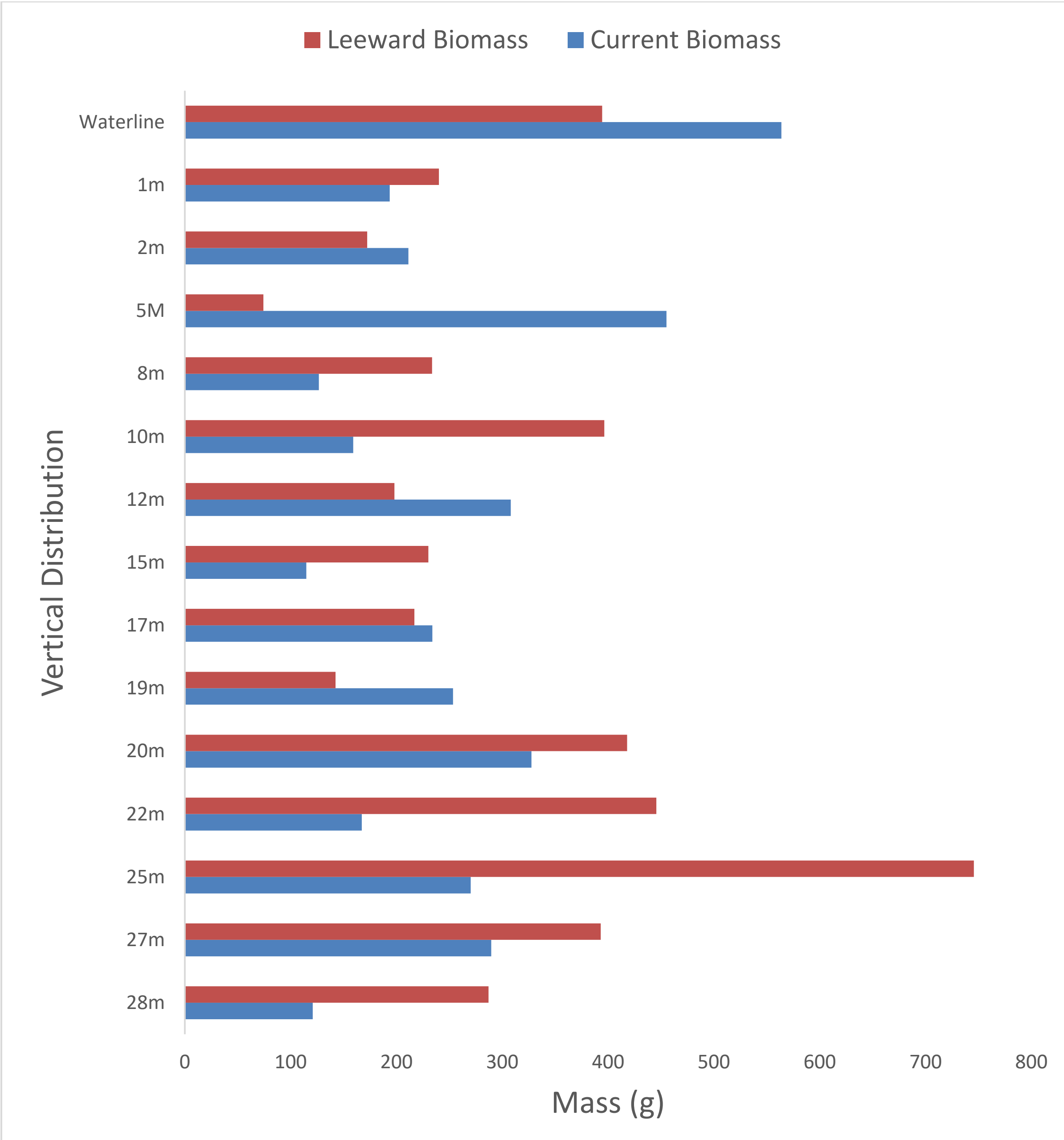


Figure 85. Biomass of all epifauna collected from each 0.01 m^2 scrape sample collected from both leeward (inner) and current (outer) sides on the Turbine 1 south leg (Year 3), from the waterline to 28 m depth.

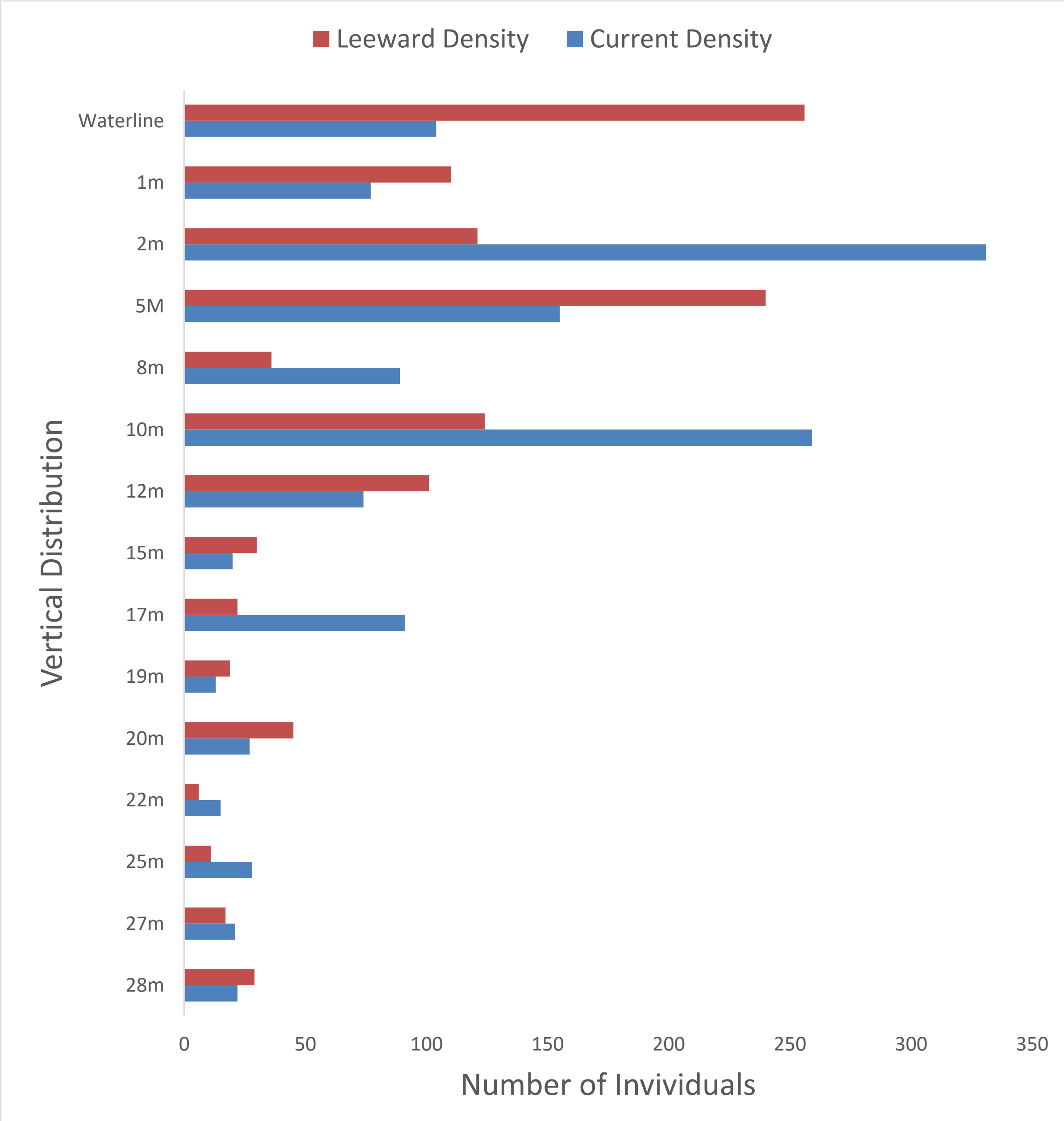


Figure 86. Density of mussels from each 0.01 m^2 epifaunal scrape sample collected from both leeward (inner) and current (outer) locations on the Turbine 1 south leg (Year 3), from the waterline to 28 m depth.

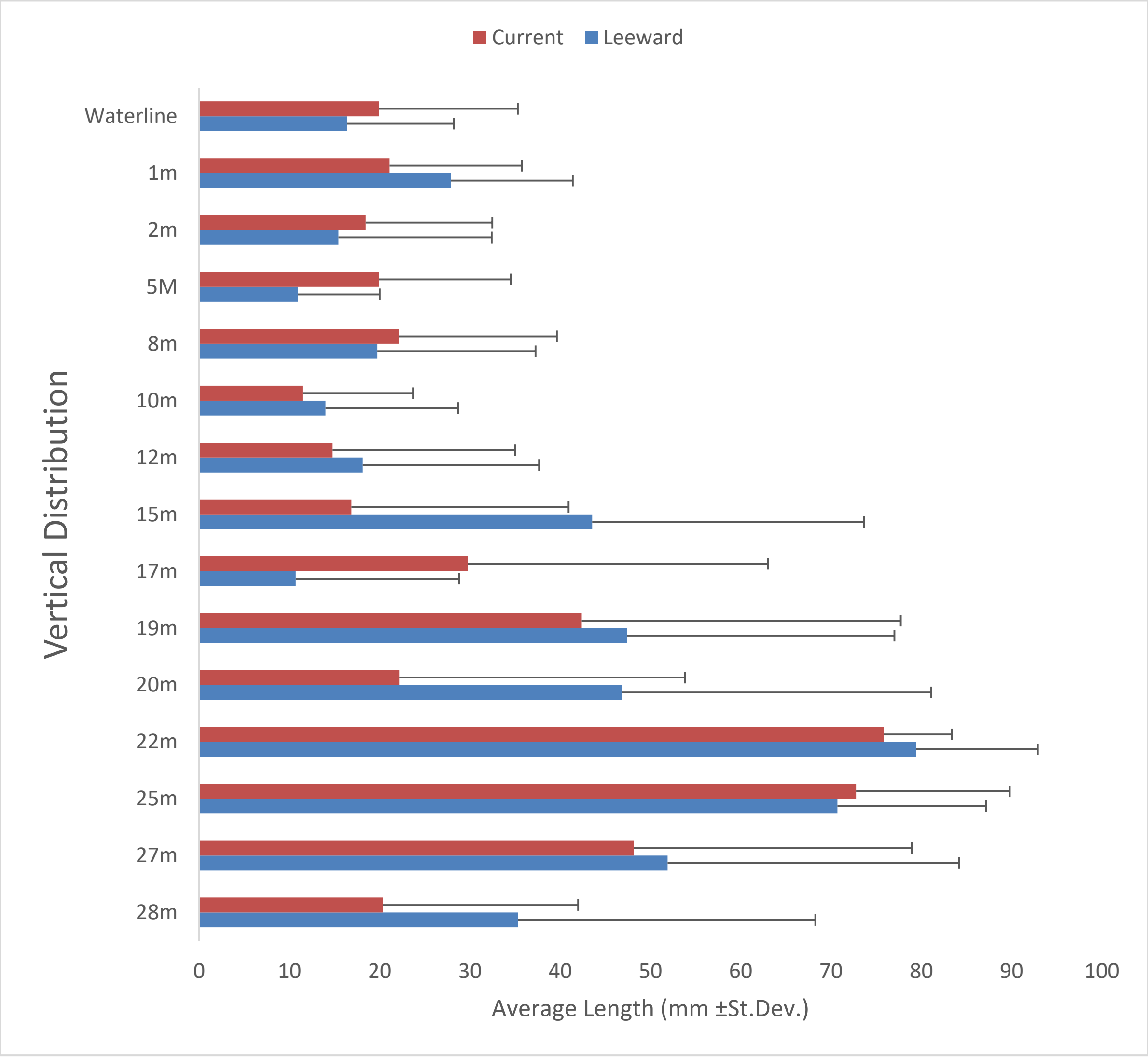


Figure 87. Average length of all mussels collected from each 0.01 m^2 epifaunal scrape sample collected from both the leeward and current sides on the Turbine 1 south leg (Year 3), from the waterline to 28 m depth.

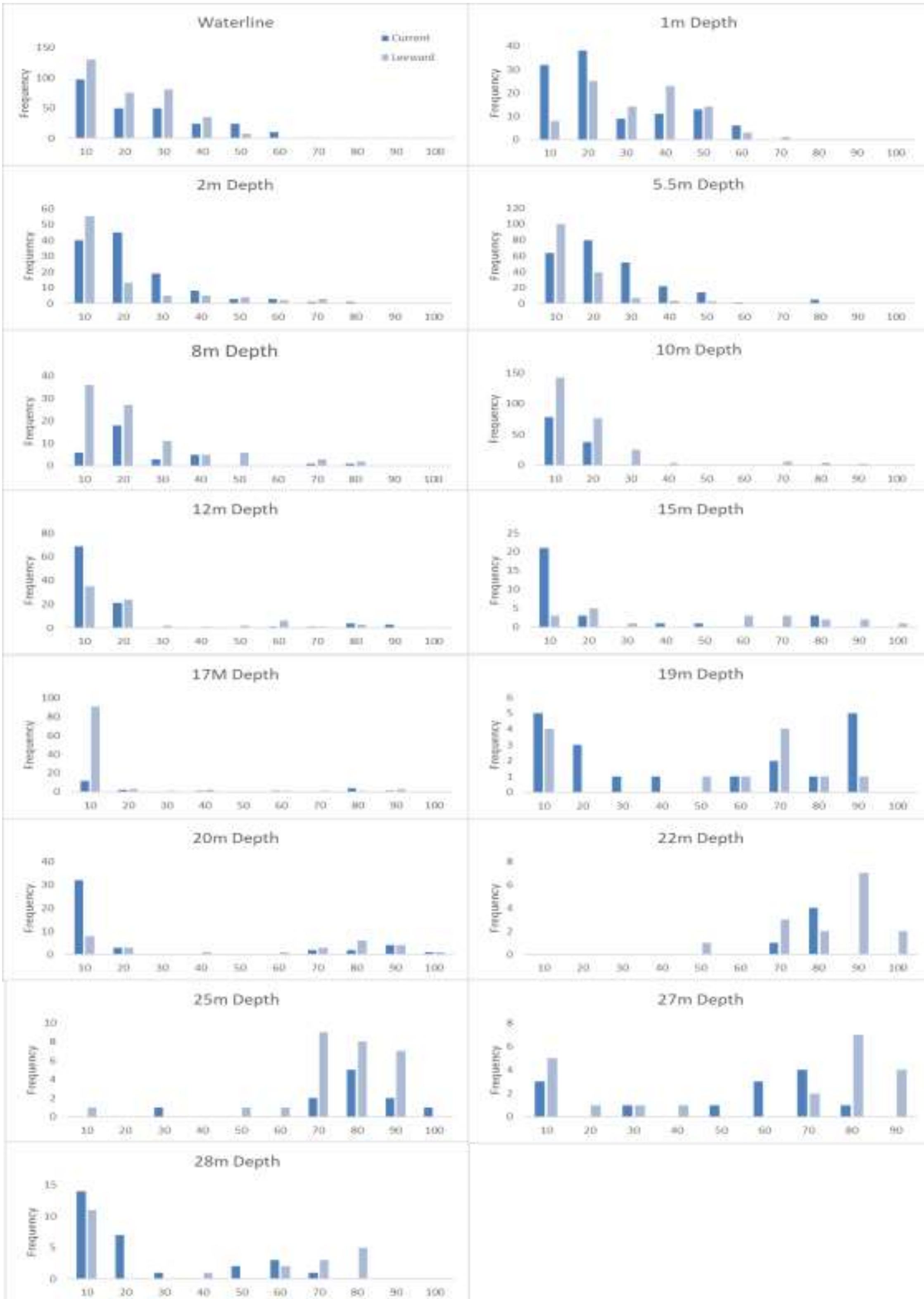


Figure 88. Size frequency distributions of the lengths (mm) of mussels, *Mytilus edulis,* collected at each depth and locations (leeward and current side) of the south leg of Turbine 1 in Year 3 (only).

3.5.3.3 Epifaunal Thickness; Current and Leeward side comparison

When each epifaunal scrape sample was collected from the south leg of Turbine 1 in Year 3, the thickness of the epifauna present was measured (cm), i.e., from the base of the structure to the top of the epifauna. There was no significant difference found for the thickness of epifaunal cover, between the leeward and current locations of the turbine leg (p >0.05) (**Figure 89**). The epifaunal thickness on the outside of the turbine leg ranged from 2 to 10 cm and on the inside of the turbine leg, the thickness ranged from 2 to 15 cm.

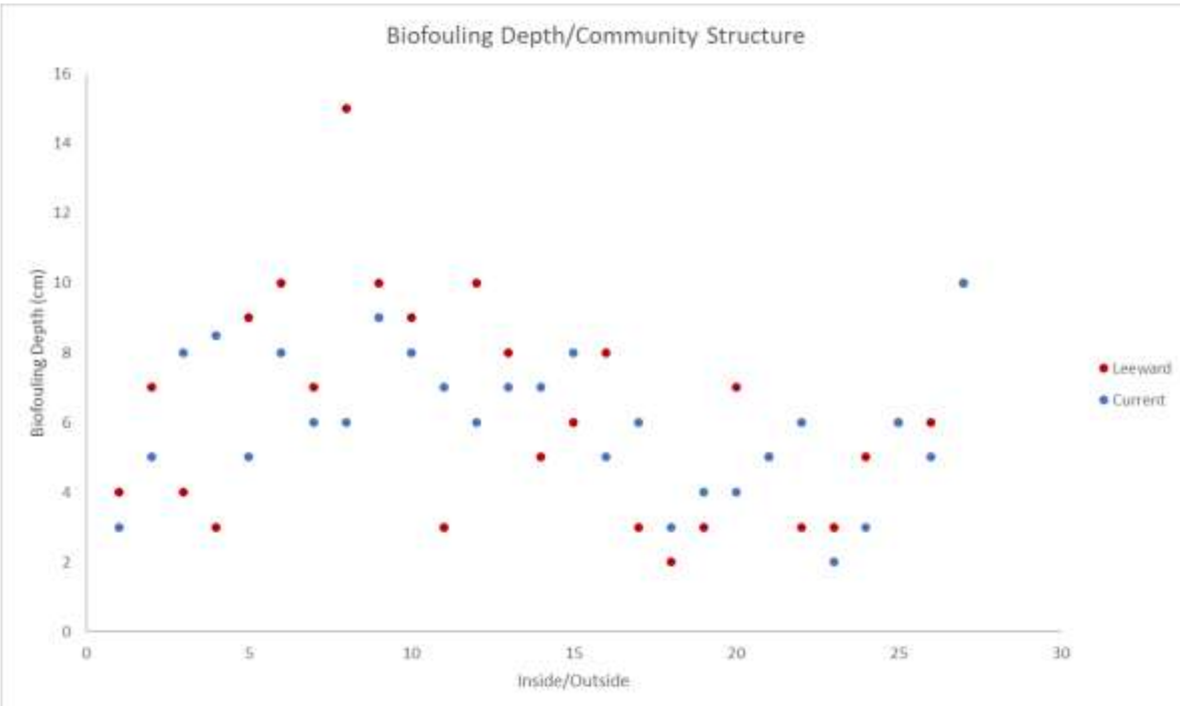


Figure 89. Epifaunal thickness (i.e., depth from the base of the structure to the top of epifaunal cover) on the south leg of Turbine 1 on both the leeward (inner) and current (outer) location in Year 3 (n = 27 for each but some samples overlap in the graph).

3.5.3.4 Comparison of Epifaunal Cover between Years

From the epifaunal specimen collections, the average percent cover of (i) *Mytilus*/epibiont complexes and (ii) Other species were determined. In Year 2, the *Mytilus*/epibiont cover at Turbine 1 only, was 94.8% and the Other species contributed 5.2% cover. In Year 3, the *Mytilus*/epibiont cover was 89.84% and the Other species contributed 10.52% cover. The average percent cover of all *Mytilus*/Epibiont complexes and Other species for Years 2 and Year 3 (Turbine 1 only) are shown in **Figure 90**. Statistical comparisons were not undertaken because only ten samples were collected in Year 2 compared to a total of 30 samples from Turbine 1 in Year 3.

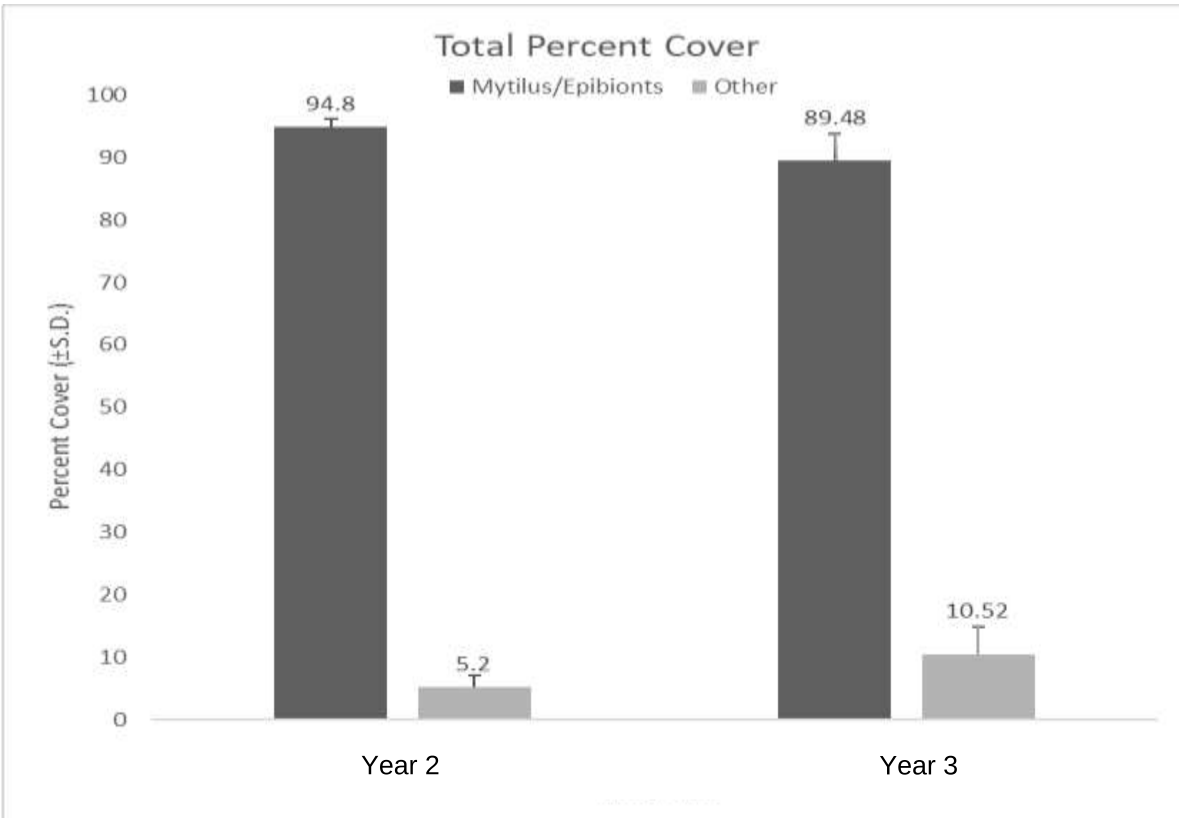


Figure 90. Average percent cover of (i) *Mytilus*/Epibiont complexes and (ii) other species determined from scrape samples from the southern leg of Turbine 1 in Year 2 and Year 3.

3.6 Turbine Foundation Epifaunal Mass and Estimates of Drag Forces

A bioengineering analysis was conducted to evaluate effect of the extensive epifaunal growth on the weight and loads of the turbine support structures. Total biomass, surface area, and weight of the epifaunal organisms on the turbines were estimated and presented below.

3.6.1 Estimation of Total Epifaunal Mass

Epifaunal samples were collected from the southern leg of the Turbine 1. From the surface to water depths up to 28 m, epifaunal scrape samples (10 cm × 10 cm area) were collected along the inner and outer portion of the leg. The thickness of epifaunal growth was measured by divers when collecting the samples and the submerged mass (i.e., wet weight) of each sample was measured on return to the laboratory; these data can be found in **Appendix M**. The results and trends with water depth are shown in **Figure 91**.

A maximum epifauanl thickness of 15 cm was observed on the inside leg surface at a depth of 21.25 m. Despite the variation of epifaunal thickness along the pile, the mean epifaunal thickness for the outside and inside portions of the leg was similar, at 5.94 and 6.33 cm, respectively. The submerged mass distribution (also shown in **Figure 91**) shows a trend increasing mass as the water depth increases. The greatest sample mass was 210 g from an inside leg sample collected at a depth of 25.5 m. The mean sample mass was 77.4 and 78.3 g for the outside and inside legs, respectively.

Based on the measured data, the estimated total additional mass imposed on the foundation by epifaunal growth on the southern pile with a diameter of 127 cm and length, L_{leg}, of 28 m was 1,025 kg (**Table 57**), which corresponds to a weight of 10, 059 kilonewtons. For comparison, a very conservative scenario of epifouling was estimated using the highest values of $\rho_{bmax} = 0.70$ g/cm^3 and $t_{bmax} = 15$ cm for both outside and inside region. Note that the thickest epifaunal samples did not correspond to high values of density. This calculation results in an estimate of 13,115 kg of added mass to each pile foundation (DNV 2014). This corresponds to a maximum added weight of 128,658 N per pile.

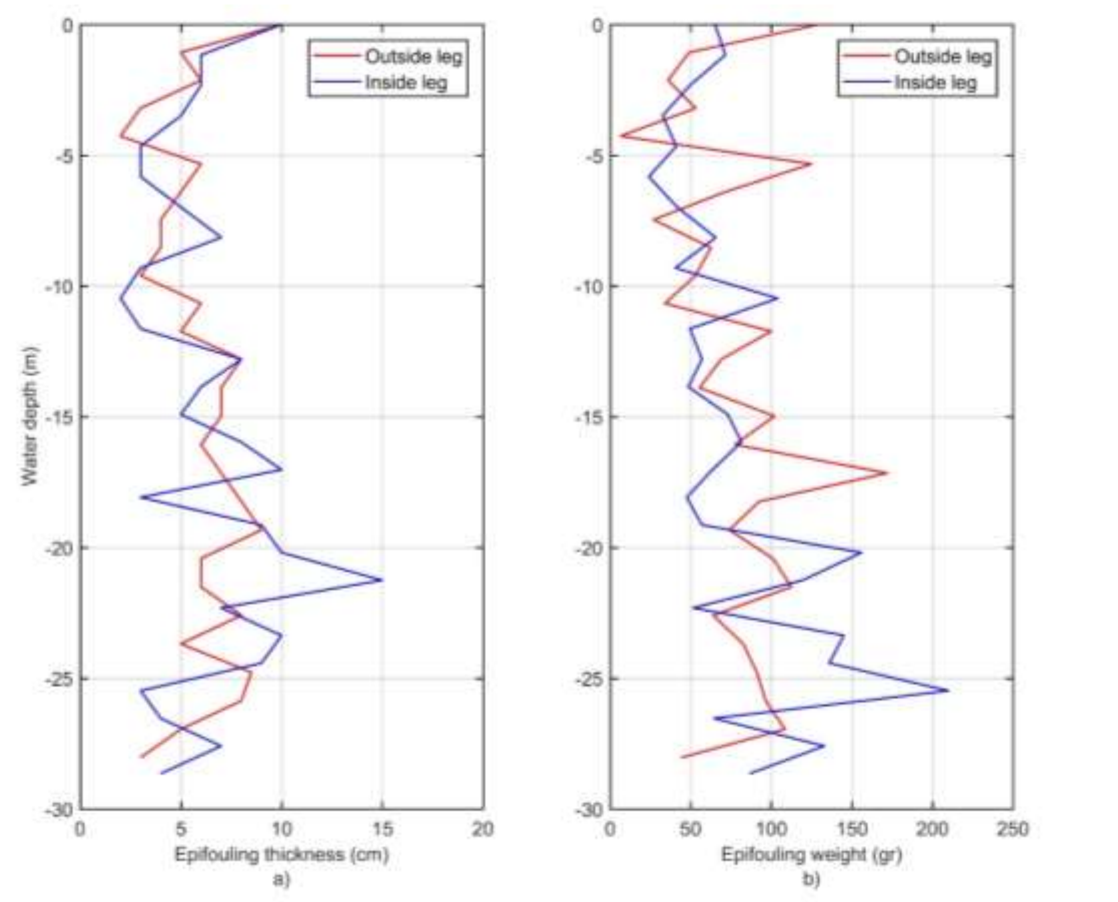
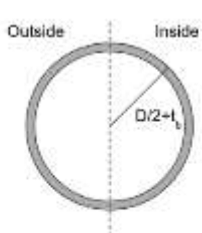


Figure 91. Measured epifaunal a) thickness and b) weight at the southern BIWF leg of Turbine 1.

Table 57. Additional weight imposed by epifauna on the southern leg of BIWF Turbine 1.



Region	$\overline{\rho_b}$ (g/cm^3)	$\overline{t_b}$ (cm)	$\overline{A_b}$ (cm^2)	m_b (g/cm)	Total weight, $m_b . L_{leg}$ (kg)
Outside	0.13	5.94	1241.37	164.65	461.03
Inside	0.15	6.33	1326.45	201.56	564.38
				Total	**1,025.41**
D=127 cm, L_{leg}=28 m; see **Appendix M** for details.					

3.6.2 Estimation of the Change in Surface Area and the Possible Effect of Drag on the Support Structure

Using the physical parameters of the epifaunal scrape samples from the southern leg of Turbine 1 (thickness and mass) and the calculations as set out in **Section 2.4.3.2**, an estimation of the associated change in surface area and potential effect of drag of the support structure was made. Note that these estimates assume that the southern leg is a single pile for simplicity.

The mean drag force per unit length in the presence of epifauna was calculated to be 4300 N and 4313 N for the inside and outside leg, respectively (**Figure 92**), compared to approximately 2543 N in the same situation with zero epifaunal growth. This corresponds to, a maximum of 75 to 85% increase in drag force per unit length of the jacket leg (assumed to be a single vertical pile).

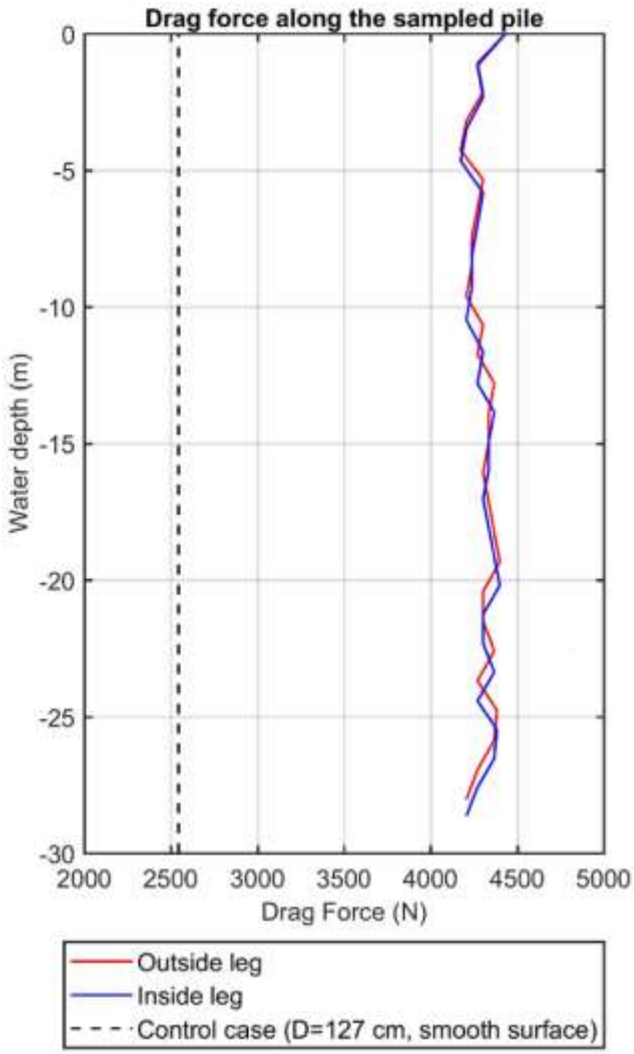


Figure 92. Calculated drag force using the collected epifaunal samples of the southern pile; simulated as a single pile and compared to a smooth pile without epifaunal growth.

3.6.3 Comparison of Drag Force on Offshore Wind Turbine Support Structures (Jacket foundations vs. Monopile foundations)

Estimates of the potential drag forces due to epifouling on the structures of two different offshore wind projects were calculated and compared. The structures used in this comparison were the BIWF project (jacket structure) and a generic large monopile representative of upcoming offshore wind projects in the United States. For simplicity, the BIWF jacket structure was modeled as four, vertical piles (**Table 58**). The total drag force was calculated using the mean drag force per unit length that was uniformly distributed along one pile. The large monopile was modeled as a single, large diameter pile. The thickness of biomass from the inside of the jacket legs was used in the estimation of the drag forces (**Section 3.6.2**). The results of this comparison are summarized in **Table 58**.

Table 58. Summary of BIWF jacket and large monopile structure comparisons.

	BIWF jacket support structure[6] (4 legs, represented with 4 monopiles)	Generic large monopile
Pile Diameter	1.27 m	8 m
Pile length	28 m	60 m
Maximum current (U_{max})	2 m/s	
Assumed wave period (T_{max})	10 s	
Mean Drag Force per unit length (for one pile)	**4,313 N**	**22,456 N**
Total drag force	483,056 N	1,347,360 N

Higher drag forces due to epifouling are predicted for the large monopile than the BIWF jacket structure because of the larger diameter of the monopile, which leads to a significant cross flow area that governs the drag force calculations. The actual jacket at the BIWF would have additional drag forces due to the cross-bracing. However, it is unlikely that the full 2 m/s current would act on all four jacket legs simultaneously.

The mean drag force per unit length of BIWF jacket leg was calculated at approximately 4,313 N for the southern leg (alone). Assuming similar conditions at all jacket legs (and excluding the remaining infrastructure for simplicity), the mean drag force per unit length for one leg was 4,313 N and so for four legs of the jacket structure would be 17,252 N. Although this is an overly simplified comparison, the drag force from four monopiles comprising the jacket at BIWF estimated at 17,252 N is much lower than the drag from the large single monopile estimated to be approximately 22,456 N.

Additionally, deeper water depth intended for the large monopile also significantly increases the total drag force working on the monopile supporting structure. Typically, drag force can be represented as distributed lateral force along the pile crossflow area. Based on the results shown in **Figure 92**, the variation of epifouling depth and calculated drag force per unit area was found to be small. Therefore, uniform load assumption using the mean value along the pile can well represent the force distribution. The total drag force acting on each structure was calculated at approximately 483,056 N and 1,347,360 N for BIWF project and the generic large monopile respectively. From these estimates, the total drag force

[6] https://espis.boem.gov/Final%20Reports/BOEM_2018-029D.pdf

due to epifauna at BIWF is less than half that calculated for a large monopile representative of future offshore wind projects in the U.S.

3.7 Results Summary and Conclusions

Monitoring program hypotheses were originally formed with regard to the 30 to 90 m sample area. However, as the monitoring program progressed, it became clear that changes observed on and immediately around the turbines were not observed at the control sites. In that regard, some hypotheses became applicable to the additional sampling within Years 2 and 3. As a reminder, the following three hypotheses were tested over the three-year study period, with respect to sediment composition, organic enrichment and macrofaunal communities:

- $H_0$1 – There are no differences between turbine areas.
- $H_0$2 – There are no differences between control areas and turbine areas.
- $H_0$3 – There are no effects of distance from the wind farm foundations.

Evidence from the sampling strategy as a whole is summarised in **Table 59**.

Table 59. Summary of results with regard to hypotheses; hypotheses 1 and 2 are considered together. (Hypotheses were designed for vessel-based sampling, but are considered for the additional diver-based sampling and epifaunal assessments also, where relevant.)

$H_0$1 – There are no differences between turbine areas. **$H_0$2 – There are no differences between control areas and turbine areas.**
Vessel-based sampling (30 to 90 m) area: • Particle size distribution was generally similar and dominated by medium and coarse grain sand, but there was evidence of increased clay and silts at a limited number of discrete sampling stations around Turbine 1 in Year 3 (**Section 3.1.2**) • Significant differences in organic matter were detected between turbines in Year 3; Turbine 1 had elevated levels of enrichment compared to the other Turbine and Control areas (**Section 3.1.5**). • Changes in macrofauna were observed between years and within years, in terms of the number of species and species abundance, both between turbines and control areas (**Section 3.1.6.4**). • Differences in macrofauna species composition were observed in Year 2 and Year 3 as shown in the nMDS plots (**Figure 43**) and supported by ANOSIM, SIMPER and permanova analyses (**Section 3.1.6.4**). • Variation in species dominance between turbines was evident throughout the study period (**Table 20 and Table 21**). • No significant differences in phyla biomass between turbines were observed in Year 3 (only) (**Section 3.1.6.6**) • Sampling indicated a limited number of patches of strong changes associated with mussel presence within 42 m of Turbine 1 (**Figure 44, Figure 45** and associated text in **Section 3.1.6.4**). Diver-based sampling (turbine footprint and very near-field area): • The clay and silt content of sediment within the footprint of Turbine 1 was much higher than Turbines 3 and 5 in Year 2 and Year 3 (**Table 31, Section 3.2.2**). The same trend was observed in the very-nearfield areas measure in Year 3 but to a lesser extent (**Table 30**). • Total organic matter within the footprint of Turbine 1 was significantly higher than that of Turbines 3 and 5 in Year 2 and Year 3 (**Figure 56, Section 3.2.4**).

• Within the very near-field area, the total organic matter levels were similar but more variable at Turbine 1 with a broader range **(Figure 57, Section 3.2.4)**. • The Turbine 1 footprint had a significantly higher abundance of species than Turbines 3 and 5, and the macrofaunal composition was more distinct, as shown in **Figure 62** and supported by the SIMPER analyses (**Section 3.2.5.3**). • Differences in mean macrofaunal abundance and species richness were not detected between turbines in the very near-field area, but the nMDS plot and SIMPER analysis supported differences in macrofaunal composition, with Turbine 1 being more distinct from Turbines 3 and 5 (**Figure 66, Section 3.2.5.3.2**). • The total biomass within the footprint of Turbine 1 was significantly greater than that of Turbines 3 and 5 (**Figure 67, Section 3.2.5.4**). Within the very near-field areas, the total biomass was significantly greater than that of Turbine 5 (**Figure 68**). Note: biomass was only assessed in Year 3. Epifauna sampling: • Epifaunal coverage assessed from video footage was found to differ at Turbine 1 compared to Turbine 3 and 5, and also between the leeward and current sides of the turbines (**Section 3.5.2.2**). • Large numbers of black sea bass were observed around the turbines in Year 3 but differences between turbines could not be assessed (**Section 3.5.2.2**). • Epifaunal scrape samples were taken from only one turbine and did not allow comparisons to be made between turbines (**Section 3.5.3.3**).
$H_0$3 – There are no effects of distance from the wind farm foundations.
Vessel based sampling (30 to 90 m) • No clear relationship between distance from the center of the turbine and sediment particle size was observed. However, notable areas of change occurred within the near band (30-49 m) in Year 3 (**Figure 23, Figure 24c, and Section 3.1.2**). • No clear relationship with distance from the center of the turbine and organic enrichment was observed (**Figure 28, Section 3.1.5**). • No clear relationship was detected between macrofaunal characteristics and distance from the center of the turbine (**Section 3.1.6.5**). However, there is some evidence of a gradient in macrofaunal change occurring around Turbine 1 (**Table 24, Section 3.1.6.5**). Diver-based sampling and Epifaunal Sampling • Not applicable

There is demonstrable evidence to reject $H_0$1 and $H_0$2 on the basis of changes in sediment particle size, organic enrichment, and macrofaunal change within the vessel-based samples (30 to 90 m area). There is also evidence to support the rejection of $H_0$1 for the diver-based sampling (turbine footprint and very near-field area) and for the epifaunal sampling at the turbine foundation structures.

The diver-based sampling and epifaunal sampling strategy did not specifically address $H_0$3. Working from the vessel-based sampling effort alone there is insufficient evidence, currently, to reject this hypothesis. However, considering the evidence from all sampling efforts and the changes reported for $H_0$1 and $H_0$2, there is clear evidence of stronger changes occurring close to the turbine and weaker changes occurring at farther distances.

Important results and significant observations from data analyses are listed as follows:

- Within four years of initial installation, significant modification of the seabed has occurred within the footprint of the turbine foundations, with the area underneath Turbine 1 exhibiting the fastest rate of change (**Section 3.2**).
- The transition of the area underneath the turbines to a dense mussel and fine, organic rich sediment dominated habitat appears to be occurring along a gradient across the BIWF, with area

underneath Turbine 1 exhibiting the greatest degree and fastest rate of change, and Turbine 5 the least change within the study period (**Section 3.2**).

- The transition that has occurred under the turbines is from a clean coarse sandy/polychaete association to a fine grained, organically enriched sediment supporting dense mussel aggregations (**Section 3.2** and **Section 3.4**).
- The greatest rate of transition is occurring below Turbine 1, which may be due to the apparent seabed stability at this location compared to the other turbines studied (**Section 3.4**). This underscores the highly localized (turbine specific) nature of benthic responses that can occur within offshore wind farms in this region.
- There has been a large increase in the incidence and abundance of juvenile mussels settling on the seafloor beyond the foundation footprints of Turbine 1 and up to distances of 90 m away compared to Control sites (**Section 3.1.6.4** and **Section 3.1.6.5**). Patches of larger mussels also have been observed up to 42 m from the foundation structures, and those patches were associated with highly modified seabed conditions and macrofauna in Year 3 (**Section 3.1.6.4**).
- Four years post installation, the foundations support dense mussel populations which colonize the structures between the intertidal and seabed. Several epifaunal species are becoming more common on structures including: anemones, sponges, and the invasive tunicate *Didemnum vexillium.* The coral *Astrangia poculata* has appeared near the base of the foundations (**Section 3.5.2**).
- Changes in the mobile epifaunal community are evident. For example, sea stars were present but not common in Year 2; in Year 3, they have become more abundant at the base and on the bottom of foundations (**Section 3.2.3** and **Section 3.2.5**).
- Abundance of black sea bass (*Centropristis stiata*) around the foundations increased dramatically between Years 2 and 3 (**Section 3.5**).
- Epifaunal growth on the turbine foundations was estimated to add approximately 1,025 kilograms of weight to each turbine jacket leg at the BIWF. More importantly, this growth was found to increase the mean drag force (per unit length) on the leg from approximately 2543 N (no growth) to 4313 N during an extreme current event (velocity of 2 meters per second) (**Section 3.6**). This represents a maximum of 75 to 85% increase in drag force (per unit length) due to epifaunal growth on the leg structure.
- The total drag force on the simplified BIWF jacket structures in an extreme current event was estimated to be 483,056 N, whereas it was considerably higher 1,347,360 N for the larger and deeper monopile structures, such as those being considered for future offshore wind projects. (**Section 3.6**)

The footprint of each turbine jacket foundation measures approximately 576 m^2. The study only investigated alterations in the seabed underneath and in the vicinity of Turbines 1, 3, and 5. Assuming that similar changes have either already taken place or are starting to occur underneath all five turbines, the total extent of the benthic habitat altered due to the presence of the turbines is about 2,880 m^2 (0.003 square kilometers). It was therefore concluded that while the effects of the turbines on the benthic habitat are localized, they are profound given the strong change from a sand habitat to a habitat characterized by mussel aggregations with associated organic matter, sediment fines and macrofaunal communities. Also, the Year 3 data indicate that the effects observed within the turbine footprint seem to be expanding beyond the turbines. Lastly, the foundations provide suitable surfaces for colonization by epifauna, and may facilitate range expansion of these species. Larval dispersion from BIWF and connectivity between future offshore wind projects, for mussel populations but also for other associated native and non-native species, indicate clear potential for larger scale changes in the longer term at BIWF and future offshore wind projects.

4 Discussion

4.1 Current Monitoring Practice

To date, there is little, if any, consensus on the level of acceptable benthic ecological change caused by OWF construction and operation, or on the relevant spatial scales over which such changes may occur. Permit conditions applied in Europe, for example, 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 and may be considered positive or negative changes in ecology.

More recently in the United Kingdom, monitoring has focused on valued features, such as areas of pockmarks or reefs which receive protection through national and international statutes. This approach has been criticized as failing to acknowledge the validity of the results in terms of 1) severity and spatial extent aspects against established value systems, 2) the metrics used or 3) 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 argues for reduced attention on determining significance in the context of null hypothesis testing in impact assessments and instead promotes adopting justifiable thresholds of change, around which meaningful management decisions can be based.

Localized impacts due to the operation of OWFs on benthic ecology have so far received little attention in Europe. Statutory monitoring in the UK for example, has been conducted at medium and broad scales such as several kilometers, with no significant impacts reported, and with limited or no cover of areas close to turbine foundations (English et al. 2017). License monitoring in Belgium has included assessment of close range impacts (e.g., tens to hundreds of meters) and epifouling assessment over several years (Degraer et al. 2019) and has substantially progressed understanding of wind farm/benthic interactions along with many research efforts (reviewed by Dannheim et al. 2019). However, wind farm device types, seabed types and water depths are variable between projects. These characteristics can provide contrasting benthic conditions and responses and may need to be considered on a case by case basis.

While impacts across finer scale distances (tens of meters) 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. To date, benthic monitoring has at best only been undertaken over the medium term (e.g., approximately 10 years) in relation to the operational life of an offshore wind farm (25 to 30 years or more). Long-term (i.e., operational life) effects on local benthos, specific to OWFs, remain largely understudied. Although there are some synergies with other man-made structures in the sea (e.g., Picken 1986 and Coolen et al. 2018), it is important that future assessment of OWFs acknowledge this knowledge gap and incorporate a precautionary approach as part of permitting and decision-making processes. It is currently assumed that benthic impacts of operational OWFs will be reversed on decommissioning (removal of foundations and scour material) and that natural conditions will be restored over time. However, the decommissioning approaches and ecological benefits of options available are currently under debate (Fowler et al. 2018; Birchenough and Degreaer 2020).

Although there is a lack of longer-term study (e.g., operational life) of potential localized benthic impacts at OWFs, there is mounting evidence of benthic changes, in particular, from the Belgian monitoring effort which has now been running for a decade (Degreaer et al. 2019). At the time of the BIWF monitoring design (2015), there was some evidence of organic enrichment, sediment fining and macrofaunal changes close (< 15 m) to gravity devices and monopiles (e.g., Coates et al. 2014; Wilhelmsson et al. 2006) and limited information of effects surrounding jacket structures (Schröder et al. 2006). However, benthic ecological changes linked to enrichment effectswere well-documented around fixed oil and gas structures off the west coast of the United States and in Europe (Wolfson et al. 1979; Page et al. 2005; Manoukian et al. 2010). In the aforementioned studies, conspicuous changes in sediment and benthic species composition have been recorded at up to 100 m distance 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 BIWF 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 BIWF study, so it is uncertain whether such oil facilities offer a suitable analogue to the BIWF situation.

Nonetheless, observations of epifouling on renewables infrastructure such as monopile and jacket foundations (Emu Ltd. 2008a, 2008b; Schröder et al. 2006) suggest considerable quantities of additional biomass could be introduced to offshore areas with turbine foundations acting as biomass ‘hotspots’ (Krone et al. 2013). Wind turbine structures provide new habitat for native and non-native species (De Mesel et al. 2015). Such increases in artificial structures may increase connectivity between populations and have potential to act as stepping-stones thereby expanding or shifting the geographical range of species (Adams et al. 2014; Henry et al. 2018; Barbut et al. 2019). Furthermore, they have the potential to act as aggregation and nursery sites for mobile fauana such as *Cancer pagurus* (Krone et al. 2017) and may serve as important sites for fish either for refuge or for food (Reubens et al. 2014). While conclusive evidence of the exact patterns of organic enrichment around turbines remains elusive (Lefaible et al. 2018, 2019), sediment changes and alteration of macrobenthos are increasingly being documented in relation to the construction and presence of wind farm turbines (Coates et al. 2012, 2014; Reubens 2016; Lu et al. 2020).

The RODEO Program has provided a timely opportunity to study short-range spatial and temporal interactions between OWF and benthic macrofaunal communities at Block Island and has allowed relevant benthic information to be collected from as close as possible to the foundations of the United States’ first commercial scale offshore wind farm at Block Island. Under the caveat that the study has only covered a short timescale (3 years), covering the first 4 years of operation, the data presented here establishes a baseline of information against which subsequent studies can be compared to 1) detect the presence of any gradient effects, 2) measure the spatial extent of effects from the foundations, and 3) characterize the effect in terms of the biotic and abiotic change compared to control data.

Importantly, the RODEO study at BIWF has allowed for method adaptation and optimization which can better inform future monitoring efforts on the U.S. continental shelf. For example, following the Year 1 vessel-based grab sampling campaign, the introduction of a diver-based sampling campaign provided valuable insights of very close-range (<30 m) benthic modifications. These include the abundance of mussels currently colonizing the entire vertical depth of the turbines’ foundations, and the development of mussel aggregations within the jacket foundation footprint. Diver observations have also proved important in capturing evidence as to the wider ecosystem interactions with larger, more mobile epibenthos and fish (reef effect) which is widely reported elsewhere (Dannheim et al. 2019). 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 temporal and spatial ecological influences of offshore wind farm development, and to provide valuable information to underpin future management objectives.

4.2 Sediment Data

4.2.1 Particle Size Data

Studies at European offshore wind farms have recorded significantly finer sediments (mean grain size) close to a gravity base foundation (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 15 m of the foundation when compared to those farther away and demonstrated considerable inter-annual variability. These observations were attributed, in part, to the effects of the construction of the wind farm and to modification to the local hydrodynamic conditions as a result of the presence of the foundation. 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 depending on tidal orientation and current speeds (Coates et al. 2014).

At BIWF, the foundations are jacket type structures, as opposed to gravity bases, 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 1.5 m deep in which the heavier shell material had been retained.

No significant sediment changes were noted at close ranges from turbines at a wind farm dominated by jacket type and high-rise cap pile foundations (Reubens et al. 2016) suggesting alternations to grain size distributions remain localized to within a few tens of meters of turbine foundations (Colson et al. 2017). The authors go on to identify the discrepancy with the earlier results of Coates (2014) and suggested that foundation effects on seabed sediments may manifest at closer ranges than currently monitored and recommended that future targeted studies be undertaken within very close vicinity (7 to 100 m) (Colson et al. 2017).

Overall, within the project study area, the field sampling data support 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 in Year 1. Although it should be noted that the latter was specific to Control 1 in Year 1, which was not resampled in Years 2 and 3 for that reason.

The low values and absence of sediment fines in samples collected during the vessel-based grab sampling survey (>30 m from foundation center points) over the three-year study is 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 collected over the course of the study contained no silt or clay particles at all. From the video data, a degree of local seabed disturbance is suggested by the presence of sand waves in some places. Additional information on seabed conditions in the vicinity of the turbines is presented in an accompanying seafloor disturbance and and recovery monitoring report (HDR 2020).

Evidence of natural seabed disturbances are also revealed in bathymetry data collected under parallel RODEO research efforts (HDR 2020). These data show the presence of localized sand ripple fields at Turbines 3 and 5 suggesting natural current induced disturbances of the surficial sediments here. This can be seen in **Figure 15** (**Section 2**) which shows clear ripple or sand wave features around Turbines 3 and 5. The bathymetry data also show no or limited seabed physical impacts from initial cable and foundation installation activities at Turbines 3 and 5, suggesting that successful in-filling and covering of cable trenches and seabed scars from construction vessels by locally available transient sediments has occurred and is likely ongoing. In contrast, the seabed at Turbine 1 appears to be comparatively immobile (less naturally disturbed) with fewer or less conspicuous sediment ripples or sand wave features. Also, construction related impacts remain more conspicuous on the seabed at Turbine 1 suggesting that there has been comparatively limited in-filling and covering by transient sands compared to that at Turbines 3 and 5.

Beyond 30 m of the foundation center points, vessel-based grab data showed that the dominant sediment fractions include medium, coarse and very coarse grade sand with occasional gravel and cobbles noted. In general, levels of fines (silt and clay) have remained consistently low (around 1–2%) over the monitoring period with no gradient with distance from turbine within this area, evident in any of the years. The levels of sediment fines were generally greater around Turbine 1 than they were at Turbines 3 and 5, suggesting lower hydrodynamic seabed disturbances and erosion of fines here but were broadly within the range recorded at control sites indicating natural background sediment conditions.

In Year 3, the silt and clay content at two locations at distances of 29 and 42 m north and north-west from the center of Turbine 1 was found to be substantially higher than that previously recorded and far exceeded control values. Levels here exceeded of 60%. This represents a new record of this magnitude at these distances from any turbine. Contemporaneous video footage at these two sample locations did not support the presence of predominantly fine sediment and instead described the seabed as predominantly medium sand and some gravel. The video data from the grab samples did, however, reveal the presence of whole mussel shells and mussel shell hash covering the entire field of view, suggesting the presence of large patches of mussels at these locations. Moreover, grab sampling found adult mussels with large biomass at these locations, suggesting the presence of established mussel patches or mussel beds here (e.g., **Figure 46**, **Section 3.1.6.4**). Sediment organic carbon and total organic content were also high at these locations (2.9 and 6.8%, respectively) compared to background levels at the Control sites (mean 0.2 and 0.4%, respectively).

The presence of these patches of unusually high levels of sediment fines, within an otherwise clean coarse and medium sand benthic environment, is likely to relate to the presence of the adult mussels. Mussels are considered important bio-engineers capable of altering local benthic conditions. Mussels are filter feeding, filtering suspended matter and phytoplankton from the water column and depositing feces and pseudofeces (Dankers and Zuidema 1995) within the surrounding seafloor. This may subsequently accumulate within the mussel beds and surroundings (Ysebaert et al. 2019). Fine suspended sediment may also become entrapped within interstitial spaces between mussel shells and their byssus threads, which they use to attach to the seafloor, thereby accelerating accumulation of fine sediment deposits.

Diver-based sample collection focused on the area within 30 m of the foundation center points; within the footprint and very near-field areas. Diver-based sampling identified much higher quantities of silt and clay sized particles within the sediments within the footprint of the foundation of Turbine 1 in Year 2 compared to adjacent seabed areas and control data. This confirmed the suggestion of previous authors that sediment changes, if present, would manifest much closer to foundation structures (Colson et al. 2017). The observation at BIWF in Year 2 suggested that the seabed directly below Turbine 1 had been strongly modified (became finer) quite rapidly and within 2½ to 3 years of the foundation being installed, based on an installation date between June and October 2015.

A repeat visit by the divers in Year 3 (approximately 3½ to 4 years after foundation installation) showed that the sediment within the footprint of the foundation of Turbine 1 had been modified further and comprised a thick mussel aggregation, up to 50 cm thick. The thickness of the mussel aggregation precluded diver grab sampling in some locations at this time, but where samples were collected, the levels of fines (silt and clay) exceeded 41%. Further to this, it appeared from the most recent sampling (Year 3) that the seabed samples collected in the very near-field area, located 8.8 and 10.8 m north-west of the Turbine 1 footprint had also become modified (finer) as indicated by an increase in the silt/clay fraction in these diver-based grab samples compared to surrounding areas (30 to 90 m) and Control data. Fine sediments at these locations near Turbine 1 ranged between 10 and 30% and so were considerably higher than levels typically found at Control sites.

The source of increased levels of fine sediment material directly below Turbine 1 is likely to be the Turbine associated fouling communities attached to the foundation structures such as feces from sessile filter feeding species as well as dead organisms. Wider scale effects, such as estuarine inputs or climatic factors are unlikely given the absence of any significance changes in Control data. The presence of mussel aggregations on the seafloor is also highly likely to be a key factor contributing to the observed seabed changes which may facilitate retention of fine sediments as well as acting as a source of fine sediment material themselves. Mussels, as well as other bivalve reefs, are known to be able to influence hydrodynamic processes over large areas and modify sedimentary environments far beyond the reef footprint, although the significance of this at the deeper water depths at BIWF is unclear. Furthermore, biodeposition of organic material from mussels can change the sediment composition (Ysebeart et al. 2019). Expansion of the mussel population from the foundation footprints may modify the seafloor over greater spatial scales.

The profound seabed changes occurring directly below Turbine 1 are not replicated at Turbines 3 and 5, although the data support that similar changes are now beginning to occur at those sites (as evidenced by fining of sediment and increase in mussels). However, these changes are progressing over longer timescales compared to Turbine 1. The reasons for the apparent differences in response timescales between Turbines are unclear but may relate to localized differences in bottom current velocities and associated physical seabed disturbances as highlighted in the bathymetry data (**Figure 15**). For example, the seabed around Turbines 3 and 5 appear to be regularly disturbed by hydrodynamics as evidenced by the presence of sediment ripples and waves on the seafloor. Regular seabed disturbances may act to continually winnow and erode fine sediment particles from the seabed such that any fine sediment deposits would be less likely to accumulate on the seafloor. In contrast, the seabed at Turbine 1 appears less disturbed by hydrodynamics as evidenced by the lack of seabed ripple features such that the rates of deposition and accumulation of fine sediments may be comparatively greater.

4.2.2 Total Organic Carbon

At the outset of this three-year study, it was proposed that at BIWF, the local benthic environment would receive inputs of organic material derived from the fall of biomass from epifouling communities colonizing the turbine foundations, in sufficient quantities to elicit benthic change. However, the quantification of input and accumulation rate of organic material within the local sediments from fouling organisms remains 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. To date, two diver studies of the epifauna at BIWF have been undertaken to date covering just four years of operation (sample Year 2 and Year 3). Consequently, longer-term changes in epifaunal communities and associated organic inputs to the local benthos are not known and warrant continued monitoring survey.

Expectations of epifouling colonization and community 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, Schröder (2006) describes a rapid initial colonization of the underwater surfaces of the FINO1 jacket structure within two weeks of construction followed by development of distinct patterns of vertical zonation within two years. Mussels (*Mytilus* sp.) and tube building amphipods (*Jassa*) constituted most of the biomass at the FINO1 platform although other fouling organisms were 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. Schröder (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.

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 93**). Such changes can include reduced oxygen levels and increased toxin levels (e.g., ammonia and sulfide), which can lead to depletions in species richness, abundance, and biomass. In benthic environments where food is limited, an increase in organic (food) material may lead to increased biomass of soft sediment macrofauna (Josefson 1990) as body size of individuals increase, or alternatively as the abundance of enrichment tolerant species increases. As enrichment increases, the community may become dominated by opportunistic species, which tend to be smaller bodied, while less tolerant taxa which will be removed due to the deteriorating conditions. The community thus becomes characterized by reduced biomass, high abundance and low species variety and will persist for as long as organic enrichment prevails (Pearson and Rosenberg 1978). In addition, suspension feeders give way to surface and sub-surface deposit feeders as enrichment increases.

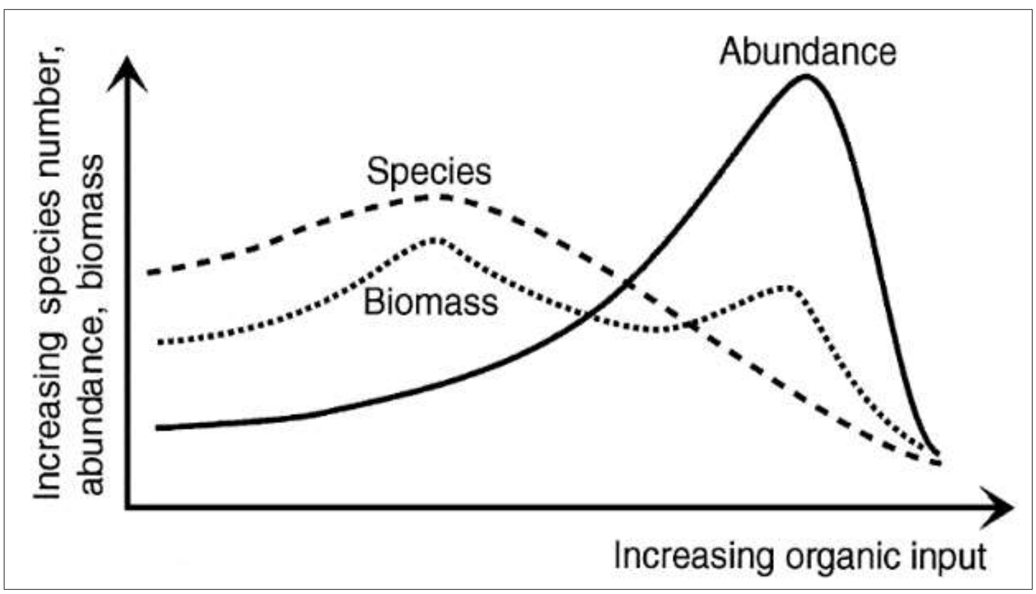


Figure 93. Pearson and Rosenberg's model of increasing organic inputs on species numbers, abundance and biomass SAB.

The vessel-based monitoring at BIWF suggests that there have been no significant effects on sediment organic matter levels at distances of 30 m or more from the foundation center points. Over the three-year monitoring period, levels have been comparable across the study area and no significant spatial distribution patterns have been observed overall. However, the two aforementioned samples at 29 and 42 m from the center of Turbine 1 demonstrated of organic enrichment (see above, Section 4.2.1) and were attributed to the presence of mussel patches and associated biodeposition.

The lack of direct effects beyond approximately 30 m from the foundations is not unexpected given that the sampling has been conducted 3½ to 4 years after the installation of the foundations. Therefore, epifaunal communities may not have had time to develop, mature, and subsequently slough off the structures, and thus contribute significantly to the organic carbon content of local sediments beyond the footprint of the foundations.

The recent use of divers to sample the sediments within 30 m of the foundation center points and within the foundation footprints has provided valuable insight into the very close-range effects of the operational turbines on sediment organic content 3½ to 4 years post installation. This has demonstrated elevated levels of organic matter at Turbine 1 compared to the other turbines. This is particularly evident within the foundation footprint where dense mussels are present however also evident at the aforementioned sample locations within 10 m of the turbine foundartion structure (the very near-field area). Notably, levels of sediment organics within the footprint of Turbines 3 and 5 have increased in Year 3 compared to Year 2. Indeed, organics levels within the footprint of Turbine 3 were found not to differ significantly to those below Turbine 1. This may be due to the increase in mussels underneath Turbine 3 and the sediment conditions becoming more similar. Continued monitoring is required to document the trend of sediment organic levels and to confirm whether changes at Turbines 3 and 5 follow the same trajectory as that observed at Turbine 1.

4.3 Biology Data

As alluded to above, this study proposes that biomass falling from the turbine foundations in the form of feces or dead organisms may enrich local sedimentary seabed habitats where this material is allowed to accumulate. The consequences of sediment enrichment may include a fining of the sediment and increase in sediment organic content, as documented previously, as well as associated changes in the characterizing sediment fauna. Seabed alteration in this way may, in turn, affect important ecosystem functions provided for by the benthos, in particular the provision of food, refuge and spawning and nursery habitat for fish and shellfish, some of which are of commercial interest. Understanding the potential magnitude and extent of such changes is key to future assessment and management of offshore wind farms and to inform sensitive and appropriate build-out of commercial scale facilities across the U.S. continental shelf. This section discusses the colonization of the BIWF turbine foundations (**Section 4.3.1**) and the changes in macrofauna detected in the surrounding area (**Section 4.3.2**), discussing the links between the two areas, where relevant.

4.3.1 Colonization of the Foundations

From a synthesis of available case studies, there is widespread agreement that; epifaunal colonization of wind farm structures starts soon after installation, that there are clear zones/bands, that a process of succession occurs that can be affected by storm events etc., and that the type of structure (e.g., monopile or gravity base) and natural factors influence the community composition and growth (English et al. 2017). Localized variations in community structures between turbines within the same wind farm have been accounted for by differences in age-in-water, water depth (light attenuation) and turbidity as well as tidal streams and wave action.

In other (European) studies, mussels (*Mytilus* sp.) are frequently reported to dominate the fouling communities but tend to be restricted to the upper water layers (<10 to 15 m water depth) (e.g. Krone et al. 2013; De Mesel et al. 2015). Increased predation, for example by sea stars, is suggested to limit their distribution below these depths, although other factors could be important such as sediment scouring at and near to the seabed. Below the belts of mussels, soft fouling species, including anemones, tunicates and hydroids, characterise the fouling communities at deeper depths. The anemone *Metridium senile* is occasionally dominant at deeper depths while intermediate depths may be characterised by transitional communities of both *Mytilus* and *Metridium*. Mussel aggregations on foundations are typically associated with a wide range of cryptic and larger fauna including amphipods, caprellids and crabs. Interstitial spaces between mussel shells within mussel colonies, as well as the shells themselves, provide various micro-niches for various species to inhabit. Deeper water *Metridium* communities tend to be associated with a lower variety of encrusting and attaching fauna including calcareous tube dwelling worms, bryozoans, sponges, and hydroids.

Increased drag by currents/wave action can cause clusters of mussels to occasionally loosen and detach. This creates 'bare' patches on the structure for subsequent organisms to colonize or new mussel larvae to settle and grow. In this way, mussel aggregations on wind farm structures may comprise various age classes including juvenile and mature specimens. The clumps that have been dislodged from the foundations presumably fall to the seafloor where they may be consumed by predators and scavengers. The sea star *Asterias rubens* has been frequently recorded to occur in large numbers at the base of turbine foundations feeding on mussels. Crabs such as *Necora puber* and *Cancer pagurus* are also frequently recorded at the base of turbine foundations where that are presumed to refuge in the rock scour protection and feed on the foundation biomass.

Kerckhof et al. (2019) report a comparatively species poor community on a gravity base foundation and a mixed *Mytilus/Metridium* community on a monopile some nine years after installation in the North Sea. During longer-term monitoring, three successional stages of colonization of these turbines were recognized (Kerckhof et al. 2019). These included a pioneer stage characterized by an influx of opportunistic taxa over the first two to four years, an intermediate stage characterized by several super-abundant filter feeding species including polychaetes, bivalves, amphipods and hydrozoans, and a climax stage which had developed by Year 5, characterized by *Metridium* and lower overall species diversity. Both monopile and gravity base type foundations exhibited these successional stages with some differences in some of characterizing species.

The jacket foundations at BIWF are different again, and so the development of comparable successional communities over similar timescales may not be expected. However, review of epifaunal communities of local artificial substrata within the region may provide useful insight in this regard. The presence of species-poor climax epifaunal communities (comparative to intermediate communities) on the North Sea foundations suggested that earlier accounts of wind farms acting as biodiversity hotspots may have been premature (Kerckhof et al. 2019). Once the climax community had appeared, it was found that the artificial substrates were different from the species-rich natural hard substrata and may not be considered an alternative replacement habitat (Kerckhof et al. 2019). Comparison studies of the marine life associated with local natural rock and artificial hard substrata at Block Island would allow assessment of the potential biodiversity benefits of offshore wind foundations.

At BIWF, diver studies on the foundations were not undertaken in the first two years following installation and so any initial pioneer stage may not have been captured. The data now available (two to four years post installation) seem to align with early to intermediate successional stages characterized by super-abundant filter feeders (*Mytilus* sp.) and some species variety (**Figure 94**).

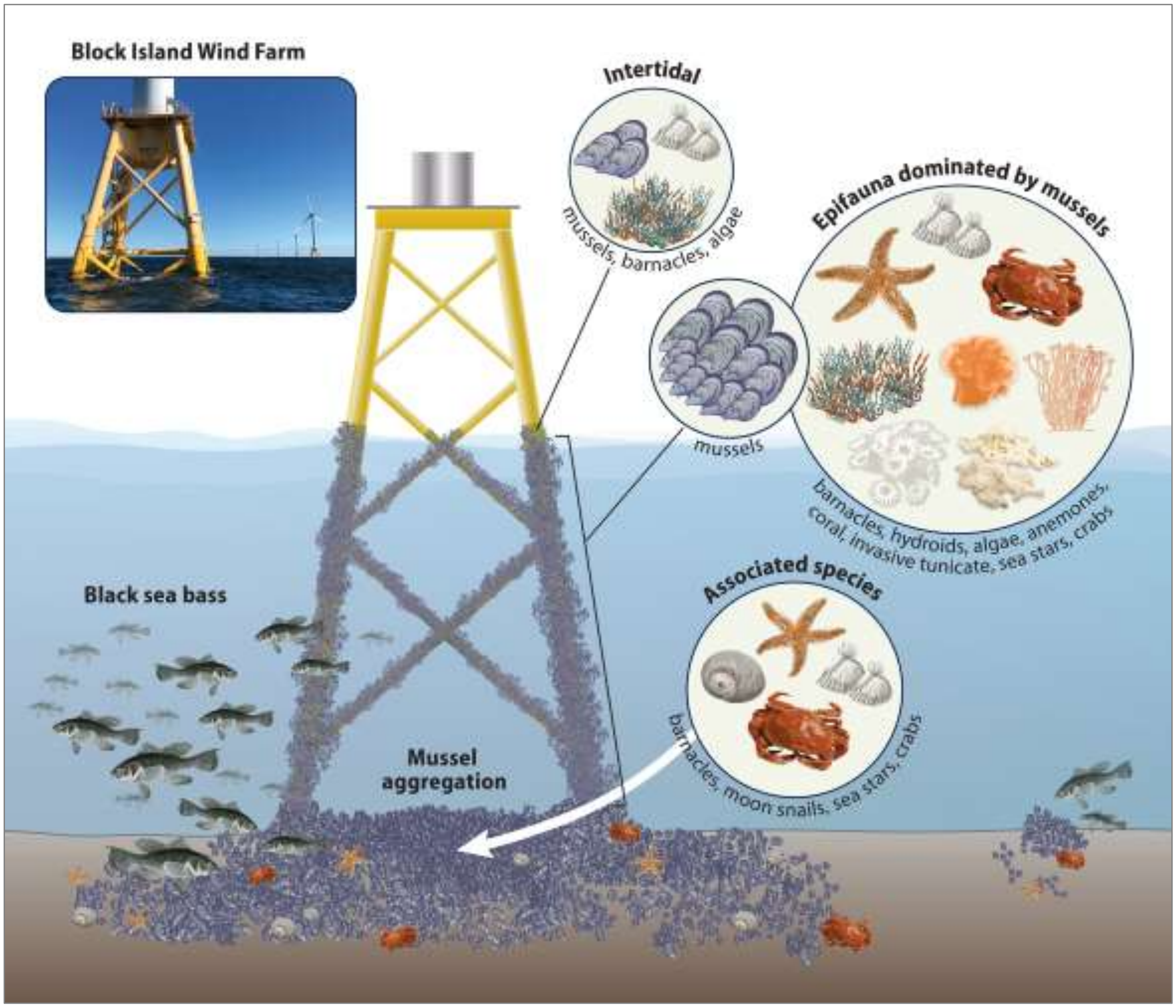


Figure 94. The BIWF jacket foundation structures and underlying footprints were dominated by mussels and associated species.

Note: Epifauna was dominated by mussels (*Mytilus edulis*) along the vertical length of the foundations. Other epifauna were present in comparatively low coverage. Dense mussel aggregations developed within the footprint of the structures. Numerous fish species were observed around the structures, the most dominant of which were black sea bass (C. stiata), estimated to be in the hundreds.

Observations at BIWF show that the foundations support a robust mussel population over the full vertical extent of all three of the turbines studied. Although zonation has been reported at other OWFs, mussel coverage to the lower regions of offshore structures (i.e., 2 m above the base) has been reported at oil and gas platforms (Wolfson et al. 1979) and to colonise up to depths of 20 m in deeper oil rigs in the North Sea (Whomersley and Picken 2003).

Differences in the sizes and densities of mussels at BIWF, between current and leeward leg surfaces and over time (i.e., between Year 2 and Year 3) were not significant. However the significant difference in size classes of mussels found at varying depths may reflect the periodic sloughing of clumps of mussels and rapid replacement and growth by subsequent cohorts. Differences in the percentage coverage of *Mytilus*-epibiont complexes were found between Turbines but were all characterized by a *Mytilus* dominance. High abundance and biomass of *M. edulis* has been recorded at OWFs in Europe (e.g., Wilhelmson et al. 2006; Krone et al. 2013) and at offshore oil and gas platforms (Wolfon et al. 1979;

Whomersley and Picken 2003). The presence and high percentage of of mussels at BIWF introduces an ecological seasonality to the area which must be considered in future sampling efforts.

The current diver work has only been undertaken over two years (up to four years post installation) and longer-term successional dynamics of the BIWF mussel populations are not known. Increased predation, storms, or other factors may be important in the future structuring of the mussels and local benthic environment to a greater or lesser degree. Should they become established, more competitive species may eventually displace the mussels resulting in a change to the epifaunal community, associated organic inputs and wider ecosystem relationships in the future. Again, a review of epifaunal communities of other submerged artificial structures in the Block Island region may be useful in determining what the final turbine communities at BIWF may eventually look like.

At other offshore wind farm sites, mussels on foundation structures are typically restricted to comparatively shallow water depths (<15 m). Factors limiting the spread of mussels down turbine foundations at other wind farm sites include predation, removal by sea stars and other mobile epibenthos and/or the effects of increased sediment scouring at the seabed. The presence of mussels at comparatively greater depths at BIWF suggests that such effects are absent or are not significant, allowing the mussels to grow and spread un-checked over the entire vertical structure.

At BIWF the development of mussel aggregations on the seafloor within the foundation footprints has been observed (**Figure 94**). This may be similar to mussel mounds reported from oil and gas platforms (e.g., Wolfson et al. 1979) but has not been assessed at other wind farms, or quantified. At present, it is not clear whether the mussels are spreading down the turbines and over adjacent seafloor areas within the foundation footprint or whether clumps of mussel falling from the overlying structure have subsequently established on the seabed. Spat fall from overlying populations could also facilitate colonization of the structure base and seabed by mussels. It is likely that mussels on the BIWF turbines are exported to the surrounding seabed, as proposed by other studies (Krone et al. 2013; Lefaible et al. 2019).

The numbers of mussels now colonizing the BIWF foundations represents a substantial pool of larval recruits for possible seeding and further colonization of surrounding seabed areas. As reported in **Section 3.1.6,** video and vessel-based grab sampling records over the three-year monitoring program showed an increase in the occurrence of mussels inhabiting the seafloor in patches or as individuals beyond the Turbine footprints, including in control areas, although the abundances of mussels at control stations in Year 3 remained low. **Figure 44** illustrates the changes in the occurrence and mean abundances of mussels at vessel-based grab sampling stations over the three-year monitoring period.

Whereas mussels were found to be confined to the footprints of the Turbines in Year 2, they now appear to be present beyond the boundaries of the foundation footprint at Turbines 1, 3 and 5 as indicated in the Year 3 data (**Figure 45**). Additionally, several areas of high mussel densities have also been recorded some tens of meters from the turbines during the recent in the Year 3 survey and particularly around Turbine 1. Numbers of mussels in some places beyond 30 m distances exceeded 1,000 individuals per grab sample in Year 3. In these instances, the mussels were juveniles, suggesting a recent spat fall, but aggregations of adult mussels were also present (**Figure 46**).

The abundance of mussels around the turbines exceeded control data, suggesting some effect of the turbines. If the turbines are seeding adjacent seabed areas, then this may represent an indirect effect of turbine presence beyond the foundation footprints. Further monitoring of the seabed around the turbines would be required to confirm future expansion of mussel populationsover surrounding seabed areas and the extent and intensity of associated indirect effects.

The mussels attached to the BIWF foundations are themselves fouled by various epibionts, including barnacles and hydroids and at shallower depths both red and green macroalgae (**Figure 94**). *Metridium senile* is present but no clear zonation is yet evident. In Year 3, the coral *Astrangia poculata* was recorded for the first time at BIWF. Additionally, within the foundation footprint, the macrofauna community associated with the mussel aggregations is quite different to surrounding areas. Within the footprint the macrofuana recorded included species such as barnacles, *Balanus* spp., arthropods *Caprella linearis* (skeleton shrimp), *Cancer irroratus* (Atlantic rock crab) and mollusks (snails) *Astyris lunata* and *Cotonopsis lafresnay* and the slipper limpet *Crepidula fornicata.* Numerous juvenile crabs were also noted (*Cancer* sp.) Several species of polychaetes were recorded including scaleworms *Lepidonotus squamatus* and *Harmothoe extenuate,* as well as *Capitella capitata* which can be indicator species for enrichment (Pearson and Rosenberg 1978). Colonization of hard structures of offshore wind farms is often considered a positive impact, regarding biodiversity and biomass enhancements as well as the provision of food for prey; however, potential ecosystem linkages, as a result of enhanced feeding opportunities for higher tropic levels over the life of a project, remain unclear.

Various species of fish are clearly attracted to the turbines in the current study, particularly black sea bass (*C. stiata*), and are likely using the turbines for food and refuge (**Figure 94**). However, whether this represents a benefit in terms of increased fish biomass or a displacement of local populations is not yet known. Impacts of decommissioning of offshore wind farm infrastructure should consider effects on biodiversity, productivity and any wider ecosystem interactions that have developed over the life of the facility. Also, and as stated previously, earlier mention of foundations acting as biodiversity hotspots in some literature, may be premature (Kerckhof et al. 2019).

The potential use of offshore wind farms as 'stepping-stones' for non-indigenous invasive species to expand their range is of concern (Adams et al. 2014). Recordings of *D. vexillum* on the BIWF turbines is notable in this regard although it is already prolific in the region and does not constitute a range expansion, yet. The extent to which offshore wind farms contribute to the increased spread a species and/or increase connectivity between populations of species (Henry et al. 2018), is uncertain and should be accounted for and addressed in any project plan where this is deemed a risk factor.

4.3.2 Sediment Macrofauna

The macrofauna within the BIWF study area have been shown to be naturally highly variable both spatially and temporally. While the identities of characterizing species have generally been recorded year on year, their abundances have differed considerably resulting in apparent significant differences between turbine study areas and between years. Control data have been important in confirming natural temporal change at distances of >30 m from turbine foundations rather than effects of foundation presence.

The annelids dominate the BIWF macrofauna followed by crustaceans and mollusks. Other phyla such as echinoderms, cnidarians and chordates contribute only a low percentage to the species richness based on current grab sample data. Over the three years of monitoring, the number of species comprising the top phyla have remained consistent, suggesting a degree of macrofaunal stability. Characterizing species include those which would be expected in coarse sand substrates such as the polychaetes *Pisione* spp., *Polygordius* spp., *Polycirrus eximius, Lumbrineris* spp*, Goniadella gracilis, Parapionosyllis longocirrata*, the amphipod *Unciola irrorata* and Nematoda.

However, within these phyla there has been considerable variations in relative abundances of individual species both spatially and temporally, and this has led to problems in interpreting the significance of observed changes and the acceptance/rejection of the test hypotheses in previous years. Overlying these changes in abundance of characterizing species, there was a large influx of nematodes in Year 2, further confounding the analyses at that time. Additionally, in the current (Year 3) data, there has been a marked increase in mollusk and crustacean abundances from Year 2. This was attributed to the settlement (albeit patchy) of high numbers of juvenile mussels, suggesting a recent spat fall, as well as barnacles recorded at a limited number of stations. Larger individuals and clumps of mussels were also present in grab and video data, suggesting more established mussel clumps in some locations.

As well as temporal variability, macrofaunal abundance also has been shown to be spatially variable. This could be an effect of the initial sampling design and the siting of the three study turbines (Turbines 1, 3 and 5) within different biotope types (see **Figure 7**). This could have resulted in natural spatial differences appearing in the ensuing datasets as the different biotopes would be represented by different top ranking (numerically dominant) species. In this regard, hypothesis $H_0 1$ (no difference in benthic communities among turbines) would be difficult to assess as the fauna across the different biotopes, within which study turbines were sited may not be expected to be comparable. Also, the inherent natural differences between the turbines, in terms of benthic communities mean that evaluating change at one turbine relative to another becomes challenging. This hypothesis is perhaps more suited testing in more homogeneous benthic environments, where macrofauna would likely have been comparable across the three turbine study sites, and where the natural habitat heterogeneity would not have confounded conclusions.

With respect to vessel grab data (+30 m distances), Turbine 1 is different to Turbines 3 and 5, which are more similar to each other in terms of macrofauna. In Year 3, Turbine 1 is separated from Turbines 3 and 5 due to lower abundances of the polychaetes *Polycirrus eximius* and *Pisione* sp. and higher abundances of barnacles *Balanus* spp. mussels, *Mytilus edulis*, and polychaetes *Nepthys* spp., *Exogone* spp. *Polygordius* spp., *Goniadella gracilis*, Cirratulidae and *Parapionosyllis longocirrata*, relative to Turbines 3 and 5.

It is also notable that Turbine 1 is not generally represented by control data for Control Sites 2 and 3, although it is partially represented by Control Site 1. Key differences between Turbine 1 and control sites in Year 3 included increased abundances of *Balanus* spp., *Mytilus edulis*, Nematoda, and *Polygordius* spp. at Turbine 1, relative to the control sites and reduced abundances of *Polycirrus eximius*, *Pisione* sp., *Unciola irrorata*, *Sphaerosyllis erinaceus*, *Travisia carnea* and *Parapionosyllis longocirrata*. Over 17% of the faunal dissimilarity between Turbine 1 and control sites was attributed to elevated abundances of barnacles and mussels at Turbine 1 alone.

The presence of abundant mussels at Turbine 1 in Year 3, compared to the control suggests some local effect over and above the natural variation. While the overall incidence of mussels at control sites increased, abundances at control sites remained very low in comparison. The total number of mussels recorded at Turbine 1 (> 30 m distance) in Year 3 was 5,335 and was substantially more than the total number of mussels recorded at the Control sites (36 individuals). An increase in mussels also was noted at Turbine 5 (>30 m distances) albeit less pronounced (383 individuals). Also, the incidence of mussels captured on seabed video, as either individuals, clumps or empty shells, around the turbines has increased in Years 2 and 3 over Year 1.

The mussels found around Turbine 1 were small juveniles, suggesting a recent spat fall. However, some locations supported larger individuals, suggesting more established mussel patches. The source of the spat is unclear but is likely to be the BIWF turbines themselves since they have been shown to support dense (presumably reproducing) populations present in close proximity. If this is the case, then this would constitute a potential indirect benthic effect of turbine presence. The potential spatial extent of this indirect effect over adjacent seabed areas will depend on larval survival on the plankton and the prevailing tides and winds. Larvae settling within Control sites would explain increased incidence of mussels here. Dispersion modelling may be informative in this regard and may help assessment of potential connectivity with other future offshore wind facilities in the wider region.

Mussels are important bio-engineers, able to stabilize and consolidate seabed sediments allowing colonization by benthic species as well as modifying sediments through biodeposition. Within the 30 to 90 m vessel-based sampling regime, it is notable that a different macrofauna was recorded in association with the patches of large mussels (29 and 42 m north and north-west from the center of Turbine 1) and where sediment fines and organics contents were exceptionally high. The fauna here was characterized by mussels and scale worms (*Harmothoe* sp. and *Lepidonotus squamatus*) together with the mysid crustacean *Heteromysis formosa*, the polychaete *Capitella* sp., the shrimp *Lebbeus zebra* and crab *Cancer borealis*. Importantly, the common and frequently occurring species normally associated with the BIWF study area, such as *Polycirrus eximius*, *Polygorgius* sp., *Pisione* sp., *Lumbrineris acuta*, Dorvilleidae and *Goniadella gracilis,* were absent from these locations.

Patches of large mussels were not found within the control sites and were not recorded during preliminary seabed surveys prior to BIWF construction (Normandeau Associates 2012) although are known in the wider region.

Krone et al. 2013 calculated vast mussel exports from FINO1 in Germany, indicating not only a high mass but a vast provision of hard surface area (shell) available for colonization on surrounding seabeds. In the Baltic Sea, mussels populating the seabed were noted to be highest within 1-5 m of the turbines, and lower 20 m from the turbines (Wilhelmson et al. 2006). Additionally, patches of mussels with associated macrofauna, and sediment charcteristics typical of mussel beds, were recorded 37.5 m distance from turbines, likely transported from the turbine structures (Lefaible et al. 2019). Expansion of mussels over the seabed at BIWF in the future could result in additional areas of seabed alteration beyond the immediate footprints of the turbines. Strong evidence of this is already observed, particularly around Turbine 1 (within 30 to 90 m). Furthermore, mussels have now been recorded at South East Ledge where they were not previously present (Wilber et al. 2020). It would thus be useful to conduct further monitoring to determine whether current aggregations of mussels are ephemeral populations or whether they develop into more permanent (and expanding) features.

Average biomass within 30 to 90 m distances of Turbine 1 was much higher than at Turbines 3 and 5, and this was attributed to the presence of large specimens of mussels at a limited number of stations. The crabs (*Cancer borealis*) also were found in association with these aggregations of large mussels and further contributed to the overall biomass here. The mollusk biomass was 80% higher than it was for Turbines 3 and 5. Elsewhere, mussels were recorded as juveniles with comparatively low biomass. Other contributors to the biomass at Turbine 1 included barnacles (*Balanus* spp.) and other mollusks. The average total biomass was greater at Turbines 1 and 5 compared to the control areas, and some inconsistent patterns of increased biomass in distance bands around turbine areas, compared to the control areas, were evident.

Benthic communities close to the turbines (between 30 and 49 m) were not significantly different from those farther away (50 to 69 m and >70 m), suggesting that four years after installation, there are no gradient effects due to the presence of the turbines. Previous reports, following the Year 1 and 2 monitoring surveys, suggested that given the short duration since installation, enrichment effects may not have had time to have developed at ranges of 30 m or more. This holds true four years post-installation; however, hotspots of change are clearly occurring and relate to recent spat falls around the turbines in the near-intermediate distances.

Summarizing the vessel grab data, strong evidence of organic enrichment as a result of the turbine presence at BIWF remains elusive beyond 30 m of the foundation center points although pockets of elevated sediment organics content are clearly apparent, particularly around Turbine 1 (29 and 42 m north and north west). These pockets relate to the occurrence of patches of large mussels on the seafloor which may be locally modifying the sediment as a result of biodeposition and retention of fine, organically enriched material. Elsewhere, the macrofauna around Turbine 1 is differentiated from that at the other turbines and control sites by the presence of high numbers of juvenile mussels and barnacles and reduced abundances of some characterizing species.

With respect to the diver data, the seabed within the footprint of the foundations of Turbine 1 was shown to be heavily modified in Year 2 (2½ to 3 years after installation of the BIWF foundations) and continued to be modified in the subsequent year (Year 3) by the development of thick mussel aggregations. The total number of mussels sampled within the foundation footprint at Turbine 1 in Year 3 was 7,045 despite only two samples being collected here. The same degree of seabed alteration was not seen at Turbines 3 and 5 although clearly patches of mussels were starting to aggregate below the foundations here in Year 3. Numbers of musssels collected on this occasion were 1,714 and 353 individuals below Turbines 3 and 5 respectiviely across five samples at each site. On this basis, hypotheses $H_0 1$ (no differences in benthic communities between turbines) is rejected as per the vessel grab data, although further monitoring will be required to assess whether Turbines 3 and 5 become similar to Turbine 1 (i.e., develop comparable thick mussel aggregations) albeit over a longer timescale. Also, the dense mussel communities within the footprint of the foundations are now very clearly different from the predominantly clean coarse and medium sand habitats beyond 30 m from the foundation center points. As well as dense mussels, the communities below within turbine footprints were characterized by polychaetes *H. extenuata*, *L. squamatus* and *C. capitata* as well as elevated numbers of crabs and seastars. Consequently, hypothesis $H_0 3$ (no impact on distance regarding organic enrichment or benthic communities) is rejected.

Patches of seabed in the very near field at Turbine 1 have also been seen to have been modified by increased sediment organic content over and above control conditons, suggesting a potential turbine effect, although any corresponding faunal response has to date been less conspicuous. Nevertheless, diver sample data in the very near field in Year 3 revealed community differences between Turbine 1 and Turbines 3 and 5 as evidenced by the nMDS (**Figure 66**) and SIMPER (**Table 44**) as well as increased numbers of mussels at Turbine 1.

Based on the diver observations, we postulate that the comparatively depositional (or less erosive) benthic conditions at Turbine 1 have allowed for the greater deposition and accumulation of sediment fines, organic material, mussel spat and/or clumps of mussels from the overlying foundation structures which has supported development of thick mussel reefs relative to the more erosive conditions at Turbines 3 and 5. In this way, we consider the benthic environment immediately below Turbine 1 to be more susceptible to the operational effects of the BIWF than Turbines 3 and 5, having responded more quickly and with more intensity to the presence of the turbines. Whether the same effects will eventually manifest at Turbines 3 and 5 is not known, and will require continued monitoring. Likewise, continued monitoring would confirm if the benthic changes observed at Turbine 1 are stable and continue long-term.

At BIWF, the turbines in the monitoring study are spaced approximately only 1,200 m apart, and yet benthic responses have been quite different at each. In this way, we have demonstrated that impacts can be ‘turbine specific’ subject to localized physical conditions and which have elicited benthic responses over differing timescales over short distances. Similarly, we have shown that the BIWF may have unanticipated indirect effects regarding the expansion of mussels over offshore seabed areas, although further monitoring is recommended to confirm apparent links. This may have important ramifications for decision making and monitoring of future wind farms, which should consider the full range of potential benthic impacts at the micro (i.e., turbine) level as well as ‘macro’ (regional) and cumulative effect levels. Stakeholders and permitting authorities will need to decide on the spatial scales over which benthic change is acceptable.

4.4 CMECS Biotope Classification

In this study, CMECS was found to be a comprehensive and well-suited framework for classifying data, developing biotope units, and identifying statistically significant relationships between macrofaunal communities and their associated environment. The biotopes illustrate the complexity of the seabed habitats present and are useful for providing a general classification of the turbine areas (30 to 90 m sample area) in a manner which is easy to convey and understand. The Geoform and Substrate Components offered a high level of detail for classifying the seabed environments. The Biotic Component was valuable for indicating the average dominant species with respect to abundance within the turbine and control areas. The Biotic Component was found to be most informative when coupled with the SIMPER routine to obtain details of macrofaunal community composition and identify contributing species. The biotopes identified in the OSAMP study and the three years of the RODEO study are summarized in **Figure 95**.

CMECS also proved to be useful for comparing the previously collected OSAMP data and the three years of RODEO data to detect changes over time, because consistent terminology was used to classify attributes. The ability to detect temporal and spatial change proved to be true for both individual CMECS components, as well as biotopes. The biotopes within the turbine areas defined in Year 1 of this study served as a reference point for comparisons with biotopes defined in Years 2 and 3, all of which followed the same data collection and analysis methodologies (**Figure 95**).

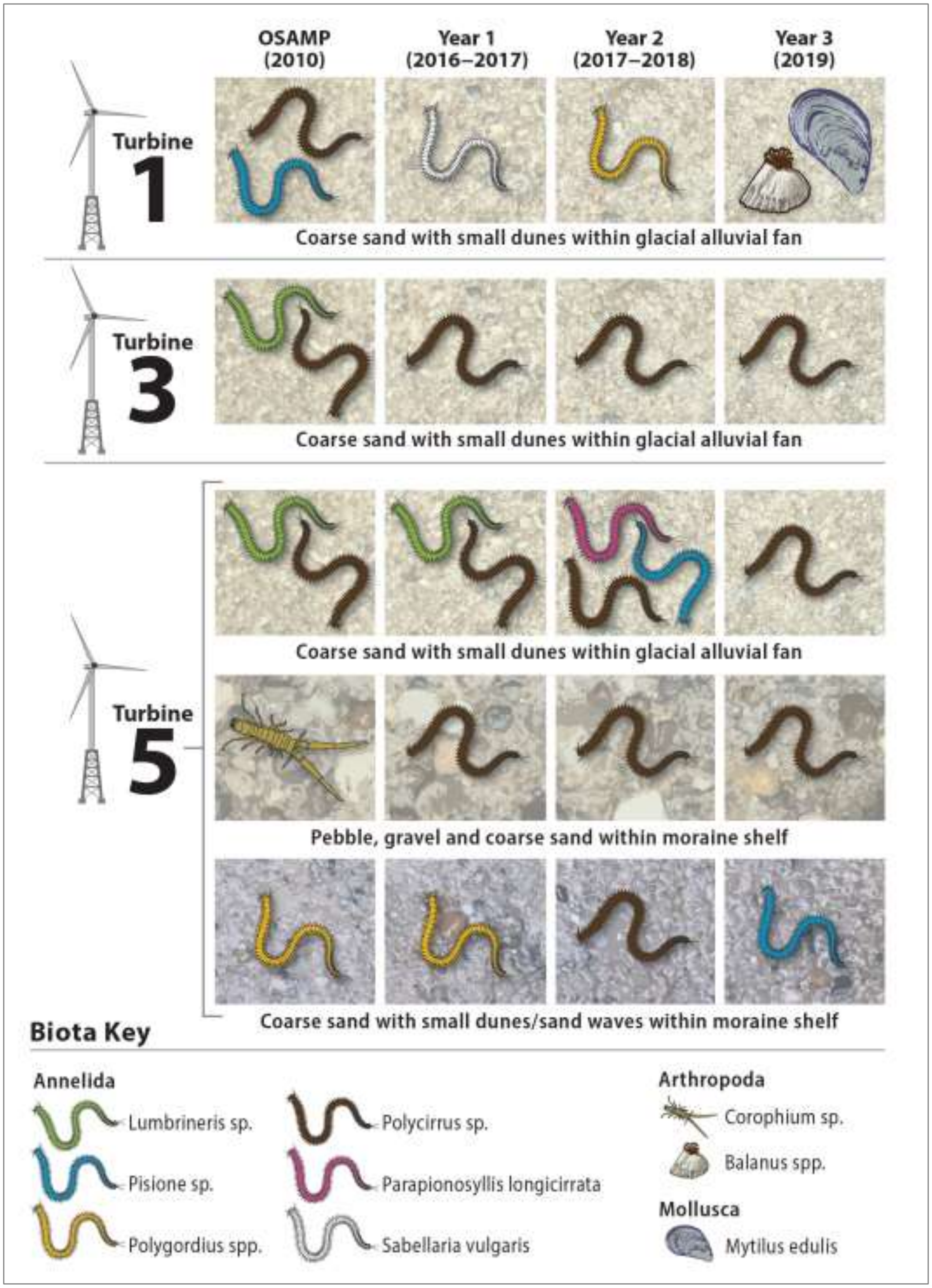


Figure 95. Comparison of CMECS biotope classifications at the BIWF turbines over time.

Note: Biotopes represent the area 30-90 m from the center point of the turbine foundation. All biotopes were characterized by polychaete worms in coarse sediments in sampling years 1 and 2, which, overall, was consistent with the OSAMP biotopes. In sampling year 3, the biotopes at Turbines 3 and 5 remained consistent, but a distinct shift was evident at Turbine 1, becoming dominated by mussels and barnacles.

4.4.1 Assessing Change among the OSAMP and BIWF Biotopes

The biotope unit 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 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 environments allows for more direct comparison of pre- and post-construction macrofaunal community structures and biotope classifications.

With regard to the biological component, the same methodology was employed for macrofaunal data acquisition and processing for both the OSAMP and BIWF studies to ensure comparability of the datasets, though 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 the remaining sample 700 m from Turbine 5. In comparison, for this study, at each turbine during each sampling year, 27 macrofaunal samples were collected within a 30 m and 90 m radius of the center point of the structure, which equates to a 0.01-square mile area. In Year 3, the sampling density increased, with an additional 27 samples collected at each turbine within a 15 to 30 m radius of the center point of the structure.

This considerable 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 most notable changes between the biotopes from OSAMP and across the three BIWF sampling years are described below.

The OSAMP biotope in the area of Turbine 1 was characterized by *Polycirrus* sp. (tube-builder) and *Lumbrinereis* sp. (burrower), though these species did not characterize the BIWF biotopes in Years 1, 2, or 3. However, *Lumbrinereis* is a dominant species within Turbine 1 in all years, is broadly distributed across the study area, and is a top contributor to the overall macrofaunal similarity of the samples collected within Turbine 1 (refer to **Table 41, Table 42,** and **Table 43**). *Polycirrus* sp, conversely, has a minimal presence at Turbine 1 over the three sample years.

While the Turbine 1 BIWF biotopes in Years 1 and 2 were defined by different polychaete species, *Sabellaria vulgaris* (sand-builder) in Year 1 and *Polygordius* spp. (burrower) in Year 2, they had similar functional traits as the OSAMP defining species. The change in classification between Year 1 and Year 2 is attributed to the highly localized and patchy distribution of *S. vulgaris* and relocation of the sampling sites between years, rather than a result of the turbine structure.

Turbine 1 in Year 3 was the only biotope that exhibited substantial change from the BIWF Year 1 and 2 classifications. This biotope showed a clear change in dominant species from polychaetes in Years 1 and 2 to crustaceans (*Balanus* spp.) and bivalves (juvenile *Mytilus edulis*) in Year 3, representing a distinct shift in the functional designation of the biotope. Though, in Year 3, the third dominant species was *Polygordius* spp. (defined Year 2 biotope), followed by other polychaete species. Aside from *Balanus* spp. and juvenile *Mytilus edulis*, all of the species most responsible for the biotope similarity in Year 3 are polychaetes and were also identified most responsible in Year 1 and/or Year 2 (refer to **Table 41, Table**

42, and **Table 43**). These results suggest that *Balanus* spp. and juvenile *M. edulis* are present in addition to the macrofaunal community that existed in Years 1 and 2, i.e., that they had not yet caused a shift in macrofaunal community composition throughout the biotope as a whole. Additionally, changes in the physical aspects of the biotope include patchy areas of increased fine-grain material and organic content, though these changes are currently not widespread enough to support a reclassification of the depositional environment. However, as a reminder, biotope classifications represent the average condition within a given area because they are defined by combining all samples collected within the area. In this case, further examination of the invidual sample sites was warranted to further examine if and how macrofaunal community composition had changed. Of the 27 Turbine 1 samples, two contained mature *Mytilus edulis*, and these sites were found to exhibit a different macrofaunal community composition relative to the other sample sites. This finding indicates that there is a shift occurring within the biotope that is associated with the presence of *Mytilus edulis*. While *Mytilus edulis* has patchy spatial distribution throughout the Turbine 1 study area at this time (two sample sites), there is high potential for the species to expand within the area (and beyond) over time, and manifest in significant shifts in benthic macrofaunal community characteristics.

The biotopes at Turbines 3 and 5 were found to be comparable with respect to species identities and functional designation, both when assessing change between the OSAMP and BIWF biotopes, and between the BIWF biotopes across the three sampling years (**Figure 95**). These biotopes were characterized by polychaetes in depositional environments containing coarse sediments (with the exception of one OSAMP biotope at Turbine 5 defined by an amphipod). As such, from a broader perspective, it can be considered that these biotopes have remained stable over time; there are no substantial differences in either benthic macrofaunal communities or ecological function at these sites. This finding is not unexpected given that the sedimentary environment is largely comparable throughout the BIWF study area, and 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 OSAMP biotope in the area of Turbine 3 was defined by *Polycirrus* sp. and *Lumbrinereis* sp., which shifted to being solely defined by *Polycirrus* sp. in the BIWF biotopes in Years 1, 2, and 3. Similar to Turbine 1, while not the defining species, *Lumbrinereis* is considered a key species within Turbine 3 across all three years, being a dominant species and also a top contributing species to the overall macrofaunal similarity (refer to **Table 41, Table 42,** and **Table 43**).

Within Turbine 5, the biotope with the depositional environment “coarse and with small dunes within glacial alluvial fan” identified *Polycirrus* sp. as a co-dominant species for the OSAMP and all three BIWF sampling years. Both the OSAMP and BIWF Year 1 biotopes were also co-defined by *Lumbrinereis*. Though, the co-dominant species changed to *P. longicirrata* and *Pisione* (burrower) in Year 2, and there was no co-dominant species in Year 3.

The Turbine 5 biotope with the depositional environment “coarse sand with small dunes/sand waves within moraine shelf” was defined by burrowing polychates in the OSAMP biotope (*Pisione* sp.) and the BIWF Years 1 and 2 biotopes (*Polygordius* spp.). The tube-building polychaete *Polycirrus* sp. became dominant in Year 3, signifying a functional shift within the biotope. However, all three of these species occur in relatively high abundances and contribute to the overall macrofaunal similarity across the three BIWF sampling years (refer to **Table 41, Table 42,** and **Table 43**).

The third biotope at Turbine 5 exhibited the greatest disagreement between the OSAMP and BIWF designations with respect to species but remain similar on a functional level. The amphipod, *Corophium*, defines the OSAMP biotope, where as the polychaete, *Polycirrus*, defines the BIWF biotope in Years 1, 2, and 3. Further, *Corophium* has a minimal presence in the BIWF samples. Examination of the functional roles of these defining species, however, reveals they are both tube-builders.

4.5 Potential Spread and Influence of Biotopes Dominated by Epifouling Species

One anecdotal observation made between Years 1 and 2 was that epifouling organisms, primarily *Mytilus edulis* and *Balanus* sp. were likely sloughing off of the turbine foundation structures and colonizing the bottom beneath and adjacent to the foundations. This observation was particularly strong at Turbine 1 where a continuous layer of mussels had formed beneath the foundation by Year 2. Primarily for this reason, the methodology in Year 2 was modified to include diver collected samples beneath the foundation structures and an epifouling study of the foundation. These studies were done in Year 2 and Year 3.

The RODEO study has shown that the five turbine foundations and their footprints have become *M. edulis* aggregations providing a three dimensional habitat to associated species. In Year 3, Turbine 1 exhibited extensive change beneath the foundation structure, which appears to be expanding beyond the structure out into the 30 to 90 m distance bands. There is substantial evidence for patches of change in the physical aspects of the biotope that include increasing organic carbon content and an increasing proportion of fine-grained material, both within the turbine footprints and at specific locations within 50 m of the center of Turbine 1. In addition, the biological aspect of the biotope classification changed in Year 3, as epifouling species *Balanus* spp. and juvenile *M. edulis* come to dominate the area. At Turbines 3 and 5, epifouling organisms, particularly *M. edulis*, have also become more important underneath and immediately adjacent to the foundation over time, though to a lesser degree, as of yet.

4.5.1 A Case Study in Narragansett Bay

Altieri and Whitman (2006) have shown that *M. edulis* is a reef-forming ecological foundation species within Narragansett Bay and regionally. The population of mussels is largely controlled by predation by the keystone species of sea star (*Asterias forbesi*), crabs, and fish species, and by episodic hypoxia events that can dramatically reduce or eliminate populations of subtidal reefs. In favorable years, large sets of *M. edulis* have occupied large areas of sandy bottom habitat in the lower West Passage of Narragansett Bay and have persisted for multiple years (J. King, personal observation). The most recent example of this phenomenon occurred in 2007-2009 when the area shown in **Figure 96** was covered by nearly continuous *M. edulis* beds. The total area occupied exceeded 10 km^2.

During the spring and into the summer of 2009 a massive swarm of the sea star, *A. forbesi*, arrived in Narragansett Bay as well as regionally along the southern coast of New England. The sea stars decimated the subtidal mussel beds, and they were eliminated by 2010. That year, large mussels could only be found either in rocky intertidal settings, or on pilings in the intertidal to shallow subtidal zone, within lower West Passage, and the seafloor was littered with mussel valves and shell hash. Clearly sea stars can exercise great control on mussel populations. However, the sea star swarm suffered a massive die off of *A. forbesi* starting during the summer of 2009 that persisted for several years until 2013 (Stokstad 2014; McLeish 2016).

Initially the die off was thought to be related to starvation after exhausting the local shellfish prey population. Over time, it became more likely that the mass mortality event was caused by sea star wasting disease. This disease is thought to be caused by a virus that spreads quickly through sea stars, particularly when populations congregate (McLeish 2016), although the die off in southern New England cannot be unequivocally be ascribed to a virus (Bucci et al. 2017). Sea star populations usually rebound over time, but they have remained episodically lower than usual within the region to date (McLeish 2016). The Three Seas Program at Northeastern University performs a small-scale, ongoing monitoring study using diver transects. The program monitors sea star abundance including *A. forbesi* off of two beaches in Nahant, Massachusetts. The Nahant data indicate that since the initial regional decrease in abundance in 2012, sea star populations have not recovered to a stable higher level, but rather exhibit a boom-bust cycle from year to year (pers. comm. with P. Barrett, RIDEM).

Due to the possibility of diseased-induced population instability in sea star populations, the regional importance of *A. forbesi* predation for limiting *M. edulis* populations (Altieri and Whitman 2006) may still be diminished at this time. Another possible contributing factor to the instability in sea star population may be warming waters (Bucci et al. 2017), perhaps causing outbreaks in warmer years after populations have increased. Overall, regional conditions may be favorable for large *M. edulis* specimens and the spread of mussel bed and/or reef habitats in the intervals of low sea star populations. It is acknowledged that sea stars have been observed in associations with mussel aggregations close to the turbines, as would be expected of a typical predator-prey relationship. However further monitoring would be required to determine if this sea star population is stable over time and the consequences for the mussel population.

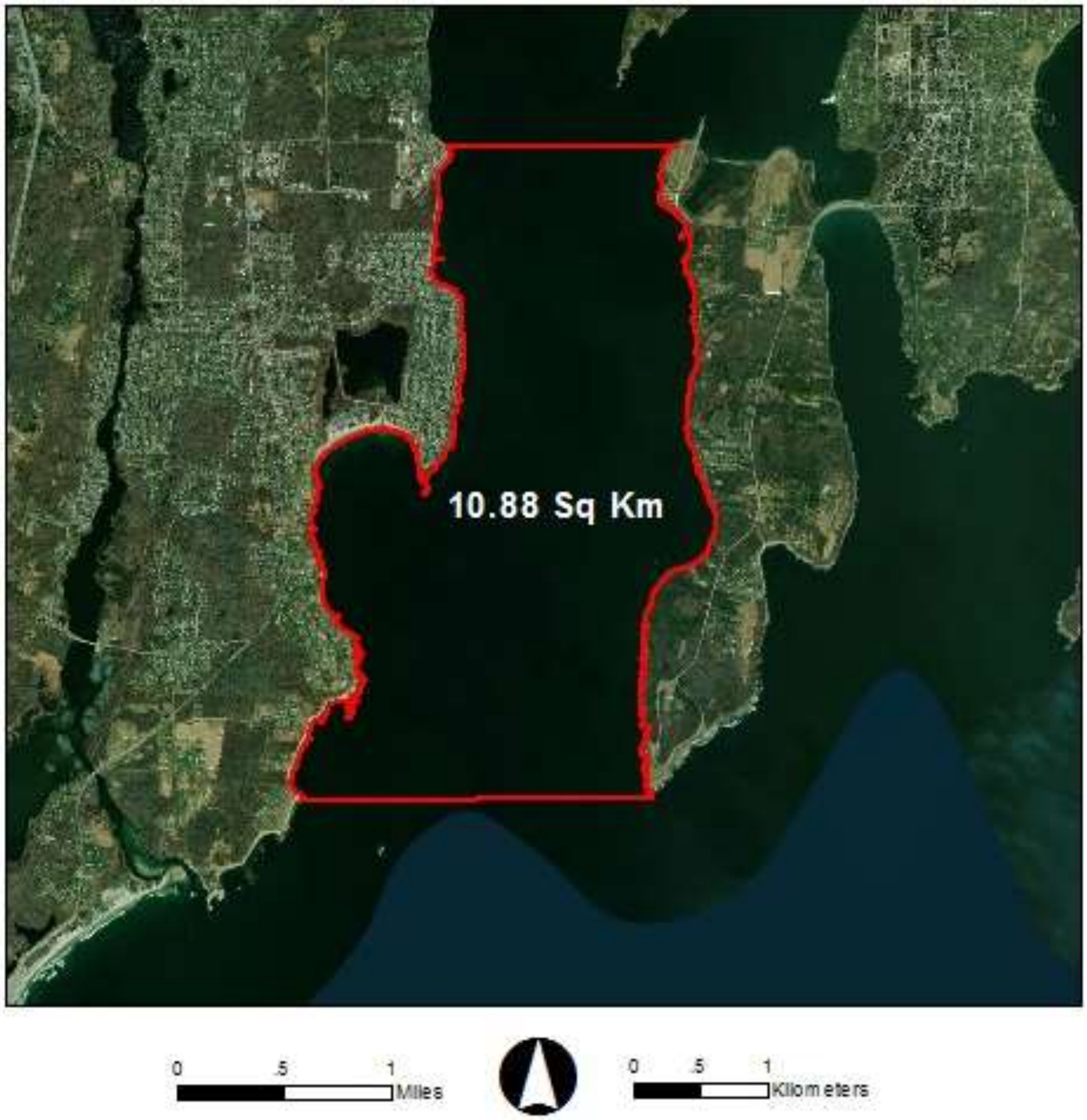


Figure 96. Subtidal area colonized by *Mytilus edulis* in 2008-2009 in lower West Passage, Narragansett Bay.

4.5.2 Estimates of the Current and Future Importance of the *Balanus* spp. and *Mytilus edulis* Biotope within the Study Area

In this section, estimates of the coverage of the *Balanus* spp. and *Mytilus edulis* biotope are made to determine the biotope's current importance and predict its potential future importance within the BIWF study area. This biotope type did not exist within the study area prior to the construction of the BIWF. The study area for purposes of discussion was estimated to be a box 4 km long and 2 km wide that encompassed the five turbine structures. The entire surface area of the structures was considered to be part of this biotope, as was the area beneath the jacket foundation. It was observed that the epifauna on the structures was often at least two layers thick and that the area beneath the foundation had increased to several layers thick. For these reasons, estimates were determined for the minimum and maximum surface area currently occupied by the *Balanus* spp. and *M. edulis* biotope within the study area. The estimates for the turbine structures only are summarized in **Table 60** for the jacket structure and base and for a comparable large monopile. The minimum estimate (single layer on jacket structure and base) is that this biotope occupies 0.08% of the study area, whereas the maximum estimate is 0.2% (double mussel layer on structure and triple on base). Therefore, the amount of "new" habitat created by the epifouling on the turbines and the colonization of the areas beneath the foundations is comparatively small. The estimations of mussel coverage on a large monopile were smaller with a maximum estimate of 0.07%. Note that the scour protection around a large monopile was not considered in these estimates, only the monopile structure was considered, and therefore may be an underestimate. However, estimating the aerial coverage of the biotope in this way is a gross underestimate of the potential, given the ability of larval dispersal to cover tens of kilometers (Gilg and Hilbish 2003).

The evidence of mussels (particularly juveniles) around Turbine 1 has resulted in the reclassification of the Turbine 1 30-90 m area as a *Balanus* spp. and *M. edulis* biotope. Within the 30-90 m area around Turbine 1, areas of adult mussel aggregations with distinct sediment, organics and macrofaunal composition now exist. Mussels were also recorded at Turbine 3 and 5 with evidence of increased abundance from Year 2 to Year 3. It is also likely that mussel colonization is occurring at Turbines 2 and 4 (not sampled). If we assume continued colonization over time, at all turbines, then this biotope has the potential to become progressively more important within the study area as shown in **Table 61**. Given the rapid colonization of over 10 km^2 of seafloor in the case study within Narragansett Bay (**Section 4.5.1**), and the apparent ongoing regional depression of sea stars (McLeish 2016; pers. comm. with P. Barrett, RIDEM), and therefore predation, the *Balanus* spp. and *M. edulis* biotope has the potential to expand widely within the BIWF study area and change the current ecological function. Since this biotope type is perceived as high-quality habitat, then its continued expansion could be perceived as a positive environmental impact of the BIWF. Continued monitoring of the study area with a broader spatial focus would be justified to determine the future fate of this biotope.

Table 60. Estimate of *Balanus* spp. and *Mytilus edulis* habitat expansion in the BIWF study area, considering turbines only. For comparison, estimates of the BIWF jacket structure are provided with estimates of coverage for a generic large monopile, without scour protection.

	Jacket	Large monopile
Surface area of turbine and calculated mussel coverage		
Circumference of Leg(s)	4.335 m	-
Diameter of Leg(s)	138 cm*	6 m
Length of Legs	28 m	30 m
Surface Area of 1 Leg	121.4 m^2	565.5 m^2
Mussel coverage associated with one jacket* or large monopile structure		
Minimum Mussel Area (assuming single layer of mussels)	728.4 m^2	565.5 m^2
Maximum Mussel Area (assuming double layer of mussels)	1,456.8 m^2	1,131 m^2
Additional mussel coverage associated with jacket base (24.5 m x 24.5 m)		
Minimal Mussel Area (assuming full single layer of mussels)	600 m^2	-
Maximum Mussel Area (assuming full triple layer of mussels)	1,800 m^2	-

Table 60. Estimate of *Balanus* spp. and *Mytilus edulis* habitat expansion in the BIWF study area, considering turbines only. For comparison, estimates of the BIWF jacket structure are provided with estimates of coverage for a generic large monopile, without scour protection.

	Jacket	Large monopile
Estimated total mussel area associated with 5 turbines		
Minimum Mussel Area	6,642 m^2 (6.64 x 10^{-3} $km^{2)}$	2827.5 m^2 (2.83 x 10^{-3} km^2)
Maximum Mussel Area	16,284 m^2 (1.63 x 10^{-2} km^2)	5,655 m^2 (5.65 x 10^{-3} km^2)
Mussel Coverage as a percentage of the BIWF project area (4 km x 2 km= 8 km^2)		
Minimum Percentage	0.08 %	0.04%
Maximum Percentage	0.2 %	0.07 %
* Assumed to be 127 cm diameter plus 11 cm epifauna ** Six legs were approximated to equal four legs plus the lattice structure		

Table 61. Estimate of *Balanus/Mytilus* habitat expansion in the BIWF study area including expanding radius of seabed colonization (jacket structure only).

Radius of cover beyond foundation (m)	Cover (km^2)	Percent cover of study area
100	0.198 + 0.016 = 0.214	2.68
200	0.708 + 0.016 = 0.724	9.05
300	1.532 + 0.016 = 1.548	19.35
400	2.670 + 0.016 = 2.686	33.58
500	4.122 + 0.016 = 4.138	51.17

4.5.3 Temporal Comparison of Local Benthic Communities

While limited to the 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 both studies, polychaetes and amphipods account for the majority 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. However, it is possible that based on the emerging importance of the *Balanus* spp. and *Mytilus edulis* biotope and the case study outlined in **Section 4.5.1** that this biotope that is new to the study area could significantly change the stable sandy bottom communities that characterized the study area prior to the construction of BIWF.

4.6 Discussion of Results with Respect to Hypothesis

Test hypotheses have been developed and used here to guide and focus study designs and data analyses and to determine relevant outcomes in the event that the hypotheses are rejected. It is recommended that the future monitoring of offshore wind farms is designed around such purpose-driven research and that these are to be developed in response to prior impact assessment and/or in relation to a valued benthic receptor or management objective.

The following three hypotheses were tested over the three-year study period, with respect to sediment composition, organic enrichment and macrofaunal communities:

- $H_0$1 – There are no differences between turbine areas.
- $H_0$2 – There are no differences between control areas and turbine areas.
- $H_0$3 – There are no effects of distance from the wind farm foundations.

Hypothesis 1 and 2 were evaluated jointly, results are discussed in **Section 4.6.1**. A discussion of the testing of the third hypothesis is presented in **Section 4.6.2**.

4.6.1 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.

Previous reports of Year 1 and Year 2 benthic monitoring have argued for acceptance of these hypotheses based on the presence of characterizing species within all groups and which has been clearly demonstrated in nMDS and SIMPER procedures. However, this has often been contrary to the outcomes of significance testing which highlight significant differences between turbines. Conflicts arose due to differences in the abundances of the characteristic species rather than difference in species identities.

The influence of differing grab sample sizes and sampling efficiencies as an underlying cause of differences in species abundances was addressed in the Year 2 report. This found that 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 was thus considered to be well represented within the current data dataset. Several species were found to be patchily distributed and occurred in high densities within one or a few of the cluster samples only. This included encrusting epifaunal species such as calcareous tube dwelling polychaetes Spirobidae and the barnacle *Amphibalanus amphitrite*, which occurred on localized hard substrate on which they attach and grow.

It was also considered in Year 2 that the species that exhibit wide variations in abundances also tended to be less dominant, which reduced their overall influence on macrofaunal community structure from an ecological standpoint. Consequently, while differences were detected, they did not tend to be representative of the characterizing species. A review of ANOSIM and Permanova+ used during Year 2 showed that they were more sensitive to variations in abundances among samples, whereas nMDS and

SIMPER were able to consider the samples in a broader context. So, depending on perspective at that time, one may have accepted or rejected $H_0$1 and $H_0$2, and conclusions were equivocal.

In Year 3, Turbine 1 was different from Turbines 3 and 5. This was observed in the epifaunal assessment as well as the macrofauna comparisons between turbine footrpints, the very near-field areas and the vessel-based sampling 30 to 90 m from the center of the Turbine. Within the 30 to 90 m study area, this can be seen in the nMDS outputs as well as the results from significance testing for the vessel-based grab samples for seabed areas beyond 30 m from the foundation center points. Key differences are highlighted previously in this section, but the main factor driving dissimilarity is the high abundance of mussels and barnacles at Turbine 1 relative to the other turbines. Abundance of characteristic species also differ and contribute to the dissimilarity. In addition to this, video and diver observations show profound changes to the seabed directly below Turbine 1 which differ from those observed at Turbines 3 and 5, although conditions may be converging. On these bases, $H_0$1 (no differences in benthic communities among turbines) is rejected.

Benthic communities >30 m from Turbine 1 were different from control data in Year 3, suggesting local effects over and above natural conditions. Differences relate to increased mussels and barnacles at Turbine 1 relative to the controls. Furthermore, conditions below Turbine 1, and to a certain extent below Turbines 3 and 5, are different from controls. Mussel aggregations within the turbine footprints and patches of mussels within the 30 to 90 m area from the turbine center are clearly developing which are not reported within control site from current grab and video data. In these regards, $H_0$2 (no difference in benthic communities between control and turbine areas) is rejected.

4.6.2 Comparison of Distance from Turbine with Respect to Organic Matter Enrichment and Benthic Communities

With respect to the vessel-based grab data (>30 m from the foundation center points) benthic communities between the different distance bands (>30 to 49 m, 50 to 69 m, 70 to 90 m) are not significantly different. Beyond 30 m, distance from the turbine has no effect on benthic communities based on current data. ANOVA tests between the stations for each turbine distance band did not detect any significant differences in TOC levels and benthic communities with distance from foundations. In general, levels of sediment organics content were not indicative of adverse macrobenthic effects. 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 (approximately 3½ to 4 years) and so may not have contributed to the organic composition of adjacent sediments beyond the footprint of the turbine foundations when considering the 30 to 90 m area as a whole.

In contrast, levels of organic carbon in the sediments below, and within the footprint of, Turbines 1 and 3 during the Year 2 and the current Year 3 sampling survey were higher than those recorded elsewhere across the study area and suggested that macrofauna here may be at moderate to high risk of potential adverse effects. Similarly, the benthic community comprises mussel and patches of mussel below the turbines and clearly differs from that found at >30 m distances. In this regard, it is considered that $H_0$3 (no impact on distance regarding organic enrichment and benthic communities) is rejected.

4.7 Potential Ecosystem Impacts

Environmental monitoring programs of offshore wind farms to date have only focused on discrete ecosystem compartments, such as benthos, fish, birds and marine mammals, with little, if any, regard to the inter-relationships between them. This means that information about potential ecosystem scale effects due to offshore wind farm construction and operation, and methods for quantifying effects on higher trophic levels due to changes to the local macrobenthos, are lacking in empirical studies. Benthic systems provide food, refuge and critical spawning and nursery habitat for a wide range of teleost fish, elasmobranchs, cephalopods and crustaceans as well as other services such as nutrient recycling and regulation of water quality and are critical in the exchange of mass, energy and nutrients between pelagic and benthic habitats. Clearly, loss or change to benthos over important spatial scales could have significant top-down and bottom-up consequences for other ecosystem compartments such as plankton, fish and crustacean predators but this has received scant attention thus far.

Offshore wind farms have the potential to change marine ecosystem functioning by re-structuring the biological communities at and around their foundations (Slavik et al. 2017). In particular, they can increase the biomass and distribution of filter feeding organisms (Slavik et al. 2017; Krone et al. 2013) by providing suitable additional hard surface substrata for colonization and growth. From license condition monitoring studies in Europe, it has been shown that the blue mussel (*M. edulis*) is the dominant colonizer of submerged sections of offshore wind farm structures near the surface and which can grow in large numbers and densities. For example, diver studies at offshore wind farm monopile structures in the outer Thames Estuary estimated the biomass of the ‘mussel zone’ to be 4,827 kilograms (EMU Limited 2008) while an average of 4,300 kg of mussels were found to be covering the FINO jacket platform in the German sector of the North Sea (Krone et al. 2013).

Such mussel growths can have important ecosystem consequences including changes to phytoplankton concentrations through removal by filtration, reduced primary productivity, water quality effects through the excretion of ammonia products and increased benthic deposition of organic material as well as providing additional structural complexity for attachment for various epibionts. Mussels on the seafloor may modify sediment habitats by increasing the underlying sediment carbon and nitrogen concentrations and boosting species richness and biomass through bio-deposition and nutrient regeneration (Norling and Kautsky 2007). Expansion of mussels has been shown to be occurring at BIWF while the foundations themselves may be seeding adjacent seabed areas over medium and far ranges, although further study would be required to confirm this.

Numerical modelling studies of the marine ecosystem at Courseulles-sur mer (northern France) (Raoux et al. 2017) predicted an increase in detritivory following the construction of a local wind farm comprising 75 turbines. This was related to the higher consumption of detritus by benthic organisms and associated expansion of blue mussels (*Mytilus edulis*) causing a shift from a primary producers- and grazers-dominated food chain to a more detritus feeding community. Increases in benthic production were expected through deposition of feces and dead organisms from sessile organisms colonizing the structures. Overall, the model predicted that the turbines and scour protection material will lead to an increase in the system biomass and supported hypotheses that benthic invertebrates colonizing the turbines serve as food for fish predators, which in turn would benefit fish predators, in particular, marine mammals.

This study has shown profound benthic changes have occurred within the footprints of the turbines foundations including a transition from previous clean medium or coarse sand associations to a predominantly organically enriched mixed muddy sand and mussel aggregations with associated communities. This was most promintent at Turbine 1 but also evident at Turbine 3 and 5. Further, there is evidence of expansion of changes into the surrounding area around Turbine 1. As well as shifts in macrofaunal species composition, the changes noted may have important consequences for a range of species. In particular, accumulation of sediment fines within local sediments may be detrimental to a number of species that depend on clean, well aerated coarse-grained sediments as habitat such as sand lances or for spawning, such as herring. These aspects, habitat important to fish species, are considerations for future leases, globally.

Sand lances have been recorded during the BIWF video and photography surveys and so are likely to be present within the locale. These species are highly specific to habitat type, requiring clean coarse sand in which they live and spawn, and so any alteration in benthic conditions would decrease habitat quality and availability over their range. Expansion of the effects recorded at BIWF, such as sediment fining could therefore lead to a further reduction in suitable habitat for these species resulting in potential adverse effects for local populations over the life of the wind farm. Sand lances are important food for a wide variety of predators including teleosts, elasmobranchs, birds and marine mammals and thus detrimental effects on these species may have important wider implications.

Conversely mussel aggregations support substantially greater biomass of mobile macrofauna and fish that would not have otherwise been present on soft sediment substrates and enhance biodiversity by increasing habitat heterogeneity (McLeod et al. 2014). The provision of structure and capture and retention of organic material means that reefs can support a diversity of marine life (MCCIP 2018).

Video records from the current monitoring program show a variety of fish species around the foundations. These species are likely attracted by increased feeding opportunities offered by the growth of fouling communities and/or the availability of refuge (reef effect). While seemingly beneficial for these fish populations, it should be noted that is not yet clear whether the turbines are supporting an increased fish biomass over the local or wider area or whether the turbines have simply caused a local displacement in the natural distribution of fish populations. Also, the diel use of the turbine structures by fish is not known. Some species may disperse widely over adjacent seabed areas to feed during hours of darkness, for example, while aggregating near the foundation structures for refuge during daylight. An analysis of fish stomach contents would clarify the diets of local fish and may help determine the relative importance of the turbines in terms of local fish feeding and contribution to the overall food web.

The potential ecosystem benefits of artificial structures in the water column are well recognized, for example the rigs-to-reef initiative in the Gulf of Mexico; however, longer-term (i.e., operational life, decommissioning) ecological consequences at offshore wind farm sites remain unknown. Specifically, 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 lease are unclear, and wider benthic linked ecosystem functions remain unknown. Given the findings of the current study, it would appear that the overall trajectory of future benthic change at BIWF relates to the continued input of organic material from fouling communities supporting seabed mussel reef development and possible expansion of enriched sediments and modified benthic fauna. Future changes in the abundance and distribution of mussels and fouling organisms on turbines as the communities mature, are predated or respond to stochastic events, such as storms, may alter the supply of organic material, thus further exacerbating uncertainties regarding future ecosystem effects.

4.8 Considerations for Management

The benthic monitoring undertaken here shows that over four years, the direct impact of the operation (i.e., presence) of the BIWF on benthos has generally remained localized. The most profound changes were observed on the structure and within the 24 m × 24 m (576 m^2) footprint of the jacket structure but evidence of changes within the 90 m radius have now been observed, which represents the spatial extent of the monitoring effort.

If the same scale of change has occured within the footprints of all five turbines, then the area of seabed affected at BIWF would be 2,880 m^2. This equates to approximately 25% of the total seafloor area that was found to be impacted by the initial (Phase I) wind farm construction (11,570 m^2) and approximately 42% of the area impacted by Phase II of BIWF construction (6,414 m^2) (HDR 2020). On this basis, benthic impacts 4 years post construction at BIWF appear negligible within a regional context but have nevertheless been profound at the local scale and may have cascading ecosystem effects not measured here (Dannheim et al. 2019). However, unlike highly localized and temporary impacts of construction, seabed changes due to turbine presence will be permanent for the life of the wind farm and may expand over time. It will be up to stakeholders and permitting authorities to consider where the thresholds of acceptable change lie and the spatial scales over which such thresholds should apply.

Furthermore, current data show that the impacts at Turbines 3 and 5 to be less severe than that at Turbine 1, although clearly modifications are ongoing at all three turbines studied. Considering that OWFs may have lease terms of 25 to 30 years (or longer where the facility is re-powered), then the available time-series data could be insufficient to have fully captured the magnitude and full spatial extent of benthic impacts which have developed over time. Continued monitoring is required to fully understand the extent and intensity of impact of wind farm operation over the lifetime of the facility. When considering future permit applications, authorities will need to consider this knowledge gap within their decision making.

This study has also highlighted a possible indirect benthic effect of the operational wind farm. This relates to the use of the wind farm by mussels which have been shown to have substantially increased in abundance throughout the study area over the three-year monitoring period. With the OWF as a new base, new larval dispersal patterns may arise. The spatial extent of this indirect effect remains unclear but presumably could extend beyond the immediate wind farm boundaries depending on *Mytilus* sp. larval dispersal. Once established within a new area, mussels can influence seabed composition including increase sediment fines and organic levels as found at BIWF. Whether mussels continue to expand within and around the BIWF turbines is not known and the wider ecosystem implications of this are unclear. Sampling large mussels around Turbine 1 revealed a different macrofauna and associated elevated levels of sediment fines and organics. Future management may need to consider wind farms as potential facilitators in the spread of such species including potential nuisance organisms and consider broad scale effects as well as potential connectivity with other offshore wind facilities to account for wider or regional level effects.

An important finding of this study is that the magnitude and pace of benthic change differs markedly even across relatively small spatial scales (i.e., across five turbines). At BIWF, impacts have been turbine specific with profound change (albeit localized) observed most strongly at Turbine 1 relative to Turbines 3 and 5. Clearly localized factors are important (e.g., hydrodynamics), and impacts at one turbine may not be detectable or as intense at another turbine or may take place over different timescales, as evidenced at BIWF. This raises potential future management and monitoring issues. Future monitoring efforts would need to ensure that that the entire wind farm is sufficiently represented in terms of the physical processes as well as habitat variety. Areas subject to natural seabed disturbances, appear to recover more quickly from initial construction impacts and to be more resilient to operational influences compared to stable, less dynamic seabed areas. Therefore, it will be important to ensure that monitoring and assessment covers the different habitat types and physical processes present to account for all potential benthic responses. Use of the results of geophysical surveys including side scan sonar and multibeam bathymetry would be helpful in this regard.

The use of cable mattresses also should receive careful attention during permitting decisions. This study has shown that limited, if any, growth of epifaunal communities has occurred on the BIWF concrete cable mattresses. This is surprising given the dense growth of mussels and other epifauna on the turbine foundations. The reasons for this remain unclear but may relate to the physical or chemical nature of the material used which is inconsistent with successful colonization by benthic species or, more likely, the effects of sediment scouring.

The placement of concrete mattresses on the seafloor causes the original benthic habitat to be lost and replaced with an artificial hard substratum. Successful colonization of the artificial substrate may offset initial biodiversity losses otherwise the mattresses may effectively sterilize the seabed within their footprint. The overall area of seabed affected in this way needs to be considered in combination with the area of habitat alteration below each turbine foundation as part of the overall impact assessment. Based on current findings, substantial use of concrete mattresses in future offshore wind farms may have significant detrimental effects in terms of the total extent of benthic habitat alteration and loss of sediment fauna at local scales. Seabed conditions are likely to be restored to natural conditions on decommissioning of offshore wind farms and removal of the turbines and cable mattresses.

5 Recommendations for Future Monitoring

5.1 Review of Monitoring Methods at BIWF

The initial sampling plan aimed to detect benthic changes attributable to the operation (i.e., presence) of the BIWF as well as any relationships with proximity to the turbine foundations themselves. A traditional grab sampling program using a quantitative grab deployed from a survey vessel at increasing distances was selected to achieve this. At the outset of the sample design, it was considered that 30 m from the center point of the foundations at BIWF would be the closest distance that could be safely sampled by the vessel. This was mainly a logistical and safety consideration of the vessels ability to maintain position due to wind and waves, during each grab deployment as well as the slope of the legs and wide base of the jacket foundation structures at BIWF. In this regard, all seabed samples were collected by the vessel safely.

The vessel-based program included cluster replicate sampling (3 replicates) at three randomly selected stations within the 30 to 59 m, 50 to 69 m, and 70 to 90 m distance bands (i.e., nine samples per distance band). This allowed for the determination of the fine-scale heterogeneity of the seabed to be assessed and also to allow for the overall sampling effort to be appropriately stratified for statistical comparison and detection of any relationships with distance from the turbines. This strategy was successfully executed in the field with the majority of intended target locations being sampled. However, there were occasions when—due to vessel drift during grab deployment—some replicates were collected over greater distances than others, and some replicates were collected from unintended locations including from different distance bands. Where this occurred, this meant that some distance bands were represented by differing numbers of samples resulting in un-balanced designs for significance testing. This was overcome by applying a Welch's ANOVA to allow comparison between distance bands (www.biostathandbook.com) as well as regressions to confirm interpretations. Because repeat vessel sampling at the exact same sample location was not achieved at BIWF, it was considered that the samples collected for each station were not true replicates. They were instead considered clustered samples which were collected in relatively close proximity to each other but not at the exact same location. Nevertheless, the clustered samples that were collected were considered successful in demonstrating the local distributions of sand and gravel habitats that characterize the seabed within and around the BIWF turbines. In addition, the camera fixed to the grab sampler in each case provided a valuable wider perspective allowing the benthic data to be placed in a wider seabed context. This was particularly important at stations around Turbine 1 (e.g., T1_5_R3) in Year 3 (**Figure 46**, **Section 3.1.6.4**) where the grab video camera revealed the seabed here to have comprised a much broader scale aggregation of adult mussels than the grab data alone might have otherwise implied. This was an important finding as such dense aggregations of adult sized mussels had not been previously recorded within or around the BIWF study area.

The random placement of sampling stations within each distance band around the turbines each year has been an important strategy in eliminating bias in the design as much as possible. We consider that this approach has been successful in detecting benthic changes, in particular the presence of patches of adult sized mussels at distance from Turbine 1, which might not have otherwise been detected using a fixed sampling location along a fixed transect approach. Following this, it is recommended that future benthic programs consider the use of a random stratified approach for the detection and assessment of benthic effects at offshore wind facilities. It will be necessary for agencies and stakeholders to agree what effects sizes may be relevant to ensure that future benthic surveys are designed with the appropriate precision to achieve desired outcomes. The results of this study are relevant to the consideration of the sizes of effects that can occur at an offshore wind facility on the U.S. continental shelf to inform decision making in this regard.

Control samples have been representative of those collected at the turbines and have allowed for the natural variation to be accounted for during effect assessment and interpretation. The value of control data has been particularly emphasized in Year 3 which showed that naturally only very low numbers mussels were found and which contrasted the very high numbers found around Turbine 1, suggesting a potential turbine effect. In Year 1, Control site 1 was considered unrepresentative, comprising very coarse sediments, cobbles and boulders, and was thus moved in Year 2. Because of this move, it was considered that the other control sites should also be similarly re-positioned to ensure all control stations were treated the same. Moving of control stations year to year was supported by detailed, pre-existing biotope maps which ensured that the new sample positions would remain representative of the turbines.

The seabed video that was undertaken in parallel with the grab sampling and seabed photography was useful and helped qualify some of the changes being observed. Knowledge from these efforts allowed adjustments to the sampling program to better capture changes in the following years. This included the introduction of the diver sampling in Years 2 and 3 and which detected and quantified the benthic changes that had occurred at closer ranges (<30 m distances) and within the footprint of the turbine foundations. Diver sampling in Year 2 resulted in variable data which was due to the use of differing approaches between divers working at different locations. Nonetheless, the data collected by the divers in Year 2 provided valuable information on the gross benthic changes that had occurred at this time and showed that change, albeit localized, can occur within the footprint of a jacket structure foundation relatively quickly (within 2 ½ to 3 years post installation). Sampling variability had been rectified Year 3 by the use of a standard diver quadrat so that all diver sampling sizes were comparable. Work was incorporated to compare the vessel and diver-collected methods and suggests that they were comparable for most indices but not organic content. If between turbine comparisons are sufficient, then this method is suitable as it currently stands, but if between turbine and control comparisons are desired, then diver-collected control samples should be obtained.

The adoption of a flexible approach to the sampling program, and the use of multiple methods, provided valuable insight as to the effects on benthic ecology. Reviewing the data obtained each year and redefining the monitoring methods and research targets based on knowledge gained was valuable. Through this flexible and strategic approach, benthic changes at BIWF were recorded in greater detail than would have been obtained using vessel-based methods alone. It is acknowledged that diver surveys at deeper sites further offshore may not be practicable and other survey techniques, such as remotely operated vehicle (ROV), may be considered for assessment of close range benthic effects.

5.2 Proposed Refinements for Year 4 Sampling Surveys at BIWF

The Year 4 sampling surveys should consider the following refinements:

- A standardized system of classifying and reporting aggregations of mussels from diver, float and grab based video cameras is needed to be developed at BIWF. This is particularly important as mussels appear to be expanding on the seafloor below all three turbines and around the foundations based on the Year 3 data, although further study is required. They may become a regular and dynamic feature of the local benthos, and a standard classification system would facilitate recording and comparison of mussel aggregations over time and between turbine/control study areas using the different video techniques. In particular, it would be useful to record standard data where thick mussel reefs prevent quantitative sampling. A system of classification of mussel aggregations could comprise different elements of the mussel aggregatiom including thickness/elevation from seabed, spatial patchiness, mussel length, relative abundance and/or biomass, associated epibionts and percentage of dead shells and warrants development prior to the Year 4 sampling campaign. Metrics used in frameworks for assessing ‘reefiness’ of other biogenic reef-forming species may also be considered, e.g., Hendrick and Foster-Smith 2006 and Gubbay 2007.

- The diver-based grab samples and underwater video should be collected within the footprint of all five turbine foundations. These additional data would allow for better understanding of the gradient along which the extent and rate of changes are occurring across the BIWF. Achieving this task while staying within the same budget and scope of work may require the reallocation of some sample stations. If such is the case, it is recommended the 70 to 90 m distance band be reduced or removed for this type of sampling, at least until changes at closer distance bands (i.e., 30 to 69 m) become apparent.
- The use of seabed video and/or still images to inform subsequent diver studies should be considered. From the image data, it may be possible to identify areas or gradients of modified seabed for targeted (stratified random) sampling and benthic assessment. This approach would require prior seabed video surveys and image analysis to be conducted, the results of which would guide subsequent diver sample location plans.

5.3 Future Long-term Monitoring at BIWF

It is important that monitoring be continued over time to track changes in benthic community structure. Monitoring over 3 to 5 years, and up to 10 years, would permit assessment of effects over medium and longer terms, respectively. However, depending on the information needed, monitoring should not be capped at 10 years. Decommissioning will require consideration of current data, and longer-term monitoring may be useful in that regard.

Extended monitoring is important for this BIWF study area because not enough time has elapsed to fully understand the potential effects of an offshore wind farm in the New England region. Changes within the footprint of the turbine structures have been recorded, with Turbine 1 exhibiting the fastest rate of change. Comparable changes are being observed within the footprint of Turbines 3 and 5 where seabed conditions may be naturally more disturbed (e.g., by hydrodynamics). As yet, it is not clear how these will progress where the physical seabed condition is more disturbed. Also, after three years of monitoring, patches of dense mussels and modified macrofauna have developed in the area surrounding Turbine 1 with no apparent corresponding development at control sites. As such, this study is still in the process of detecting and quantifying effects caused by the BIWF in the defined study area.

The Year 3 vessel grab data support increased mussel settlement around the turbines at >30 to 90 m distances compared to natural background conditions and which were not anticipated. Continued grab sampling around the turbines into Year 4 would help to determine whether these mussels are ephemeral or whether they are increasing and expanding across the local seafloor. Mussel aggregations are important bio-engineers, able to modify local sediments and macrofauna. Continued grab sampling would be valuable to determine the dynamics of mussel expansion at BIWF and associated benthic modification beyond the footprint of the foundations and to inform assessment of this potential indirect/extended reef effect.

Repeat monitoring studies should continue to employ the same sampling methods to ensure data consistency for comparison. Ideally, subsequent surveys should continue to be undertaken at the same time of year to minimize potential seasonal variations. Although 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 establishment of mussel populations will need to consider the seasonality of their ecology. 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).

Although outside the scope of this monitoring study, acoustic data collection and assessment conducted during future benthic monitoring surveys or intervening periods also would be valuable in assessing changes over time by indicating areas of differing reflectivity or alterations in sediment acoustic boundaries.

5.4 Other Parallel Studies at BIWF

Epifaunal surveys should continue to be conducted to collect quantitative information on fouling communities on the foundations at BIWF. The data may be used to describe the presence and increase of any non-native species, such as the invasive tunicate *Didendum vexillum* already noted to be present at BIWF, as well as any important species contributing to the overall fouling biomass and the ecosystem services provided (i.e., increased feeding and refugia). The data also could provide useful context for the current benthic monitoring studies. At future offshore wind projects in deeper waters, instead of using divers, the use of ROVs and cameras should be considered in order to alleviate safety concerns and align with common practices at other offshore wind farms. ROVs and cameras also may be less weather sensitive, allowing more data to be collected in marginal sea and wind conditions

Repeat studies at BIWF 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. Continued study would also provide valuable information on longer-term successional changes of epifauna. Very few studies of this nature exist, particularly for jacket foundations. Recent reports suggest a reduced epifaunal community on gravity-based foundations and monopiles after nine-ten years (Kerckhof et al. 2019). Results from continued epifaunal monitoring of the BIWF foundations may refine current perceptions about foundations acting as biodiversity and/or biomass hotspots and will inform assessment and management of offshore wind facilities in the future.

Mathematical larval dispersion modelling would provide insight into the potential area of seabed which is influenced by release of mussel larvae from BIWF. Substantial increases in the incidence and abundance of mussels on the seafloor around the turbines have been recorded over the three years of monitoring, and occurrences at control sites have increased in Year 3 although abundances remain low. The results of dispersion modelling would determine whether current control sites are within larval ranges to aid separation of natural and BIWF effects and would further inform the potential connectivity of the BIWF with the future offshore wind facilities in this region.

The Year 2 report highlighted that 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 shows cable protection material to be devoid of epifauna. Continued monitoring would provide 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 or Year 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.

In the same way, comparison between natural rock habitats and the foundations would help determine perceived biodiversity benefits of offshore wind facilities in this region. A review of epifaunal communities on other submerged artificial structures within the Block Island area would indicate the expected climax community at BIWF with any deviation potentially attributable to some feature of the foundations.

Diver videos at the BIWF have captured numerous fish aggregating within and around the foundation structures, and they likely are attracted by increased feeding and/or refuge opportunities (reef effect). It also is likely that different species of fish utilize different food source on the foundations. Fish sampling and stomach contents analysis would contextualize the importance of the different food items at BIWF for each fish species within the wider region, help establish food-web linkages, and inform likely fish interactions at future offshore facilities.

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.

Detailed quantitative analysis of the seabed video (float camera) data collected under this program, and development, or adoption, of standard analysis methodologies should be considered. Within the current monitoring at BIWF, the remote (float) camera techniques are beginning to prove a valuable field technique for the acquisition of benthic ecological information over areas which are most likely to be influenced by the operation of the wind farm, close to the turbine foundations, and where other data collection methods are not possible or are restricted by health and safety and cost concerns.

So far, the camera work has yielded important qualitative information on sediment alterations and assemblages of mobile epibenthos. Further benthic alterations are forecast in the future, the spatial extents of which remain unknown. Continued use of camera techniques is envisaged throughout the remainder of the RODEO Program to document these alterations. Adoption or development of methods which can derive quantitative information from video and stills images will be important to assist future assessment of benthic changes at BIWF. Evaluation of image collections and analysis methods for possible future use in compliance monitoring should also be considered.

5.5 Monitoring at Future Wind Farm Sites

One of the primary objectives of the RODEO Program monitoring at BIWF is to gather data that can be used as inputs to analyses or models that evaluate the effects or impacts from future offshore wind turbine construction and operations, as well as facilitate operational planning that would reduce potential impacts to the greatest extent possible. Also, understanding and insights gained from the BIWF monitoring program data analyses would 1) support evaluation and mitigating environmental risks in the future, and 2) support prioritization of future monitoring efforts and risk retirement. Data and lessons learned from the BIWF monitoring would serve as important benchmarks for benthic habitat and epifaunal monitoring that may be conducted at future OWF facilities.

For future facilities, benthic habitat monitoring should be conducted against a baseline of information collected preferably prior to the start of wind farm construction. In this way, any benthic change can be assessed against the natural, pre-existing conditions prior to potential construction or operational impacts. The BIWF study commenced between 1 and 1½ years after installation of the foundations to which the local benthos may already have been responding. This means that the condition measured and described in Year 1 may not have been the natural state but may have already been altered to some degree. This may have limited data interpretation in Year 2 and 3. The monitoring survey would be commenced as soon as possible after the baseline surveys, allowing for construction activities to be completed, to minimize temporal variability.

Benthic responses have been shown in this study, to be turbine specific. In heterogeneous habitats, such as those at Block Island, and where localized seabed processes occur, monitoring plans should ensure that all local benthic conditions and seabed types are covered. Results from the initial Environmental Assessment and geophysical survey data should be used to identify the different geographical levels or strata within which samples would be collected to ensure all benthic conditions are adequately represented.

Increases in mussels on the seafloor at distance from BIWF, as a consequence of turbine presence, were not forecasted at the commencement of this study 3 years ago, and the apparent changes noted here were not anticipated. Instead, the original study design predicted organic enrichment of local sediments due to the deposition and accumulation of epifauna directly below the foundations as the main causal factor of benthic change here, with gradual expansion of enrichment effects over the seafloor over time as inputs from epifauna continued. In this regard, the particular vessel-based grab study design employed at BIWF, including the use of randomized sampling positions within the distance bands each year, rather than repeat visits to fixed positions along fixed transects, as in other studies, has been valuable.

The monitoring team's professional judgment is that use of random sampling at BIWF removed any potential bias that might otherwise be inadvertently introduced into the sampling and has improved the probability of unanticipated events being detected and described, while still addressing the test hypotheses. In contrast, the use of fixed points along fixed transects, as in some other studies, risks bias and may reduce the probability that events, which are independent of bias factor, will be detected. Given this, and depending on management objectives, we recommend future monitoring designs consider enhanced sample randomization within pre-defined strata, rather than fixed point sampling, so that unanticipated effects, outside of original monitoring purposes, can be considered.

For future monitoring efforts, epifaunal monitoring should commence as soon as is practicable after foundation installation to capture the characteristics of the initial colonizing communities and any apparent interaction within higher trophic levels such as fish and marine mammals. Diver studies generally are not used in offshore wind farms for epifaunal monitoring because of health and safety considerations. Instead, biological data are collected by camera and ROV. The use of remote video and cameras and retrievable settlement plates deployed nearby should be considered for future epifaunal monitoring and associated studies on potential ecosystem interactions.

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Appendix A. **Field Sampling Plan**

Appendix B. **Field Survey Records of Vessel-Based Data Collection**

Appendix C. **Camera Field Notes for Float and Diver-Towed Missions**

Appendix D. **Results of the Sediment Particle Size Distribution Analysis for Vessel-Based and Diver-Based Data Collection**

Appendix E. **Results of the Seabed Video Analysis of Vessel-Based Data Collection**

Appendix F. **Results of the Sediment Organic Analysis for Vessel-Based and Diver-Based Data Collection**

Appendix G. **Macrofaunal Species List for Vessel-Based and Diver-Based Data Collection**

Appendix H. **Macrofaunal Species Statistics for Vessel-Based Data Collection and Diver-Based Data Collection**

Appendix I. **Summary of Species Biomass for Vessel-Based and Diver-Based Benthic Data Collection**

Appendix J. **Field Survey Records of Epifaunal Data Collection**

Appendix K. **Epifaunal Example Sample Images and Specimens Identified from Video Footage**

Appendix L. **Summary of Epifaunal Data used in Estimates of Drag Force**

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

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. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).