OceanEcology

Burbo Bank Extension Offshore Wind Farm

Year 2 Post-Construction Benthic Monitoring Report 2019

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Prepared for

Ørsted

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Executive Summary

This report presents the findings of the second Burbo Bank Extension (BBW02) post-construction benthic survey undertaken by Ocean Ecology Limited (OEL) on behalf of Ørsted. The benthic survey was undertaken between 8th and 9th September 2019 aboard the vessel *Seren Las*. During this survey, a total of 30 macrobenthic and 54 Particle Size Distribution (PSD) samples were collected within the wind farm array, near-field and adjacent reference areas. In addition, 102 seabed images combined with associated video were collected at eight drop-down video sampling stations and along four camera transects within the Export Cable Route (ECR) corridor. A full description of survey operations is provided in the benthic survey report (Appendix 1).

This report aims to provide an assessment of the benthic habitats and associated infaunal assemblages within and adjacent to the areas of potential impact resulting from the construction and operation of the BBW02 offshore wind farm. It also provides a comparison with previous data collected during the 2015 pre-construction and 2017 post-construction surveys to determine the magnitude of impacts predicted in the Environmental Statement (ES).

List of Abbreviations

AFDW	Ash Free Dry Weight
ANOSIM	Analysis of Similarity
B	Biomass
BBW02	Burbo Bank Extension Offshore Wind Farm
BSH	Broad Scale Habitats
DDC	Drop-Down Camera
ECR	Export Cable Route
EIA	Environmental Impact Assessment
EMF	Electromagnetic Fields
ES	Environmental Statement
EUNIS	European Nature Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IDA	Industrial Denatured Alcohol
JNCC	Joint Nature Conservation Committee
MDS	Multidimensional Scaling
MMO	Marine Management Organisation
N	Abundance
NMBAQC	NE Atlantic Marine Biological Quality Control
OEL	Ocean Ecology Limited
P	Present
PSD	Particle Size Distribution
QMS	Quality Management System
S	Total Diversity
SE	Standard Error
SIMPER	Similarity Percentages
SIMPROF	Similarity Profile
SOP	Standard Operating Procedures
WoRMS	World Register of Marine Species

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1. NON-TECHNICAL SUMMARY

Ocean Ecology Limited (OEL) was commissioned by Ørsted to undertake a year 2 post-construction benthic monitoring survey at the Burbo Bank Extension Offshore Wind Farm (BBW02) in the late summer / early autumn of 2019 as a repeat survey of the pre-construction survey undertaken in 2015 and the year 1 post-construction survey in 2017. These surveys included the acquisition of grab samples and seabed imagery across the wind farm array, near-field and adjacent reference areas. The purpose of this year 2 post-construction survey and associated analysis was to collect data relating to the habitats and features around the wind farm installation and Export Cable Route (ECR) to inform a comparison with the baseline and year 1 post-construction data as a means of validating the prediction made in the Environmental Statement (ES) (Ørsted 2013). The sampling stations targeted were consistent with those agreed previously with the Marine Management Organisation (MMO) and as per the previous pre-construction baseline survey. The survey consisted of two complimentary survey methods; benthic grab and drop-down camera sampling. This report presents data collected during the survey undertaken in 2019 and compares the data to that collected during the 2015 pre-construction baseline survey and 2017 year 1 post-construction survey.

Grab and drop-down camera sampling was undertaken during favourable weather conditions between 8 and 9th September 2019 aboard the vessel, *Seren Las* operating out of Liverpool. All targeted grab, drop-down camera stations and transects were visited with 30 macrobenthic samples, 54 Particle Size Distribution (PSD) sub-samples and over 100 high-definition still images and associated video were successfully collected across the survey area. All corresponding macrobenthic, PSD and seabed imagery analysis was undertaken at OEL's NE Atlantic Marine Biological Quality Control (NMBAQC) scheme participating laboratory during September to December 2019. Univariate and multivariate statistical analyses were carried out on all data collected using PRIMER v7 and R v 1.2.1335 with each sampling station assigned to a treatment group to allow for a temporal comparison between pre- and post-construction periods.

Sediments sampled during the post-construction grab survey within and around the BBW02 wind farm area exhibited only minor variation between stations whilst station replicates were largely homogeneous. Sediments consisted primarily of sand and muddy sands with low gravel content, typical of circalittoral fine and muddy sand biotopes. Grab data was corroborated by seabed imagery data which demonstrated minimal variation across the area with circalittoral fine sand and muddy sand dominating with less frequent coarse and mixed sediments. Comparison of sediment data collected during the pre-construction and post-construction surveys showed that the seabed sediments had largely remained similar over time. An overall decrease in mean grain size was observed between each of the surveys, though this was less pronounced between year 1 and year 2 post-construction surveys, with mud becoming more prominent across the survey area (sands shifting to muddy sands). However, this change is thought to be attributable to differences in sample processing methodologies employed between pre-construction and post-construction surveys and in line with natural variation rather than due to the construction and operation of BBW02 between post-construction surveys.

The macrobenthic infaunal assemblage identified across the BBW02 survey area during the year 2 post-construction monitoring survey was relatively diverse with 111 taxa recorded and a mean abundance of 143.0 individuals per sample. As observed during the pre-construction survey, mollusc and annelid taxa dominated the infaunal communities in terms of biomass and diversity respectively. Patterns in abundance, diversity, and biomass were largely similar to the pre-construction survey results, though echinoderms contributed more to abundance in the post-construction surveys. This pattern was consistent across treatment areas, although near-field biomass was dominated by molluscs, as observed in the year 1 post-construction survey. This was mainly due to larger numbers of the bean razor clam (*Pharus legumen*) and two-toothed Montagu shell (*Kurtiella* bidentata) found at Station 13.

When broadly comparing the pre-construction and post-construction infaunal datasets, a marked area wide change in abundance was observed. Decreases in the numbers of infaunal taxa that characterised the pre-construction communities were observed, particularly the polychaete *L. koreni* that was found in densities of up to 14,520 per m^2 during the pre-construction survey compared to 90 per m^2 and 5,310 per m^2 in 2017 and 2019 respectively. A notable change was also recorded between the two post-construction surveys with overall abundance approximately doubling from 2017 to 2019. To investigate this and the aforementioned observations further, the post-construction datasets were examined in more detail both separately and in combination with pre-construction datasets. Further statistical analysis, on a treatment scale basis, revealed no significant changes in infaunal composition across all treatment areas between construction periods, including reference areas. This suggests that whilst there had been changes to the abundances of some key taxa, the composition of the communities remained relatively similar. Some small variations were observed, however these were not considered to be greater than changes to be expected as a result of natural fluctuations in infaunal assemblages typical of this type of environment.

In line with the findings of both the pre-construction and year 1 post-construction surveys, low resemblance Annex I 'stony reef' was identified along the BBW02 ECR during the year 2 post-construction survey. Transects 04a and 04b revealed small patches of low resemblance 'stony reef' supported by a matrix of smaller pebbles, sand and empty shell interspersed with areas of finer sand and mud. Instances of 'stony reef' along these transects did not appear to correlate well with the predicted extent of the previous surveys indicating smothering of some areas but exposure of others. 'Stony reef' observed along transects 03a and 03b had a more distinct boundary than along transects 04a and 04b and was surrounded by burrowed muddy sand. A low abundance and diversity of epibiotic fauna was recorded in areas of Annex I 'stony reef' similar to that observed during the pre-construction and year 1 post-construction survey. Communities were representative of the habitat types observed, and characteristic of areas that undergo periodic smothering and burial of the cobble substrate by the surrounding finer sediment areas which prevents colonisation during periods of exposure above the sediment.

Determining ongoing impacts and how infaunal communities and sediments are impacted over long time periods is complex due to a combination of natural and anthropogenic stressors. Change has now been assessed across two post-construction surveys compared to the pre-construction survey with results showing limited variability between the construction phases and similar levels of variation between each of the surveys. The lack of significant differences observed between the sediment composition and infaunal communities across the site throughout the monitoring period to date suggests that the construction and operation of BBW02 has had a negligible impact on the seabed sediments and associated infaunal communities across the site and its environs as predicted in the ES. However, an element of caution should still be taken when interpreting the results given the dynamic nature of the area.

2. INTRODUCTION

2.1. Burbo Bank Extension Offshore Wind Farm

Burbo Bank Extension Offshore Wind Farm (herein referred to as BBW02) is an extension to the west of the existing Burbo Bank Offshore Wind Farm in Liverpool Bay and was awarded consent in September 2014. BBW02 is located approximately 7 km north of Hoylake, Wirral and 12 km from the Point of Ayr, Wales (Figure 1). It comprises 32 8 MW offshore wind turbines, one offshore substation in English waters and one subsea export cable extending from the wind farm into Welsh waters to the landfall between Rhyl and Prestatyn.

The offshore construction programme commenced in April 2016 with the first power being generated in November 2016 and the wind farm fully commissioned by Ørsted in April 2017.

2.2. Background Information

A number of previous surveys have been undertaken in support of the BBW02 development including benthic grab, scientific beam trawling, seabed camera and geophysical surveys. Characterisation surveys were undertaken in May and early July 2011 (CMACS 2013a) with data from this survey supporting the Environmental Impact Assessment (EIA)

Following an initial Annex I habitat screening exercise (CMACS 2015b) and further review of existing information in the area, pre-construction benthic ecological survey methods were developed to investigate the presence of Annex I habitats in close proximity to planned infrastructure and acquire biotic and abiotic baseline benthic monitoring data (CMACS 2015a). The baseline benthic monitoring survey was then used as the basis to develop a monitoring plan for the post-construction benthic monitoring surveys (NIRAS Consulting 2017).

Ocean Ecology Limited (OEL) carried out the year 1 post-construction monitoring survey in August/September 2017 to provide an assessment of the benthic habitats and associated infaunal assemblages within and adjacent to the areas of potential impact resulting from the construction and operation of the BBW02 offshore wind farm. This 2019 survey acted as a repeat with all results compared to those from the pre-construction and year 1 post-construction surveys in this report.

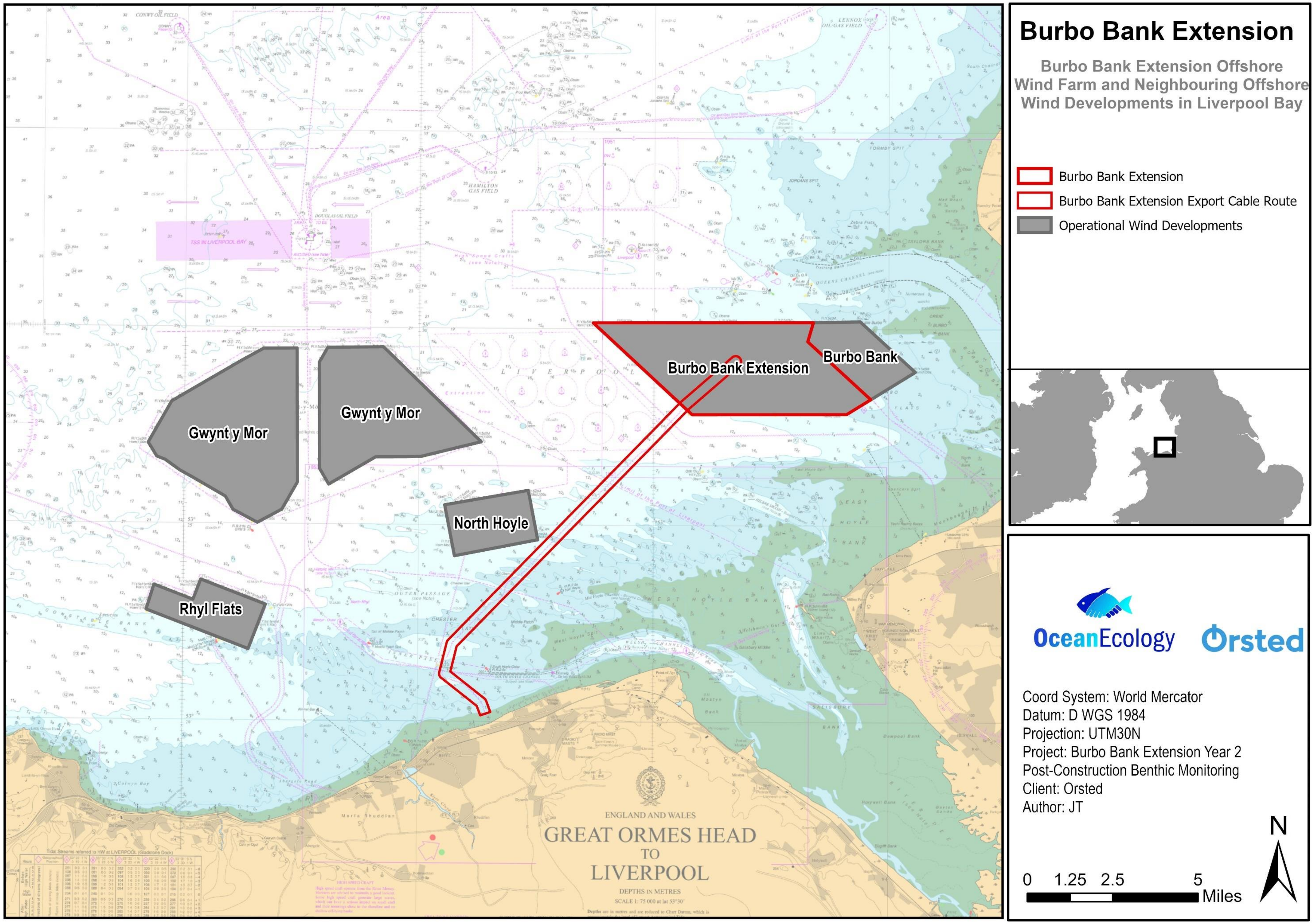

Figure 1 Map illustrating the location of the BBW02 area and its proximity to other operational wind farms in Liverpool Bay.

2.3. Environmental Statement

The BBW02 Environmental Statement (ES) was presented by Ørsted in 2013 (Ørsted 2013). The BBW02 was consented in September 2014 and awarded the Marine Licence consents (13/17/ML and EN010026 Schedule 2 and 3).

2.3.1. Baseline Conditions

BBW02 is situated in an area of water varying in depth from 3.2 m to 16 m with the shallowest areas recorded in the south-eastern corner of the wind farm site and the deeper areas found in the westernmost side of the site, furthest offshore. The predominant sediment type described during the pre-construction benthic monitoring survey was sand with localised patches of muddy sand and gravelly sand (CMACS 2015d).

Baseline infaunal communities present at BBW02 were typical of sublittoral sands and muddy sands, dominated by the trumpet worm *Lagis koreni*, the razor shell *Phaxas pellucidus,* the two-toothed Montagu shell *Kurtiella bidentata* and other characteristic species such as the white furrow shell *Abra alba,* and the tubeworm *Owenia fusiformis*. Although relatively sparse, baseline epifaunal communities present were also typical of those found in sand and muddy sands, dominated by brittlestars (*Ophiura* spp.) and the common starfish *Asterias rubens*. The presence of the nationally scarce thumbnail crab, *Thia scutellata,* was recorded at one station (Station 11) within BBW02 although in low numbers and the area is therefore not considered an important habitat for the species.

Two patches that had a low resemblance to Annex I 'stony reef' habitats were identified to the south-west of BBW02 along the ECR, a few kilometres offshore from the export cable landfall (CMACS 2015c).

2.3.2. Summary of Potential Impacts on Benthos

The predicted impacts reported in the ES relevant to benthic ecology are provided in Table 1.

Table 1 Predicted Impacts, magnitude of impact and significance of effect of the BBW02. Source: Environmental Statement (Ørsted 2013).

Description of Impact	Magnitude of Impact	Importance of Receptors	Sensitivity of Receptors*	Significance of Effect	Potential Mitigation Measures
Construction/Decommissioning Phase					
Increases in suspended sediment concentration	Minor	Low to medium	Not/very low to moderate	Negligible to minor	None
Increases in sediment deposition	Minor	Low to medium	Not/very low to moderate	Negligible to minor	None
Release of contaminants	None	Low to medium	Low to moderate	Negligible	None
Release of pollutants	None	Low to medium	Low to moderate	Negligible	None
Disturbance from vessels/machinery	Minor	Low to medium	Very low to low	Negligible to minor	None
Noise	Minor	Low to medium	Not to low	Negligible to minor	None
Operation Phase					
Loss of seabed habitat	Minor	Low to medium	Low to moderate	Minor or moderate positive to minor adverse	None
Scour leading to habitat change	Minor	Low to medium	Very low to moderate	Negligible to minor	None
Change in sediment transport leading to habitat change	Minor	Low to medium	Low to moderate	Negligible	None
Colonisation of structure leading to increased biodiversity	Minor	Low to medium	Not to low	Minor to moderate positive to minor adverse	None
Colonisation of structures by invasive species	Minor	Low to medium	Not, unknown or low	None to negligible (some uncertainty)	Risk assessment, follow IMO best practice guidelines
Electromagnetic fields (EMF)	Minor	Low to medium	Not, unknown or low	Negligible to minor	None
Cable heating	Minor	Low to medium	Not/very low to low	Negligible	None

*as determined by comparing intolerance with recoverability to each import

2.4. Project Background and Monitoring Objectives

2.4.1. Development Site

Ørsted is required to undertake a series of post-construction benthic ecology monitoring surveys of the BBW02 area and its environs in order to satisfy the requirements of the two English marine licenses (EN010026 Schedule 2 / EN010026 Schedule 3) and one Welsh license (13/17/ML) as summarised in the post-construction benthic ecology monitoring plan (NIRAS Consulting 2017).

The key aim of the survey programme is to collect data relating to the 'Subtidal sands and gravel' UK BAP and NERC Section 42 habitat in and around the wind farm array. The shallow sandy features (potential Annex I 'sandbanks slightly covered by seawater all the time' habitat) will also be monitored over time, as will the muddier sediment, included in the programme owing to potential interactions between habitats. The findings will be used to inform a comparison with the baseline data as a means of validating the predictions made in the ES (Ørsted 2013).

The requirement of the agreed Monitoring Programme was to test the following hypotheses:

$H_{0(a)}$: *There is no significant difference in sediment particle size distribution / infaunal community between wind farm, near-field and reference areas.*

$H_{0(b)}$: *There is no significant difference in sediment particle size distribution / infaunal community between survey years.*

Additional camera transects were also included in the survey programme to monitor potential impacts of the export cable installation on two areas of Annex I 'stony reef'. Although not stated in the Monitoring Programme, the following hypotheses will also be tested:

H_0: *The establishing of BBW02 Offshore Wind Farm and export cable routes does not lead to a significant impact on Annex I Habitat(s)*

The year 2 post-construction monitoring survey was the second of a series of three post-construction monitoring surveys to be undertaken by Ocean Ecology Limited (OEL). Sampling positions were consistent with those agreed previously with the Marine Management Organisation (MMO) and as per the previous pre-construction baseline and year 1 post-construction surveys. This included the use of two complimentary survey methods; 0.1 m^2 Day grab sampling and Drop-Down Camera (DDC) deployments.

3. METHODS

3.1. Sampling Rationale

A total of 19 sampling stations were targeted with either grab (triplicates) and camera or camera only deployment within the wind farm array, near-field and adjacent reference areas (Table 2). The stations were selected as a repeat of the pre-construction baseline benthic survey agreed previously with the MMO based on the sediment conditions at the site and the experience from previous surveys. A selection of the sampling stations were also sampled for Particle Size Distribution (PSD) only, with no macrobenthic samples obtained at these stations.

The stations comprised:

- Thirteen sample stations within the wind farm area;
- Three sample stations inside the expected tidal excursion (near-field); and
- Three control/reference sample stations outside the expected tidal excursion zone

Additionally, two cruciform camera transects (four transects in total) were sampled with a drop-down camera as a repeat of the approach employed during the pre-construction and year 1 post-construction surveys (Transects CRT3a and CRT3b and CRT4a and CRT4b).

Table 2 Number of sample stations, replication and site designations for the BBW02 year 2 post-construction benthic survey 2019.

Station	Location	PSD	Infauna	Drop-Down Camera	Camera Transect
1	Wind Farm	Yes	-	-	-
2	Wind Farm	Yes	Yes	Yes	-
3	Wind Farm	Yes	-	-	-
4	Wind Farm	Yes	-	-	-
5	Wind Farm	Yes	-	-	-
6	Wind Farm	Yes	-	-	-
7	Wind Farm	Yes	Yes	Yes	-
8	Wind Farm	Yes	-	-	-
9	Wind Farm	Yes	Yes	Yes	-
10	Wind Farm	Yes	-	-	-
11	Wind Farm	Yes	Yes	Yes	-
12	Wind Farm	Yes	-	-	-
13	Tidal Excursion Zone (Near-field)	Yes	Yes	-	-
14	Reference/Control Area	Yes	Yes	-	-
15	Tidal Excursion Zone (Near-field)	Yes	Yes	-	-
16	Tidal Excursion Zone (Near-field)	Yes	Yes	Yes	-
17	Reference/Control Area	Yes	Yes	Yes	-
18	Reference/Control Area	Yes	Yes	Yes	-
19	Wind Farm	-	-	Yes	-
CRT_3a	Export Cable Route	-	-	-	Yes
CRT_3b	Export Cable Route	-	-	-	Yes
CRT_4a	Export Cable Route	-	-	-	Yes
CRT_4b	Export Cable Route	-	-	-	Yes
	Total	**18**	**10**	**8**	**4**

The locations of all actual grab, camera and camera transect sampling locations are shown in Figure 2.

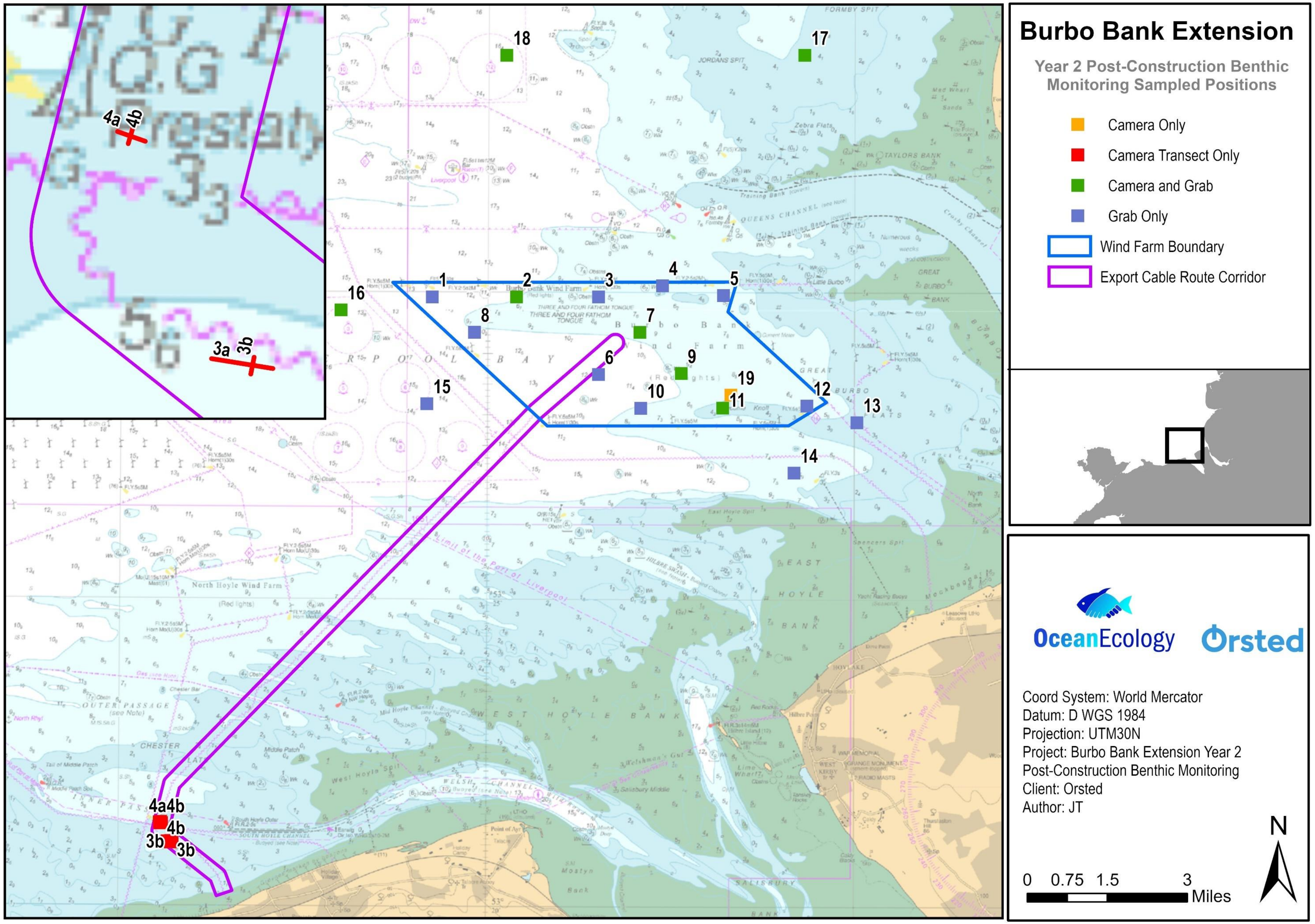

Figure 2 Actual grab and drop-down camera sampling undertaken during the BBW02 year 2 post-construction benthic survey 2019.

3.2. Field Methods

The benthic survey report for the 2019 survey is provided as Appendix 1, containing detailed notes on survey progress and methodologies.

3.2.1. Survey Vessel

OEL's dedicated 10.4 m MCA category 2 coded survey vessel, Seren Las, was employed to undertake all grab and DDC sampling (Plate 1).

Plate 1 Dedicated survey vessel, Seren Las, employed for the BBW02 year 2 post-construction BBW02 benthic survey 2019.

3.2.2. Survey Equipment

The vessel was equipped with a Vector V104™ GNSS compass GPS system that provided an accurate offset position of the sampling equipment when deployed from the stern. This provided a GPS feed to a dedicated survey navigation computer, which was later used to produce an overlay on the seabed video footage. Seabed imagery was collected using OEL's ROVTech subsea camera system providing 1080p High Definition (HD) video and 20 Megapixel (MP) still images, mounted in a hydrostatic freshwater housing and bespoke mounting frame. Two laser pointers separated by 10 cm were mounted in the frame and projected into the field of view for a measure of scale. Grab sampling was undertaken using OEL's 0.1 m^2 Day grab.

3.2.3. Benthic Grab Sampling

3.2.2.1 Sample Collection

A total of 30 infaunal samples and 54 PSD samples[1] were obtained for subsequent infaunal and PSD analysis.

To assure consistency in sampling, grab samples were screened by the lead marine ecologist and considered unacceptable if:

- The sample was less than 5 L. i.e. the sample represented less than half the 10 L capacity of the Day grab used or 2.5 L on hard-packed sands.
- The jaws failed to close completely or were jammed open by an obstruction, allowing fines to pass through (washout or partial washout).
- The sample was taken at an unacceptable distance from the target location.
- There was obvious contamination of the sample from sampling equipment, paint chips etc.

The station was to be abandoned in the event of three failed attempts at obtaining an acceptable sample, however, all stations were sampled successfully with a minimum sample volume of 5 L obtained.

3.2.2.2 Sample Processing

All field sample processing methods were undertaken in line with the *Guidelines for the Conduct of Benthic Studies at Marine Aggregate Exaction Sites* (Ware et al. 2011) and in-house Standard Operating Procedures (SOPs) in line with OEL's Quality Management System (QMS).

Initial sample processing was undertaken aboard the survey vessel in line with the following methodology:

- An assessment of sample size and acceptability was made.
- A photograph of the sample with station details and scale bar was taken.
- 10 % of the sample was removed for subsequent PSD analysis and transferred to labelled foil tray.
- Sample was emptied onto a 1 mm sieve net laid over 4 mm sieve table and washed through using gentle rinsing with seawater hose.
- The remaining sample for infaunal sorting and identification was backwashed into a suitably sized sample container using seawater and diluted 10 % formalin solution added to fix sample prior to laboratory analysis.
- Sample containers were clearly labelled internally and externally with date, sample ID and project name.

Field notes and sample photographs taken for each grab sample are provided in Appendices 2 and 3.

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[1] 10 stations sampled in triplicate for infauna with single PSD sub-sample taken from each faunal grab and eight stations sampled in triplicate for PSD only.

3.2.4. Drop-Down Camera Sampling

Detailed field notes and all seabed imagery are provided in Appendices 4 and 5.

All camera stations and transects were sampled in line with the Joint Nature Conservation Committee (JNCC) epibiota remote monitoring operational guidelines (Hitchin et al. 2015). A minimum of five images were taken from each DDC station along with approximately five minutes of video. Along the camera transects, images were taken every 10 – 20 m over heterogeneous habitat types, at the interface between different habitats and also of any notable features along the transects. Between images, the camera was moved several metres to ensure a good overview of the station was obtained and any heterogeneity in the substrate was identified. All video footage was reviewed in situ by the lead marine ecologist and representative images were taken of the substrate at each station as well as any features of interest (where possible).

At each camera station, the camera system was deployed as follows:

- Vessel approached target location and alerted deck personnel to prepare camera and umbilical.
- Sea fastening on camera frame was released to allow deployment from the deck.
- Umbilical released overboard with sufficient length paid out to cover water depth.
- Camera raised and lowered into the water column to within 5 m of the seabed.
- Ecologist switched on video recording and the camera lowered until gently landing on the seabed at which point a positional fix was taken.
- The ecologist then waited for any suspended sediments in the field of view to disperse before taking an image and confirming with the skipper to move on.
- The camera was then raised from the seabed and moved to obtain more images of the surrounding area or, when sampling transects, the camera was moved along the transect at approximately 1-2 knots. Where possible the seabed was maintained in view at all times.
- Following the capture of the final image, the camera was lifted, video recording was stopped and the camera was retrieved to the surface.
- The winch operator then took tension on the winch cable and the ecologist ensured the camera umbilical was free for recovery.
- Once the camera was at the surface, the vessel was positioned to minimise pitch and roll (e.g. into wind/tide).
- The vessel skipper then confirmed sea conditions were suitable for retrieval and the camera system was recovered aboard.
- The camera frame was then lowered onto the deck and the tension released.

3.3. Laboratory Methods

On arrival to the laboratory, all macrobenthic and PSD samples were logged in the BBW02 project database created in OEL's web-based data management application 'ABACUS' whilst the seabed imagery was stored on OEL's server and backed up to the cloud..

3.3.1. Particle Size Distribution (PSD) Analysis

PSD analysis of separate sediment samples was undertaken by in-house laboratory technicians at OEL's NE Atlantic Marine Biological Quality Control (NMBAQC) participating laboratory.

To ensure consistency in methods of analysis between pre-construction and post-construction surveys, PSD analysis methods adopted by CMACS during the pre-construction phase were employed. However, as in 2017, it was noted that these methods conflict with recommendations in NMBAQC guidelines and are particularly unsuitable for the sediment types present across the BBW02 survey area (Sand (S) and Muddy Sands (mS)). The method used in 2015 involved drying all sediments at 80°C for at least 24 hours prior to dry-sieving all samples and only laser sizing the <2 mm fraction if >5 % of the whole sample was found to be <63 µm. Oven drying sediment causes the aggregation of particles in muddy sediments (>5 % mud) and for these reasons, such sediments should not be oven dried prior to particle size analysis (Mason 2016).

Therefore, a visual assessment of all thawed sediment samples was undertaken prior to drying to ensure the optimal analysis technique was used. Due to the obvious presence of mud in a large proportion of samples, some with a considerable mud content in excess of 5 %, all samples were analysed via a combination of both dry sieving (>1 mm fraction) and laser sizing (<1 mm fraction), as summarised below.

3.3.1.1. Sample Preparation

Frozen sediment samples were first transferred to a drying oven and thawed at 80°C for at least six hours prior to visual assessment of sediment type and wet sieving over a 1 mm sieve. Before any further processing (e.g. sieving or sub-sample removal), samples were mixed thoroughly with a spatula and all conspicuous fauna (>1 mm) which appeared to have been alive at the time of sampling were removed from the sample.

3.3.1.2. Dry Sieving

The >1 mm fraction was then returned to a drying oven and dried at 80°C for at least 24 hours prior to dry sieving.

Once dry, the sediment sample was run through a series of Retsch Test Sieves ISO 3310-1 (nested at 0.5 φ intervals) using a Retsch AS200 sieve shaker to fractionate the samples into particle size classes. The dry sieve mesh apertures used are given in Table 3.

Table 3 Sieve series employed for Particle Size Distribution (PSD) analysis by dry sieving (mesh size in mm).

Sieve aperture (mm)											
63	45	31.5	16	11.2	8	5.6	4	2.8	2	1.4	1

The sample was transferred onto the coarsest sieve at the top of the sieve stack, which was then shaken for a standardised period of 20 minutes. The sieve stack was then checked to ensure the components of the sample had been fractioned as far down the sieve stack as their diameter would allow. A further 10 minutes of shaking was undertaken if there was evidence that particles had not been properly sorted (e.g. veneers of silt overlying coarse fractions).

3.3.1.3. Laser Diffraction

The fine fraction residue (<1 mm sediments) was transferred to a suitable container and allowed to settle for 24 hours before excess water was syphoned from above the sediment surface. The fine fraction was analysed by laser diffraction using a wet element Beckman Coulter LS13 320. Due to the silty nature of the sediments, ultrasound was used to agitate particles and prevent aggregation of fines.

The dry sieve and laser data were then merged for each sample with the results expressed as a percentage of the whole sample. Once the data was merged, PSD statistics and sediment classifications were generated from the percentages of the sediment determined for each sediment fraction using the Gradistat v7 software.

Sediment descriptions were defined by their size class based on the Wentworth classification system (Wentworth 1922) (Table 4). Statistics such as mean and median grain size, sorting coefficient, skewness and bulk sediment classes (percentage silt, sand and gravel) were also derived in accordance with the Folk classification (Folk 1954).

Table 4 Classification used for defining sediment type based on the Wentworth Classification System (Wentworth 1922).

Wentworth Scale (mm)	Phi units (φ)	Sediment Types
>256 mm	<-8	Boulders
64 - 256 mm	-8 to -6	Cobble
4 - 64 mm	-6 to -2	Pebble
2 - 4 mm	-2 to -1	Granule
1 - 2 mm	-1 to 0	Very coarse sand
0.5 - 1 mm	0 - 1	Coarse sand
250 - 500 µm	1 - 2	Medium sand
125 - 250 µm	2 - 3	Fine sand
63 - 125 µm	3 - 4	Very fine sand
31.25 – 63 µm	4 - 5	Very coarse silt
15.63 – 31.25 µm	5 - 6	Coarse silt
7.813 – 15.63 µm	6 - 7	Medium silt
3.91 – 7.81 µm	7 - 8	Fine silt
1.95 – 3.91 µm	8 - 9	Very fine silt
<1.95 µm	>9	Clay

3.3.2. Macrobenthic Analysis

For each macrobenthic sample, the excess formalin was drained off into a labelled container over a 1 mm mesh sieve in a well-ventilated area. The sample was then re-sieved over a 1 mm mesh sieve to remove all remaining fine sediment and fixative. Low-density fauna was then separated from the sediment by elutriation with fresh water poured over a 1 mm mesh sieve and transferred into a Nalgene and preserved in 70% Industrial Denatured Alcohol (IDA). The remaining sediment was subsequently separated into 1 mm, 4 mm and 8 mm fractions and sorted under a stereomicroscope to extract any remaining fauna (e.g. high-density bivalves not ‘floated’ off during elutriation). The residual sediment fractions were then transferred into labelled containers, preserved in Industrial Denatured Alcohol (IDA) and stored in line with OEL’s quality control procedures.

All fauna present was identified to species level, where possible, and enumerated by trained benthic taxonomists using the most up to date taxonomic literature and checks against existing reference collections. Nomenclature utilised the most up to date taxonomic classifications provided on the World Register of Marine Species (WoRMS)[2]. Colonial fauna (e.g. hydroids and bryozoans) were identified to species level where possible and recorded as present (P).

Prior to further analysis of the macrobenthic data, an initial rationalisation of the taxon list and associated abundance data was carried out. This primarily involved the removal and/or combination of taxa to avoid potential misrepresentation of numerical abundance. Abundances for individuals identified as juveniles were combined with abundances for adults and taxa identified from eggs were removed. Taxa recorded as P were given the numerical value of 1. Taxa not representative of the infaunal community were also removed prior to data analysis to address the monitoring hypotheses.

A full reference collection was retained including at least one example specimen of each taxon.

3.3.3. Faunal Biomass

Following identification, all taxa from each sample were pooled into five major groups (Annelida, Crustacea, Mollusca, Echinodermata and Other taxa) to measure blotted wet weight major group biomass to 0.0001 g. As a standard, the conventional conversion factors as defined by Eleftheriou & Basford (1989) were applied to biomass data to provide equivalent dry weight biomass (Ash Free Dry Weight, AFDW). The conversion factors applied are as follows:

- Annelida = 15.5 %
- Crustacea = 22.5 %
- Mollusca = 8.5 %
- Echinodermata = 8.0%
- Other = 15.5 %

3.4. Video Analysis

All seabed imagery analysis was undertaken in line JNCC epibiota remote monitoring interpretation guidelines (Turner et al. 2016). Determination of sediment type, such as coarse, mixed, sand etc. was facilitated using the adapted Folk sediment trigon (Folk 1954) incorporated into a sediment category correlation table. Percentage gravel (boulders, cobbles, shells, granules, and dead/live maerl), sand and mud were used to determine and assign European Nature Information System (EUNIS) Broad Scale Habitats (BSH). Where required, EUNIS categories for each of the video and still locations were considered from the information provided by on the EMODnet Seabed Habitat mapping portal [3] utilising predictive habitat mapping where habitat maps were not available from existing surveys.

3.4.1. Determination of Annex I Stony Reef

A pre-construction Annex I habitat investigation monitoring programme was undertaken at stations along the ECR and was repeated during the year 1 and year 2 post-construction surveys. Several areas sampled along video transects were identified as meeting the requirements to be classified as habitats listed for protection under Annex I of the Habitats Directive as 'reefs'. Annex I 'reefs' can be classified as either biogenic (produced by living organisms) or geogenic (rocky). Rocky reef can be either bedrock or a 'stony reef' comprising cobbles and

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[2] http://www.marinespecies.org/index.php

[3] https://www.emodnet-seabedhabitats.eu/

boulders. Habitats with 100% rock substrate (or rock substrate with thin veneers of sediment) mostly qualify as Annex I 'reef' but 'stony reef' needs to meet the criteria set out by Irving (2009) (Table 5).

Examples of how seabed imagery collected during the BBW02 year 2 post-construction benthic survey were classified as Annex I 'stony reef' are provided in Plate 2.

Table 5 Characteristics of Annex I 'stony reef' (Irving 2009).

Characteristic	Not a 'stony reef'	'Resemblance' to being a 'stony reef'		
		Low	Medium	High
Composition (proportion of boulders/cobbles (>64 mm))	<10 %	10-40 % matrix supported	40-95 %	>95 % clast-supported
Elevation	Flat seabed	<64 mm	64 mm - 5 m	>5 m
Extent	<25 m^2	>25 m^2		
Biota	Dominated by infaunal species			>80 % of species present composed of epibiotal species

Characteristic	Left – 'Reefiness' Criteria	Right – 'Reefiness' Criteria
Composition	Medium, 10-40% boulders/cobbles >64mm, clast-supported	Pebbles/gravel, <10% boulders/cobbles >64mm
Elevation	Medium, 64mm – 5m	Mostly low <64mm
Extent	Not known if >25m^2 from image alone	Not known if >25m^2 from image alone
Biota	Infaunal likely to be present but clear dominance of epibiotal species	Infaunal and epibiotal species present
Classification	**Annex I 'Stony Reef'** (if video footage shows extent to be >25m^2)	**Not Annex I 'Stony Reef'** (regardless of extent)

Plate 2 Example images taken during the BBW02 year 2 post-construction benthic survey and the rationale for classification or otherwise as Annex I 'stony reef'.

3.5. Data Truncation & Standardisation

3.5.1. Species Nomenclature Checks

As the macrobenthic data was used for comparison between construction phases spanned a number of years, it was imperative that the taxonomic nomenclature was standardised and updated. The macrobenthic taxon lists were therefore checked using the R package “worms” (Holstein 2018) to check against WoRMS taxon lists which resulted in a merged data matrix with taxon lists standardised across the pre-construction and both post-construction surveys.

3.5.2. Data Truncation

Once the nomenclature had been standardised in accordance with WoRMS accepted species names, the taxon lists were examined carefully to truncate the data, excluding incidental recordings that might have skewed the data analysis and combining species records where differences in historical sample analysis were evident. Any taxa not representative of the infaunal community were also removed.

3.6. Data Formatting and Analysis

The R software package (R Core Team 2019) was used for data manipulation and univariate analysis. Two-way Analysis of Variance (ANOVA) tests (Year and Treatment) were used to test for significant differences in overall abundance, diversity, and biomass of infauna. Abundance data was log transformed in order to meet the assumption of equal variance for the ANOVA tests.

3.7. Multivariate Data Analysis

The PRIMER v7 software package (Clarke & Gorley 2015) was utilised to undertake the multivariate statistical analysis on both the biotic (infaunal) and abiotic (PSD) datasets. To fully investigate the multivariate patterns in the biotic and abiotic data, a suite of analytical routines was employed as summarised below and described in detail in Appendix 6. Prior to multivariate analyses, data were displayed as a shade plot with a linear grey-scale intensity proportional to infaunal abundance (Clarke et al. 2013) to determine the most efficient pre-treatment method.

4. RESULTS

4.1. Sediments

In total, all 54 sediment samples were analysed for full particle size classification. Sediment data has been mapped in Figure 4, Figure 6 and Figure 7 with full particle size data provided in Appendix 7. Summary sediment statistics are provided in Appendix 8. Sediment composition by treatment area is presented in Figure 5.

4.1.1. Sediment Type

Sediment types, as classified using the Folk Triangle (Folk 1954), for each of the stations sampled across the BBW02 survey area are presented in Figure 3 and Figure 4. Each Folk classification was converted to BSH type (EUNIS Level 3) using the adapted Folk triangle (Figure 3) (Long 2006). Example images of the sediment types identified in replicated grab samples during the survey are presented in Plate 3.

Sediments were homogeneous within triplicate sampling stations (i.e. between replicates) and showed limited variation across the survey area. Sediments were predominantly made up of Sand (S) and Muddy sand (mS) with low gravel content (sediments >2 mm). Figure 4 shows the sediments sampled across the BBW02 survey area which consisted of Sand (S) and Slightly Gravelly Sand (gS) (BSH A5.2), Muddy Sand (mS), Slightly Gravelly Muddy Sand (gmS) and Sandy Mud (sM) (BSH A5.3) and Gravelly Sand (gS) (BSH A5.1).

The majority of the sediments recorded were classified as poorly sorted as a result of the mixed composition of different size fractions of all three principle sediment types (gravel, sand and mud) with some stations classified as very poorly sorted. Sediments recorded as moderately or moderately well sorted were mainly composed of clean Sands (S) or Slightly Gravelly Sands (gS).

Sand (S) Muddy Sand (mS) Sandy Mud (sM)

Slightly Gravelly Muddy Sand (gmS) Slightly Gravelly Sand (gS) Gravelly Sand (gS)

Plate 3 Examples of sediment types sampled during the BBW02 year 2 post-construction benthic monitoring survey 2019.

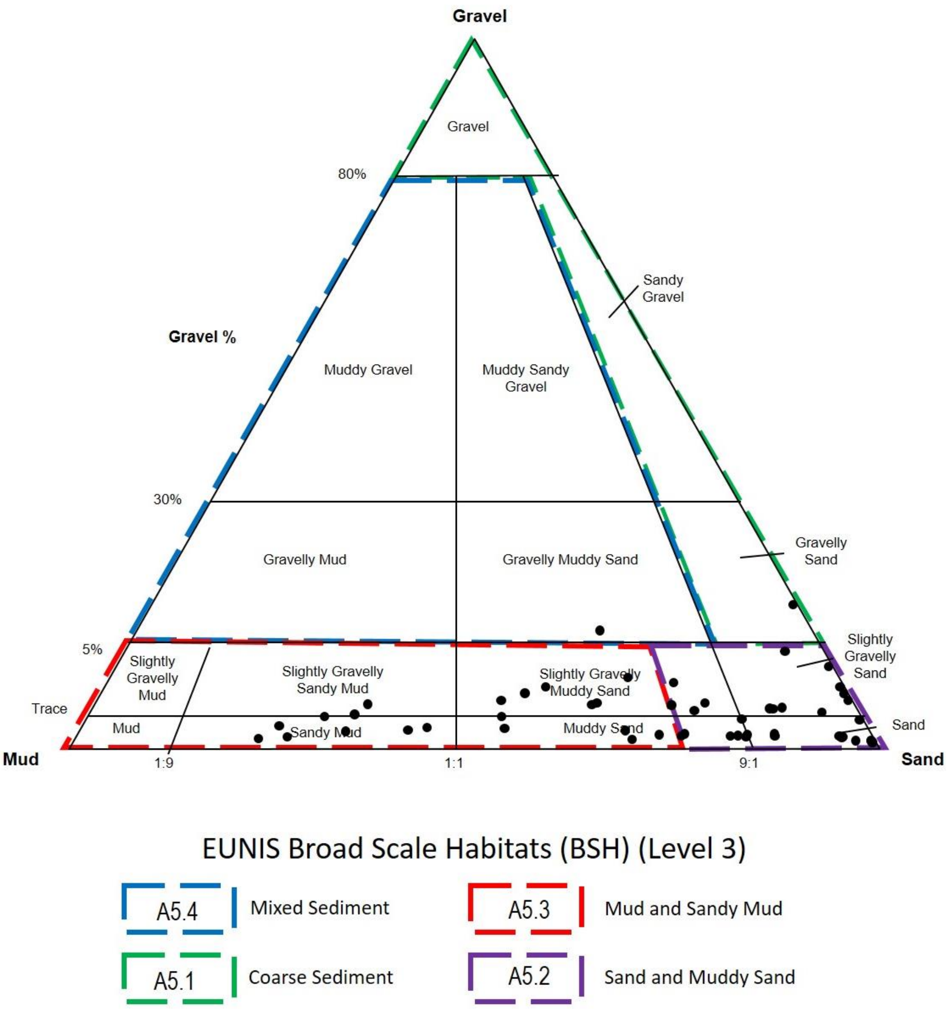


Figure 1. Folk (Folk 1954) triangle classifications of sediment gravel percentage and sand to mud ratio of replicate samples collected during the BBW02 year 2 post-construction benthic monitoring survey, overlain by the modified Folk triangle for determination of mobile sediment BSHs under the EUNIS habitat classification system (adapted from Long 2006).

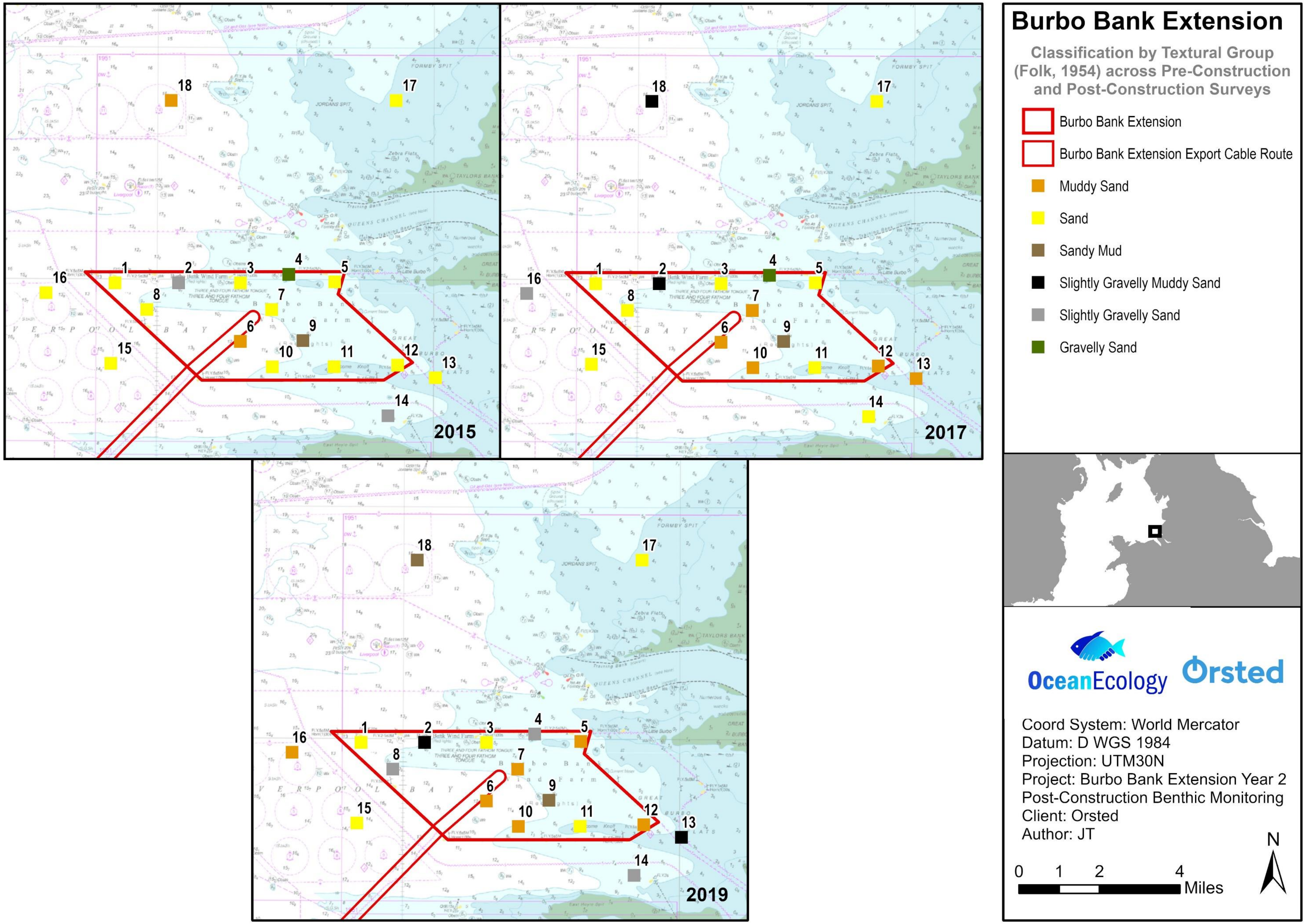


Figure 4. Comparison of Folk (1954) sediment types as determined from PSD analysis of samples acquired across the BBW02 survey area during 2015 pre- and 2017 and 2019 post-construction benthic surveys.

4.1.2. Sediment Composition

Percentage contribution of gravels (> 2 mm), sands (0.63 mm to 2 mm) and fines (< 63 µm) are presented by treatment area in Figure 6. Percentage contribution of sand was greatest across the survey area where sand was the dominant sediment fraction at most stations (except for wind farm stations 6 and 9 and reference station 18). The mean (± SE) proportion of sand across all stations was 76.4 ± 3.29 %, mean (± SE) mud content was 22.7 ± 3.32 % and mean (± SE) gravel content was 0.9 ± 0.24 %. Percentage contribution of gravel was low across the BBW02 survey area (< 5 %) where 13 of the 18 stations had < 1 % gravel content in the 2019 survey.

Comparative datasets from the 2015 pre-construction survey and two post-construction surveys are presented in Table 6. Mean sediment grain size (µm) across the BBW02 survey area in each of the surveys is spatially represented in Figure 6. Mean grain size of sediments sampled during the year 2 post-construction survey ranged between 23.0 and 389.4 µm. There was no distinct trend in grain size or sediment type within the different treatment areas across the BBW02. Generally, sediments sampled were relatively homogeneous across the survey area and characteristic of Muddy Sands (mS) and Sand (S) with very low to no gravel content. Sediments in all treatment areas exhibited a significant range in sediment grain size due to variable sediment types however generally ranged between 0.05 mm (very coarse silts) and 0.35 mm (medium sands) at the majority of stations.

Temporal comparison between survey years shows some variation in sediment composition through time (Figure 6, Figure 7). There was a greater contribution of finer sediments (i.e. mud) at several wind farm, near field and reference stations in the year 1 and 2 post-construction surveys when compared to the pre-construction survey. A change in the textural group was identified at seven of the 18 stations sampled when compared to the year 1 post-construction surveys though no obvious trends were observed across areas. Of the three reference stations, station 17 remained constant (sand), station 14 demonstrated an increase in average grain size in 2017 followed by a reduction in 2019, and station 18 exhibited the reverse trend. The largest changes, particularly when compared to pre-construction data, were observed at stations 5 (wind farm) and 13 (near-field). Both showed an increase in the % contribution of finer sediments. While the contribution of mud was observed to be much greater during the year 1 and year 2 post-construction surveys (likely due to the analysis methods as discussed in detail in Section 5.2) these stations have shown a further increase in mud content between the year 1 and year 2 post-construction surveys.

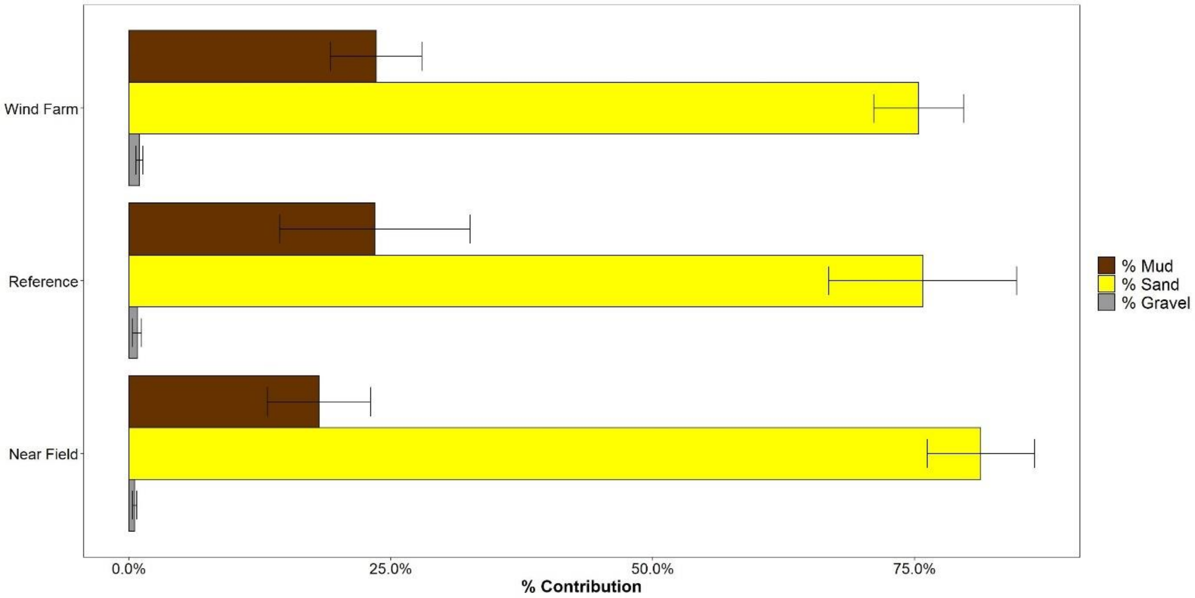


Figure 5. Principal sediment components (Gravel, Sand and Mud) as determined from PSD analysis of samples by treatment area sampled during the BBW02 year 2 post-construction benthic survey.

Table 6 Comparison of PSD data collected during the BBW02 2015 pre- and 2017 and 2019 post-construction benthic surveys.

Station	Treatment	Textural Group Classification (2019)		Textural Group Classification (2017)		Textural Group Classification (2015)	Mean µm (2019)	Mean µm (2017)	Mean µm (2015)	Major Sediment Fractions (2019)			Major Sediment Fractions (2017)			Major Sediment Fractions (2015)		
										% Gravel	% Sand	% Mud	% Gravel	% Sand	% Mud	% Gravel	% Sand	% Mud
1	Wind Farm	Sand	-	Sand	-	Sand	322.6	14.0	359.5	0.6%	90.2	9.2	0.6	89.9	9.5	0.7	98.8	0.6
2	Wind Farm	Slightly Gravelly Muddy Sand	-	Slightly Gravelly Muddy Sand	▼	Slightly Gravelly Sand	147.7	259.1	429.8	3.6	73.6	22.7	4.5	79.4	16.1	1.1	98.4	0.5
3	Wind Farm	Sand	-	Sand	-	Sand	377.5	377.2	359.7	0.0	99.5	0.4	0.0	98.1	1.8	0.0	99.9	0.1
4	Wind Farm	Slightly Gravelly Sand	▼	Gravelly Sand	-	Gravelly Sand	389.4	436.5	771.1	2.2	97.8	0.0	5.1	92.2	2.7	22.1	76.4	1.5
5	Wind Farm	Muddy Sand	▼	Sand	-	Sand	128.6	261.0	276.7	0.1	81.9	18.0	0.2	95.8	4.0	0.1	99.5	0.4
6	Wind Farm	Muddy Sand	-	Muddy Sand	-	Muddy Sand	22.12	51.9	74.3	0.2	26.1	73.7	0.2	50.7	49.1	0.0	73.4	26.6
7	Wind Farm	Muddy Sand	-	Muddy Sand	▼	Sand	97.67	210.0	211.3	0.2	76.4	23.4	0.1	87.4	12.5	0.0	98.8	1.1
8	Wind Farm	Slightly Gravelly Sand	▲	Sand	-	Sand	261.8	253.9	257.0	3.8	95.4	0.8	0.3	94.4	5.2	0.3	99.5	0.2
9	Wind Farm	Sandy Mud	-	Sandy Mud	-	Sandy Mud	23.05	26.1	19.8	0.3	28.2	71.6	0.0	26.6	73.4	0.0	23.3	76.7
10	Wind Farm	Muddy Sand	-	Muddy Sand	▼	Sand	150.3	83.3	325.8	0.7	80.4	18.9	0.8	54.7	44.6	0.8	98.3	0.9
11	Wind Farm	Sand	-	Sand	-	Sand	379.8	359.6	353.1	0.0	100.0	0.0	0.0	98.4	1.6	0.0	99.9	0.1
12	Wind Farm	Muddy Sand	-	Muddy Sand	▼	Sand	65.95	83.1	262.2	0.5	54.9	44.6	0.5	58.0	41.5	0.1	98.0	1.9
13	Near Field	Slightly Gravelly Muddy Sand	▼	Muddy Sand	▼	Sand	75.78	123.4	231.4	1.3	62.3	36.4	0.2	76.2	23.6	0.5	98.4	1.1
14	Reference	Slightly Gravelly Sand	▲	Sand	▼	Slightly Gravelly Sand	333.8	287.1	333.9	1.9	96.1	2.0	0.4	90.2	9.4	1.1	98.3	0.6
15	Near Field	Sand	-	Sand	-	Sand	353.7	314.2	355.4	0.1	95.1	4.8	0.3	92.6	7.1	0.2	99.1	0.7
16	Near Field	Muddy Sand	▼	Slightly Gravelly Sand	▲	Sand	286.8	328.7	337.2	0.2	86.6	13.2	2.6	93.4	4.0	0.1	99.6	0.3
17	Reference	Sand	-	Sand	-	Sand	165.1	173.4	179.0	0.1	90.9	9.0	0.2	93.2	6.7	0.0	99.6	0.4
18	Reference	Sandy Mud	▼	Slightly Gravelly Muddy Sand	▲	Muddy Sand	28.66	84.4	71.0	0.4	40.2	59.4	1.2	67.7	31.1	0.0	71.4	28.6

Arrows denote a change in sediment type between Post-Construction (2019) and Post-Construction (2017) and between Post-Construction (2017) and Pre-Construction (2015). ▲ = sediments become coarser. ▼ = sediments become finer. ▬ = textural group unchanged.

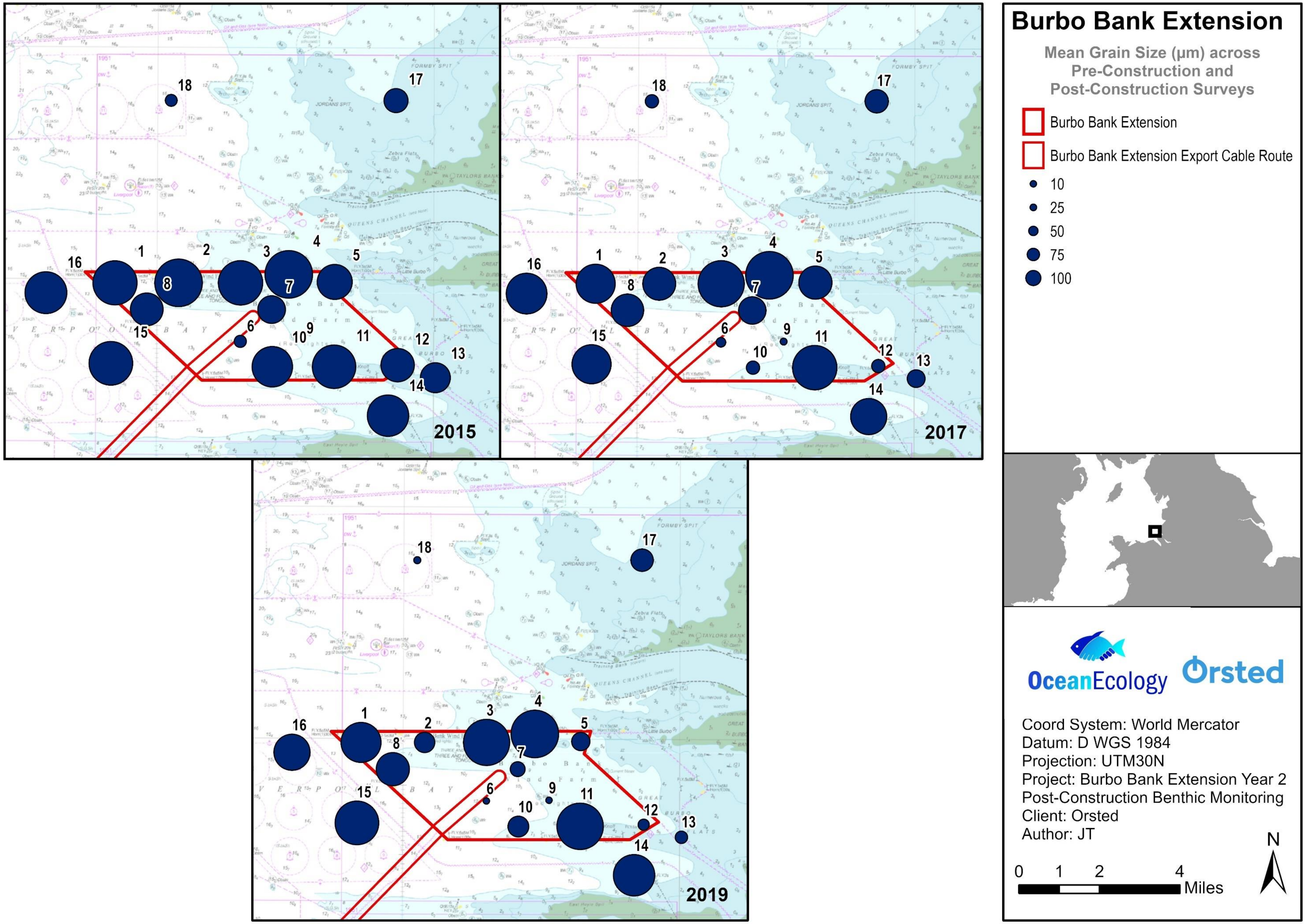


Figure 6. Comparison of mean sediment grain size (µm) of sediment samples collected during the BBW02 2015 pre- and 2017 and 2019 post-construction benthic surveys.

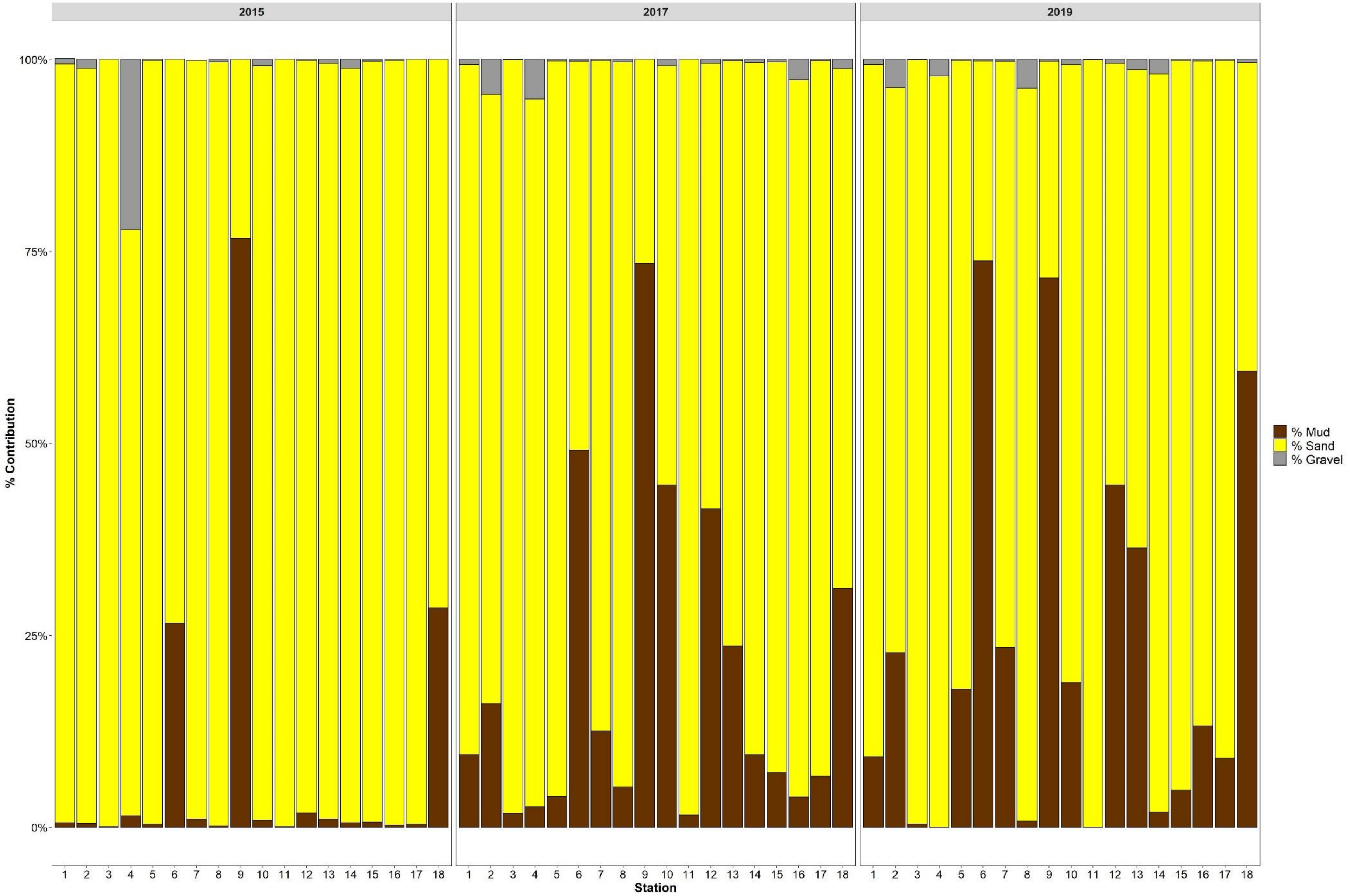


Figure 7. Sediment contribution (gravel, sand and mud) for each sampling station sampled across the BBW02 survey area during 2015 pre- and 2017 and 2019 post-construction benthic surveys.

4.1.3. Sediment Groups

Cluster analysis of sediment data was carried out using a resemblance matrix calculated using the Euclidean Distance index. This enabled samples to be assigned to various sediment groups based on the dissimilarity of sediment composition using a 35 % slice (Figure 8). Summary statistics for each of the sediment groups identified are presented in Table 7 and groups are represented spatially in Figure 9.

Group A was the most frequently occurring group across each of the surveys. Six stations fell into this group in all surveys (33% of the 18 stations sampled) and were mainly composed of Sand (S) and Slightly Gravelly Sand (gS) with little mud content. This group consisted of near-field stations 15 and 16, reference station 14, and the remainder of the stations were positioned within the wind farm. This group showed the tightest clustering in the MDS of all sediment groups.

Samples characterised as **Group B** had a very similar composition to Group A, but with a slightly greater mud content. Stations 5 and 8, both in the wind farm area, were classified within this group in all survey years, which occur at opposite sides of the BBW02 wind farm site.

Group C sediments had a greater proportion of mud present. This group composed of Station 18 (reference area) in all survey years and Stations 6, 7, 12 (all wind farm), and 13 (near-field) in both post-construction surveys. This group mainly contained poorly sorted Muddy Sands (mS).

Group D was similar to Groups A and B and stations were all characterised as Sand (S). This group consisted of Station 17 (located in the reference area) in all survey years as well as Stations 7 (wind farm) and 13 (near-field) when sampled in the pre-construction survey. These latter two stations were characterised as Group C in post-construction surveys due to the increase in finer particles present, potentially as a result of the methods used.

Group E had the highest mud content of all of the sediment groups. This group mainly consisted of Station 9 (wind farm) which was classified as Sand Mud (sM), located towards the centre of the wind farm site.

Group F had the highest proportion of gravel of the sediment groups. This group consisted of Station 2 (wind farm) when sampled in the post-construction years and Station 4 when sampled in the pre-construction survey. All these stations were classified as Group A when sampled in other years.

The low stress of the MDS plot (0.04) indicates that the two-dimensional plot provides a representative interpretation of the similarity between the samples.

Table 7. Summary of sediment similarity groups across all pre-construction and post-construction surveys.

		A	B	C	D	E	F
Mean % Mud ± SE		3.16 ± 0.84%	6.18 ± 2.75%	35.11 ± 3.81%	3.65 ± 1.75%	73.85 ± 1.06%	13.44 ± 6.27%
Mean % Sand ± SE		96.02 ± 20.43%	93.13 ± 27.34%	64.44 ± 36.7%	96.17 ± 19.66%	26.03 ± 13.91%	76.47 ± 8.71%
Mean % Gravel ± SE		0.82 ± 6.04%	0.7 ± 4.55%	0.45 ± 1.2%	0.15 ± 1.04%	0.12 ± 0.93%	10.09 ± 61.46%
Sediment Type		Sand (S)	Sand (S)	Muddy Sand (mS)	Sand (S)	Sandy Mud (sM)	Gravelly Muddy Sand (gmS)
No. of Samples	**2015**	8	3	2	3	1	1
	2017	7	2	6	1	1	1
	2019	7	3	4	1	2	1

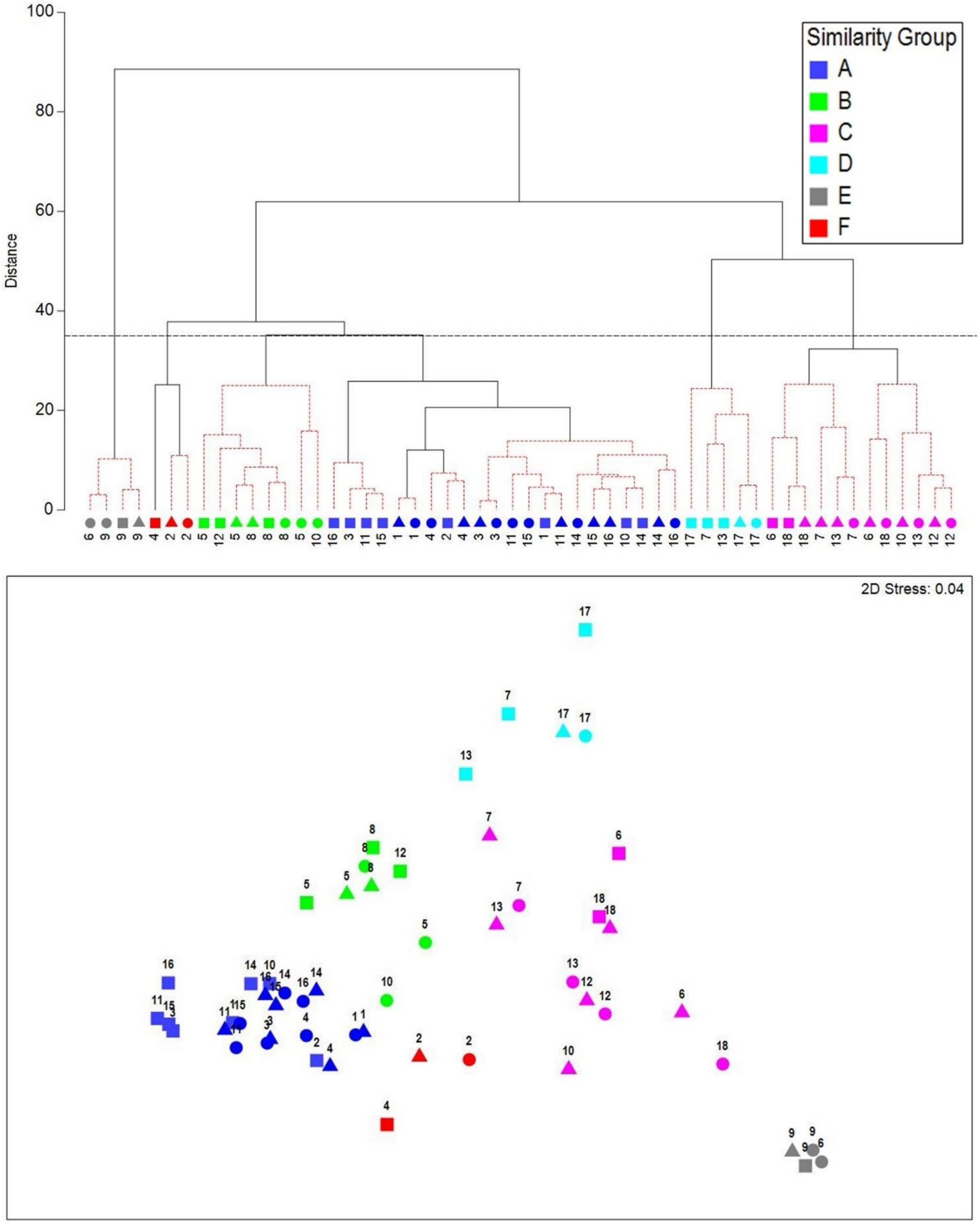


Figure 8. Dendrogram and corresponding MDS ordination plot of PSD data based on Euclidean distance weighting from samples taken during the pre-construction (squares), and year 1 (triangles) and year 2 (circles) BBW02 post-construction benthic surveys. Sediment groups were separated at 35% similarity.

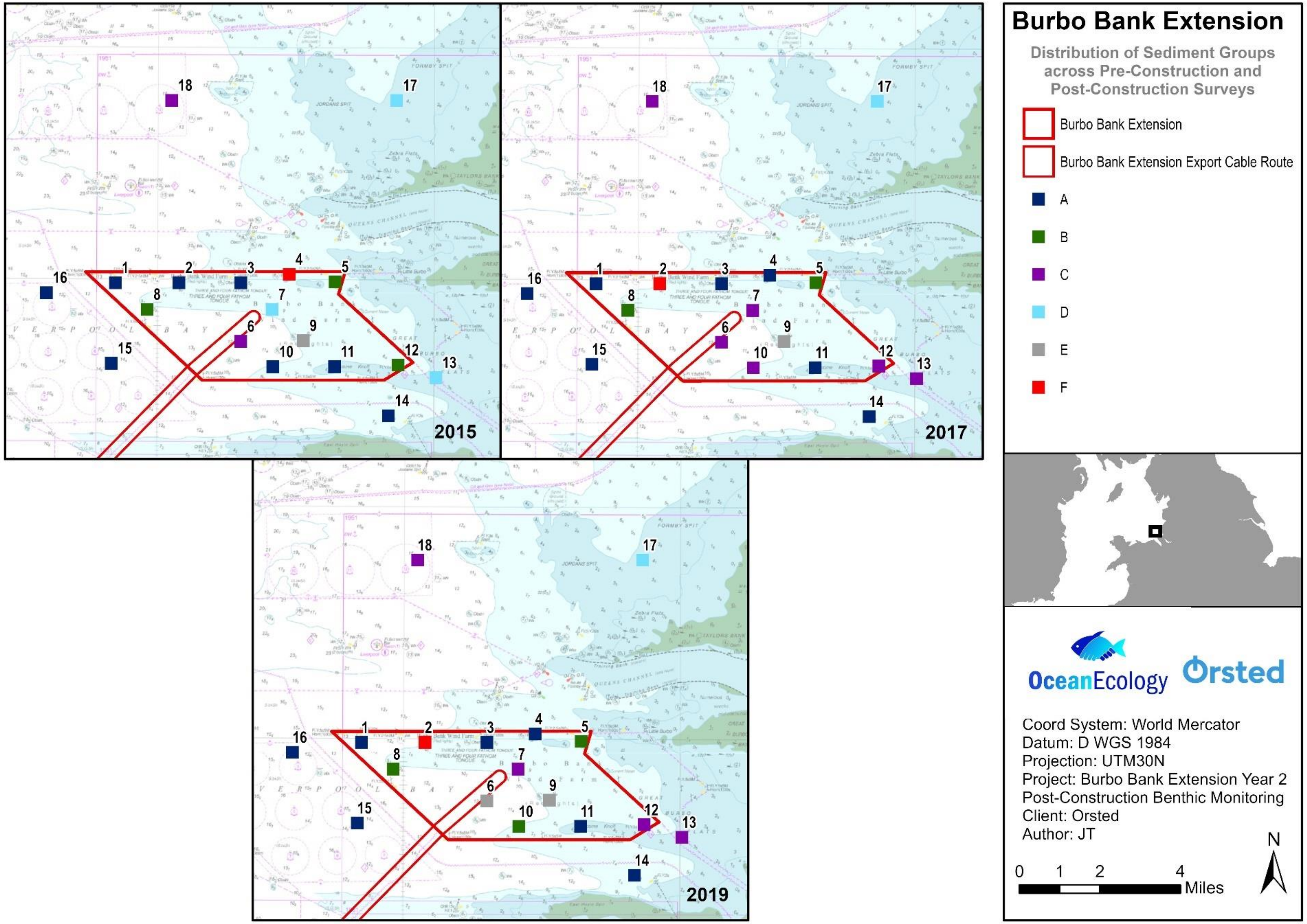


Figure 9. Distribution of sediment groups identified from samples acquired during the BBW02 2015 pre- and 2017 and 2019 post-construction benthic surveys.

4.1.4. Multivariate Comparisons of Sediments

4.1.4.1. Locational Differences (Year 2 Post-Construction Only)

A one-way ANOSIM was undertaken to determine whether differences existed between sediment data collected across the treatment areas during the year 2 post-construction survey. The resulting R statistic for the ANOSIM test (Table 8) (R = -0.012, P = 0.498) suggests there were no significant differences between sediments across treatment groups, due to the relatively homogeneous sediments across the survey area.

Table 8 ANOSIM results for Treatment areas for sediment data collected during the year 1 BBW02 post-construction benthic survey. Significant results (P≤0.05) are denoted by an asterisk.

Groups	R Statistic	Significance Level (P)
Global	-0.012	0.498
Wind Farm, Near-Field	-0.144	0.820
Wind Farm, Reference	0.108	0.222
Near-Field, Reference	-0.037	0.400

4.1.4.2. Construction Phase Differences (All Data)

The results of the ANOSIM test performed on the sediment data from each of the 18 stations sampled during the pre- and each of the post-construction surveys (Table 9) suggest that there were no significant differences in sediment composition between construction phases (R = -0.030, P = 0.775). The similarity in sediment composition between construction phase is evident in the overlap of the pre-construction (squares), year 1 post-construction (triangles), and year 2 post-construction (circles) sample points in Figure 10.

Table 9 ANOSIM results for comparison of sediment data collected during the BBW02 pre- and post-construction benthic surveys.

Groups	R Statistic	Significance Level (P)
Global	-0.030	0.775
Pre-Construction, Year 1	-0.004	0.453
Pre-Construction, Year 2	0.002	0.407
Year 1, Year 2	-0.086	0.997

4.1.4.3. Locational and Construction Phases (All Data)

The results of ANOSIM tests performed on all sediment data between treatment groups and across construction phases also identify no significant differences over time and between treatment areas (Table 10). The similarity in sediment composition between construction phase is evident in the overlap of the pre-construction (squares), year 1 post-construction (triangles), and year 2 post-construction (circles) sample points in Figure 10.

Table 10 One-way ANOSIM and pairwise test results per treatment and construction period for sediment data collected during the year 1 BBW02 pre- and post-construction benthic surveys.

Groups	R Statistic	Significance Level (P)
Global	-0.011	0.545
Pre-Construction Wind farm, Pre-Construction Near-Field	-0.092	0.604
Pre-Construction Wind farm, Pre-Construction Reference	0.084	0.299
Pre-Construction Wind farm, Year 1 Wind farm	0.008	0.347
Pre-Construction Wind farm, Year 1 Near-Field	-0.223	0.905
Pre-Construction Wind farm, Year 1 Reference	0.006	0.374
Pre-Construction Wind farm, Year 2 Wind farm	0.011	0.333
Pre-Construction Wind farm, Year 2 Near-Field	-0.125	0.677
Pre-Construction Wind farm, Year 2 Reference	0.091	0.275
Pre-Construction Near-Field, Pre-Construction Reference	0.037	0.200
Pre-Construction Near-Field, Year 1 Wind farm	0.176	0.154
Pre-Construction Near-Field, Year 1 Near-Field	-0.037	0.600
Pre-Construction Near-Field, Year 1 Reference	0.148	0.300
Pre-Construction Near-Field, Year 2 Wind farm	0.187	0.138
Pre-Construction Near-Field, Year 2 Near-Field	0	0.500
Pre-Construction Near-Field, Year 2 Reference	0.148	0.200
Pre-Construction Reference, Year 1 Wind farm	0.173	0.171
Pre-Construction Reference, Year 1 Near-Field	0.111	0.200
Pre-Construction Reference, Year 1 Reference	-0.296	0.800
Pre-Construction Reference, Year 2 Wind farm	0.182	0.130
Pre-Construction Reference, Year 2 Near-Field	0.074	0.400
Pre-Construction Reference, Year 2 Reference	-0.259	0.700
Year 1 Wind farm, Year 1 Near-Field	-0.192	0.958
Year 1 Wind farm, Year 1 Reference	0.048	0.332
Year 1 Wind farm, Year 2 Wind farm	-0.076	0.997
Year 1 Wind farm, Year 2 Near-Field	-0.149	0.851
Year 1 Wind farm, Year 2 Reference	0.127	0.178
Year 1 Near-Field, Year 1 Reference	0.037	0.300
Year 1 Near-Field, Year 2 Wind farm	-0.176	0.870
Year 1 Near-Field, Year 2 Near-Field	-0.148	0.500
Year 1 Near-Field, Year 2 Reference	0.037	0.300
Year 1 Reference, Year 2 Wind farm	0.059	0.334
Year 1 Reference, Year 2 Near-Field	0.037	0.200
Year 1 Reference, Year 2 Reference	-0.296	0.700
Year 2 Wind farm, Year 2 Near-Field	-0.124	0.719
Year 2 Wind farm, Year 2 Reference	0.113	0.189
Year 2 Near-Field, Year 2 Reference	-0.037	0.400

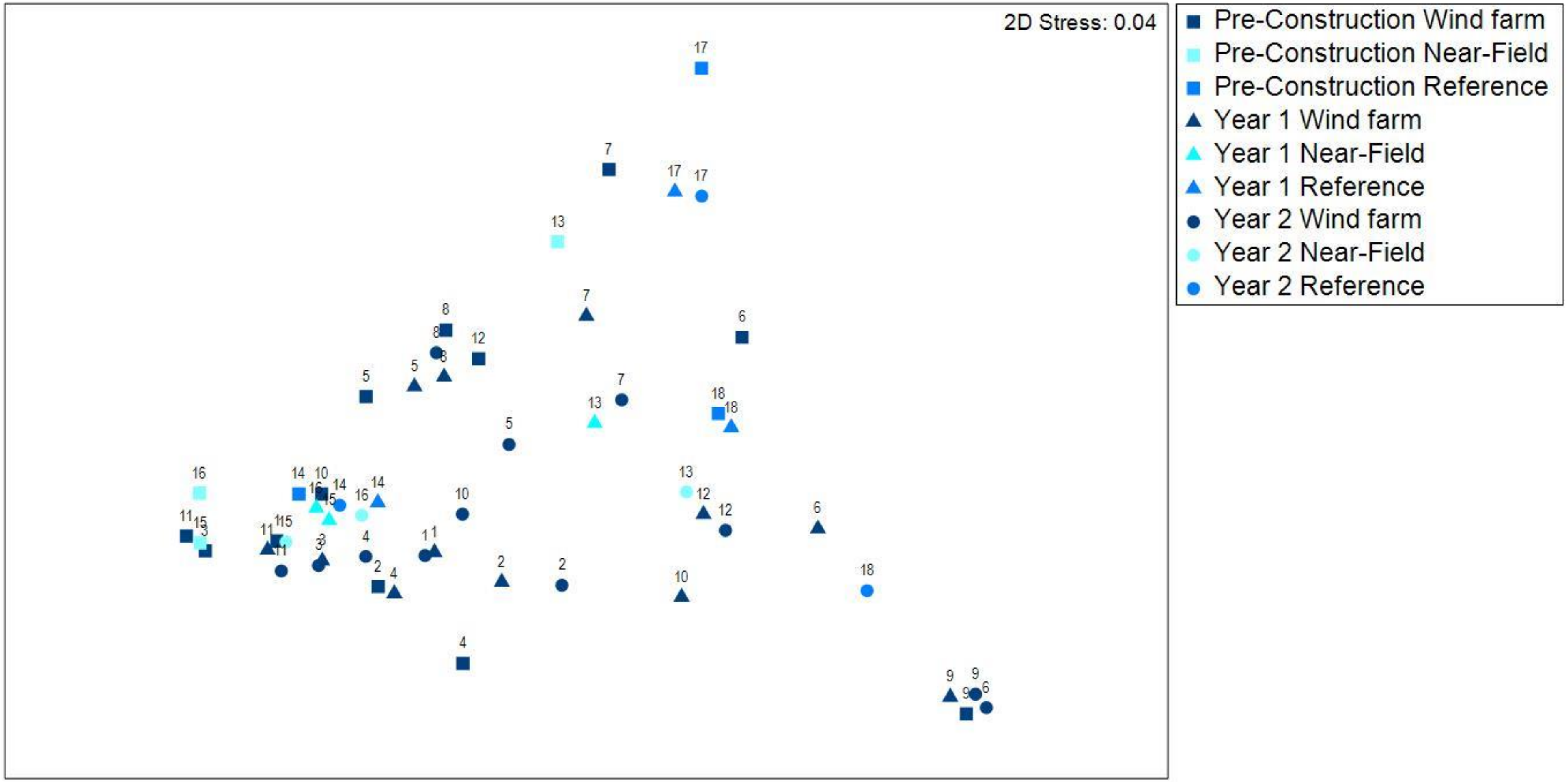


Figure 10. Non-metric MDS ordination plot of PSD data based on Euclidean distance weighting data from all stations taken across all treatments during the BBW02 pre- and post-construction benthic surveys.

4.2. Macrobenthic Infauna

4.2.1. Infaunal Composition (Year 2 Post-Construction Only)

The macrobenthic infaunal assemblage identified across the BBW02 survey area was relatively diverse with 111 taxa recorded and a mean (± SE) of 16.4 ± 1.32 taxa per sample. Mean (± SE) abundance per sample was 143.0 ± 36.8 with a mean (± SE) biomass per sample of 1.44 ± 0.47 gAFDW.

The full abundance matrix is provided in Appendix IX presenting the abundance of each taxon in all samples collected across the BBW02 survey area. The biomass (gAFDW) of each major taxonomic group (Annelida, Crustacea, Mollusca, Echinodermata and Others) in each sample collected is presented in Appendix X.

Figure 10 illustrates the relative contributions to total abundance (N), diversity (S) (i.e. the number of taxa) and biomass (B) of the major taxonomic groups in the infaunal community sampled across the three treatment areas during the year 2 post-construction survey.

Annelid taxa contributed most to N and accounted for 46.6 % of all individuals recorded (across all areas) with the highest % contribution recorded within the near field stations. Mollusc taxa were also prevalent and accounted for 37.3 % of all individuals. Mollusc taxa were more prevalent at reference and wind farm stations. Diversity (S) showed a similar pattern to abundance where annelid and mollusc taxa accounted for 34.6 and 33.7 % respectively of the total number of taxa identified across all areas.

Molluscs dominated the biomass and accounted for 67.5 % of the total biomass recorded across all areas with notably higher % contribution within the near field and reference areas. Crustaceans contributed the least to total abundance and biomass, but did contribute a relatively large % to diversity, particularly within the near field areas. Echinoderms showed a similar pattern, though they did contribute more to *N* and *S*, particularly in the reference stations. Other miscellaneous taxa contributed the least to overall *N*, *S* and *B*.

As shown in Figure 12a, the nut shell*, Nucula nitidosa*, was the most abundant taxon sampled accounting for 15.7 % of all individuals recorded. *N. nitidosa* also accounted for the greatest average density per sample (Figure 12d). Other key taxa included the cumacean *Diastylis bradyi,* which occurred in 60 % of sample stations (Figure 12b) and *K. bidentata* which accounted for the maximum abundance in a single sample (Figure 12c).
Example micrographs of key infaunal species sampled are presented in Plate 4.

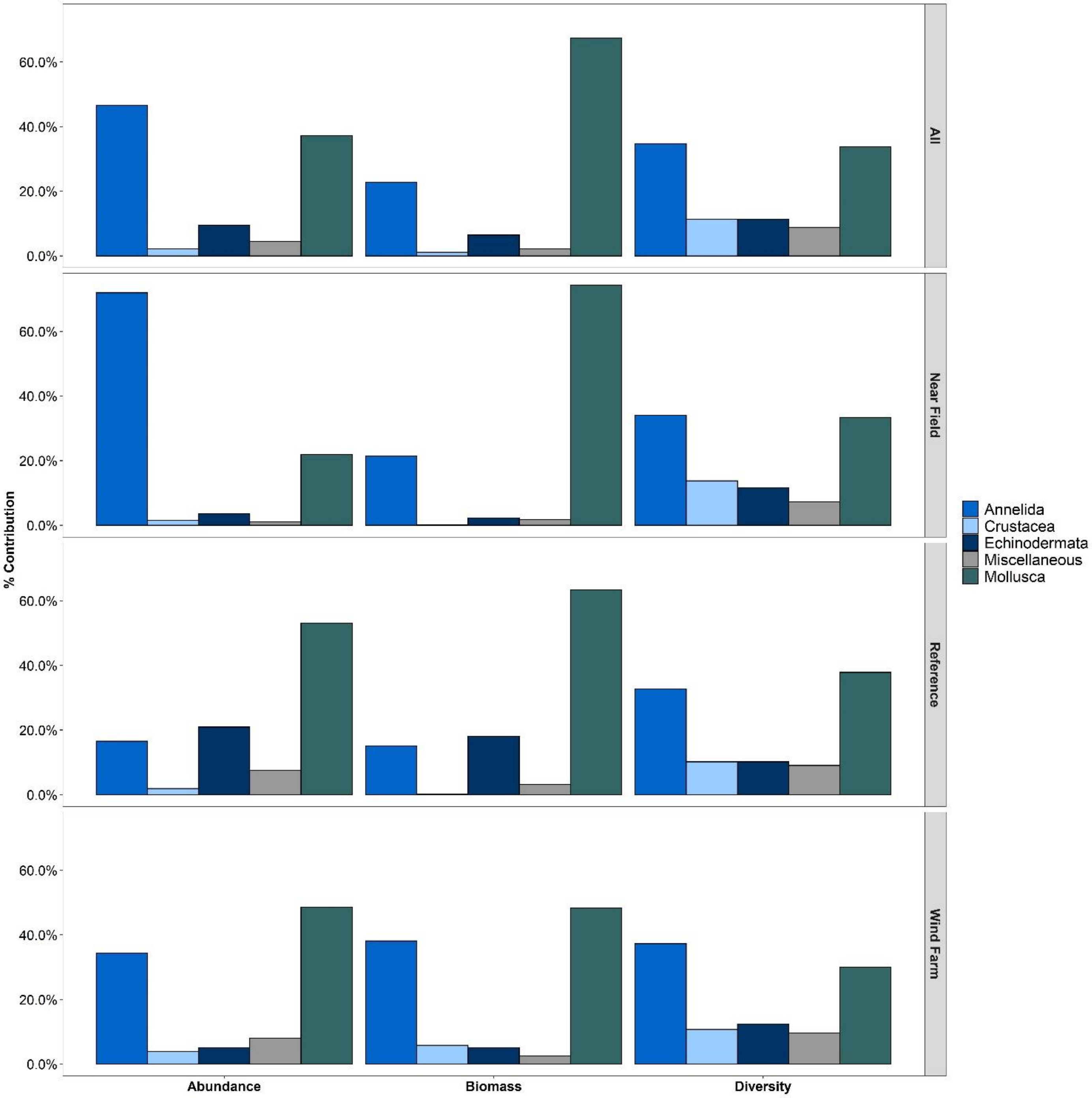


Figure 11. Relative contribution of the major taxonomic groups to the total abundance, diversity and biomass of the macrobenthic infauna sampled during the BBW02 year 2 post-construction benthic survey. Abundance counts exclude colonial taxa.

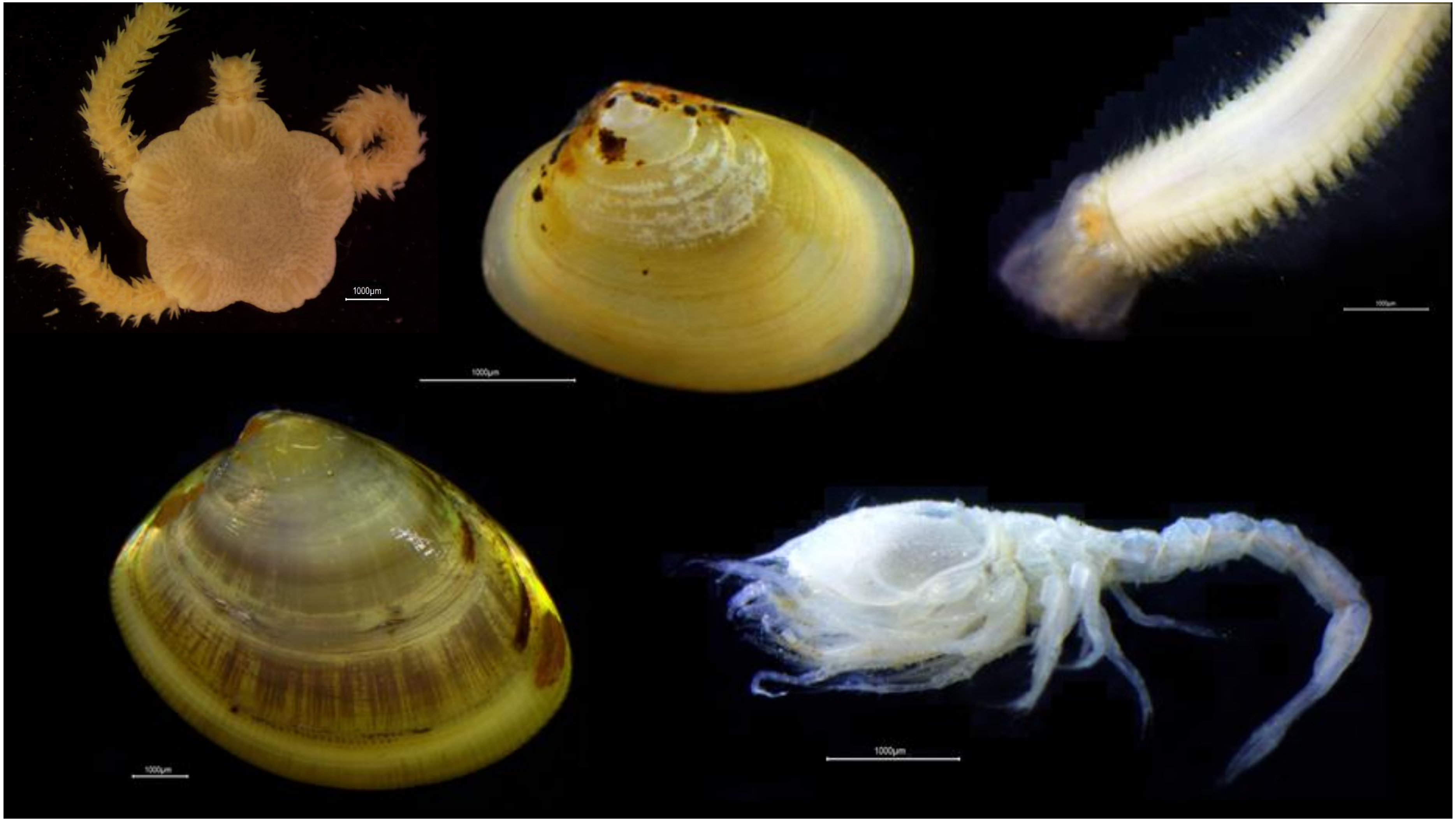


Plate 3 Example micrographs of key macrobenthic species sampled during the year 2 BBW02 post-construction survey. Top left: *Amphiura filiformis*. Top middle: *Kurtiella bidentata*. Top right: *Nephtys cirrosa*. Bottom left: *Nucula nitidosa* Bottom right: *Diastylis bradyi*. © Ocean Ecology Limited.

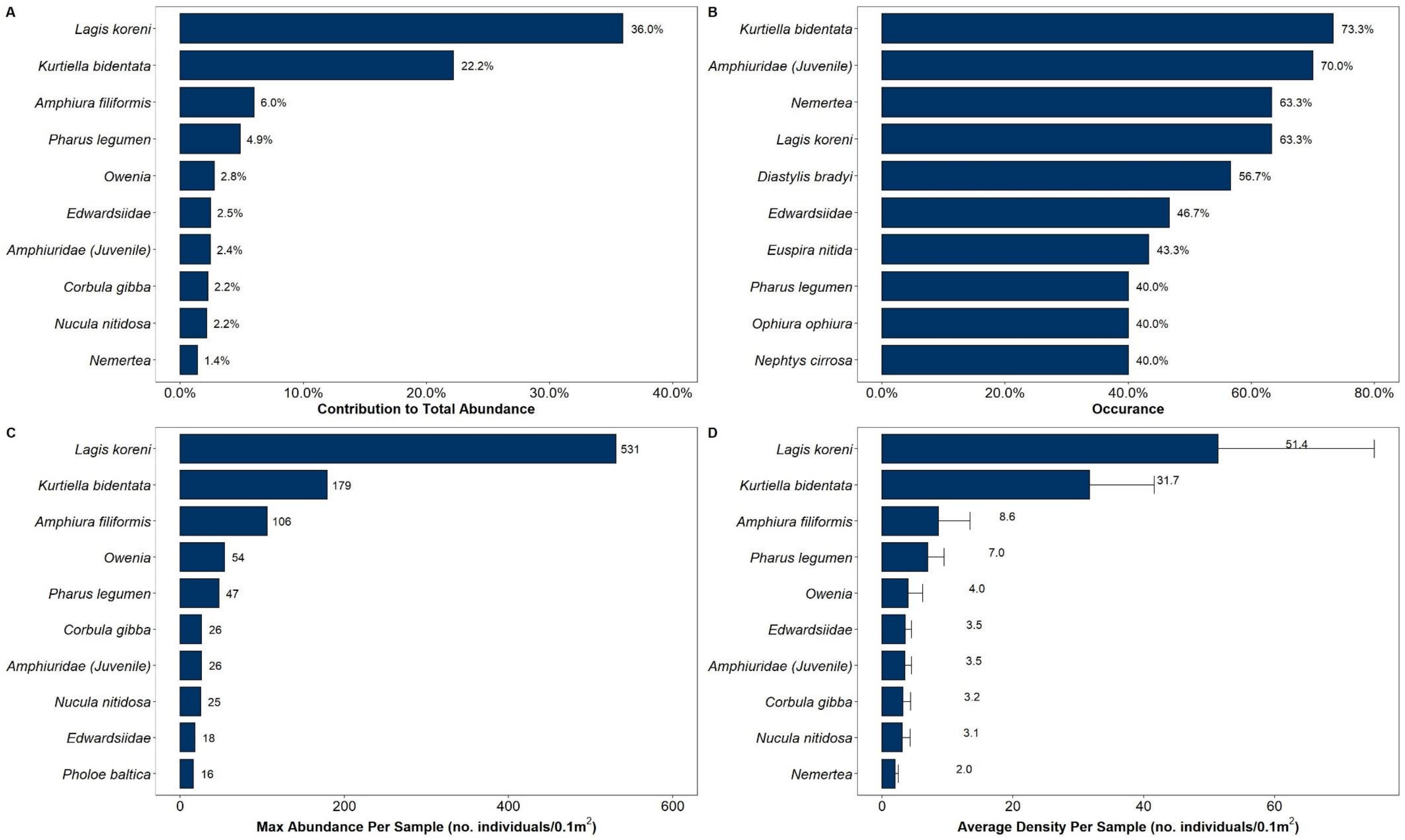


Figure 12. Percentage contributions of the top 10 taxa to total abundance (a) and occurrence (b) from samples collected during the BBW02 year 2 post-construction benthic survey. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

4.2.2. Macrobenthic Faunal Groupings

4.2.2.1. Determination of Macrobenthic Faunal Groups

Cluster analysis of square root transformed infaunal data was carried out using a resemblance matrix calculated using Bray-Curtis similarity to graphically represent the similarity of the infaunal communities recorded in each sample.

The resulting dendrogram and SIMPROF test permitted seven statistically significant faunal groups (shown by point colour) and five outliers based on the similarity of the species composition of the grouped samples. The corresponding non-metric multidimensional scaling (MDS) ordination plot (Figure 13), displayed in two-dimensions, graphically displays the similarity between the samples based on the distance between the sample points. The degree of clustering of intra-group sample points demonstrates the level of within group similarity whilst the degree of overlap of inter-group sample points is indicative of the level of similarity of the different faunal groups.

The stress value of the MDS ordination (0.18) indicates that the two-dimensional plot provides an acceptable representation of the similarity between the samples. The characteristic taxa within each of the faunal groups were determined by the results of the SIMPER routine which provide a level of percentage contribution (%Contrib) to the group similarity which is discussed for each faunal group below. Results of the SIMPER routine are provided in Appendix 12. The distribution of the faunal groups and outlier samples across the BBW02 survey area are shown in Figure 14.

4.2.2.2. Macrobenthic Faunal Groups

Faunal Group A was only observed in the pre-construction survey (six out of 10 Stations in 2015) and was dominated by *Lagis koreni*, *Phaxas pellucidus,* and *Pharus legumen* which contributed to 20.53, 12.16, and 6.92 % of the within-group similarity respectively. Stations that belonged to this faunal group comprised of a range of sediment types from Sandy Mud to Slightly Gravelly Sand.

Faunal Group B occurred at Stations 7 (wind farm) and 17 (reference) in both of the post-construction surveys as well as Station 13 (near-field) in the year 1 post-construction survey (all of which were characterised as Group A in the pre-construction survey). This faunal group was dominated by bivalves where *Fabulina fabula*, *K. bidentata*, and *Abra alba* contributed to 16.33, 10.49, and 7.33 % of within-group similarity respectively. **Faunal Group B** was typically associated with mainly sandy stations.

Faunal Group C was also only observed in the pre-construction survey and accounted for the remaining four stations. Faunal communities were dominated by Polychaetes, where *Nephtys cirrosa* and *Spiophanes bombyx* contributed 17.15 and 13.62 % of the within-group similarity, respectively. This faunal group was found at stations in the southern parts of the survey area which were characterised by sandy sediments.

Faunal Group D was observed at Stations 14, 15, and 16, located in the near field and reference areas in the year 1 post-construction survey. All these stations where characterised by **Faunal Group C** in the pre-construction survey and this group was also dominated by Polychaetes. *N. cirrosa*, *Nephtys* sp., and *S. bombyx* contributed 21.98, 13.29 and 9.54 % of the within-group similarity, respectively.

Faunal Group E accounted for Stations 11 (wind farm), 14 (reference), and 15 (near-field) in the year 2 post-construction survey and was also dominated by Polychaetes where *N. cirrosa* accounted for 17.72 % of within-group similarity. This group differed to groups C and D due to the presence of the cumacean *D. bradyi* which accounted for 17.72 % of within-group similarity.

Faunal Group F was relatively similar to **Faunal Group A** where communities were dominated by *L. koreni* and *P. legumen*, which contributed 22.03 and 19.05 % of the within-group similarity, respectively. This group was found at Stations 9 (wind farm) and 13 (near-field) in the year 2 post-construction survey, both of which were characterised as **Faunal Group A** in the pre-construction survey.

Faunal Group G was characterised by the bivalve, *K. bidentate* and the brittlestar, *Amphiura filiformis* which accounted for 16.06 and 14.11 % of the within-group similarity, respectively. This group was only observed at Station 18 in the reference area during both of the post-construction surveys.

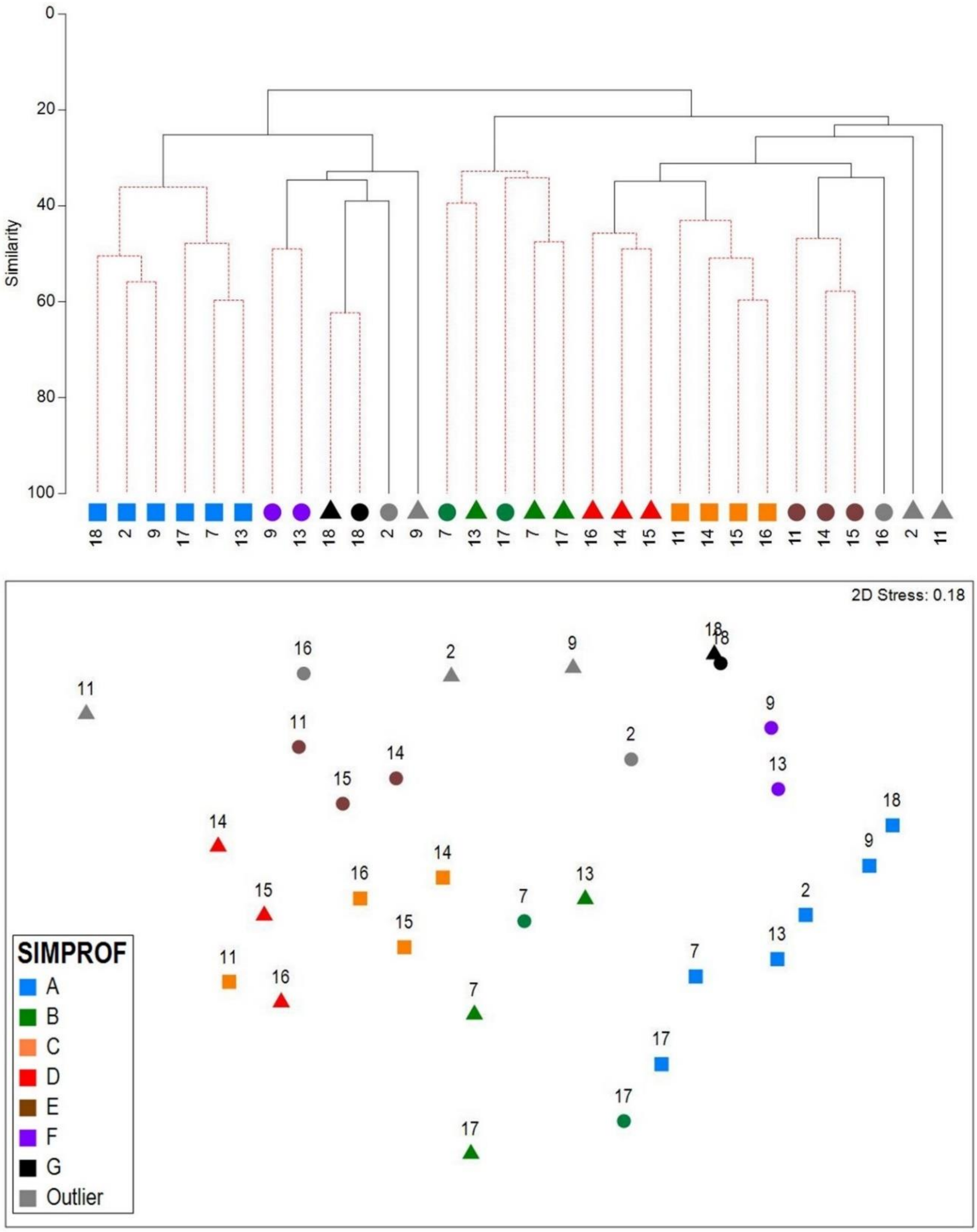
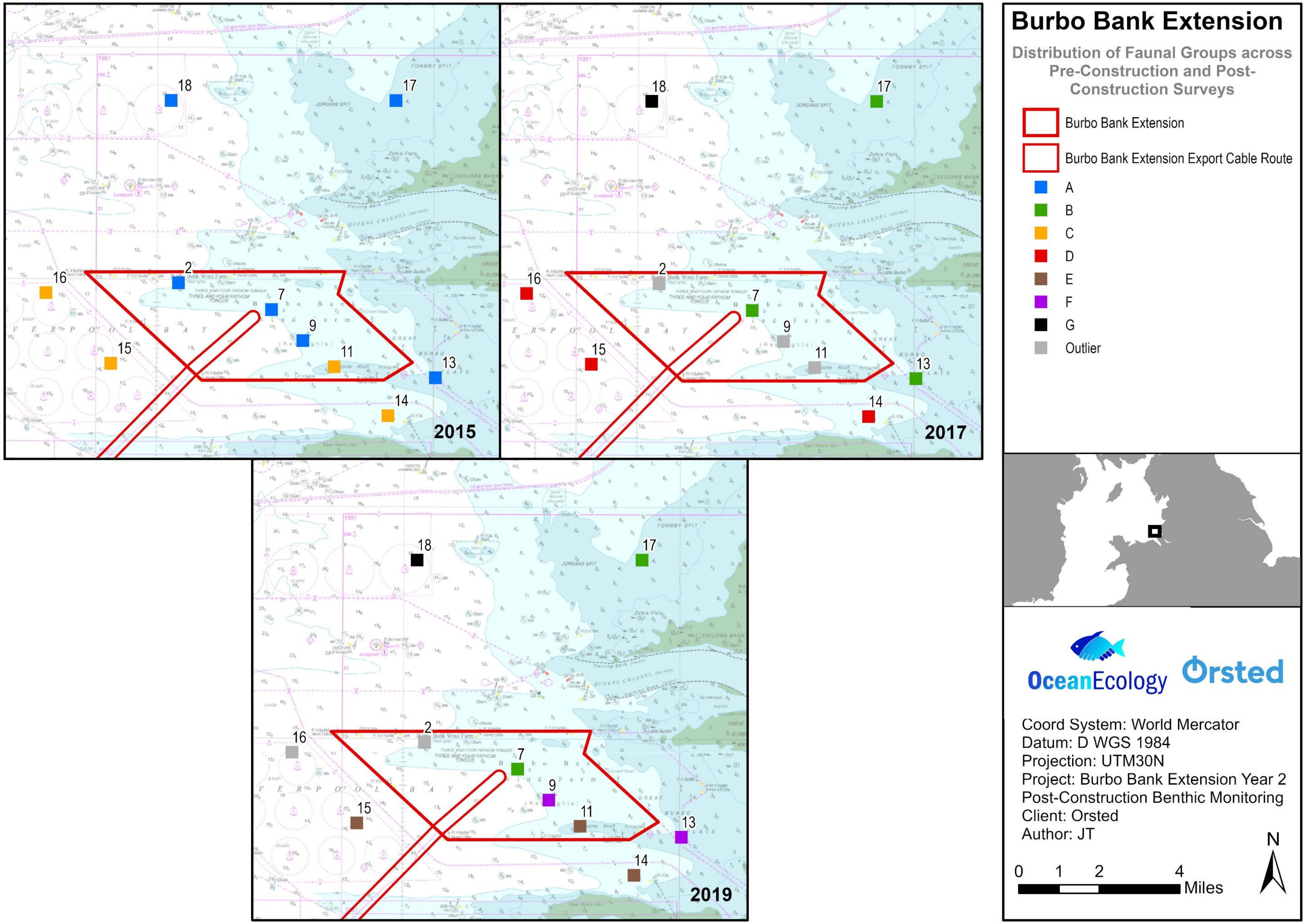


Figure 13. Dendrogram and corresponding MDS ordination plot of square-root transformed Bray-Curtis similarity macrobenthic infaunal abundance data from samples taken during the BBW02 pre-construction (squares), and year 1 (triangles) and year 2 (circles) post-construction benthic surveys. Faunal groups were separated by SIMPROF.



Burbo Bank Extension

Distribution of Faunal Groups across Pre-Construction and Post-Construction Surveys

Coord System: World Mercator
Datum: D WGS 1984
Projection: UTM30N
Project: Burbo Bank Extension Year 2 Post-Construction Benthic Monitoring
Client: Orsted
Author: JT

Figure 14. Distribution of faunal groups identified from samples acquired during the BBW02 2015 pre- and 2017 and 2019 post-construction benthic surveys.

4.2.3. Relationships between the Macrobenthic Communities and Abiotic Variables (Year 2 Post-Construction Only)

To investigate and statistically validate the correlations noted in the previous section between the infaunal communities and the abiotic variables (sediment composition and depth) the RELATE and BIOENV routines were employed in PRIMER v7.

The results presented in Table 11 demonstrated that the 250 µm size fraction (fine / medium sand) was the abiotic variable which best described the samples in a consistent manner with the multivariate patterns in the infaunal data as a single variable with a Rho value of 0.598. The best result was derived from a subset of five variables (highlighted in green) with a Rho value of 0.736. The Rho value remained the same if the number of variables was increased up to eight, however, more variables are indicative of a more complex relationship meaning a decreased similarity in the multivariate patterns between abiotic and infaunal data. The results are concurrent with the results of the year 1 post-construction survey and the large volume of literature that highlights sediment composition and depth as key factors in determining macrobenthic community composition and distribution (Ellingsen 2002, Cooper et al. 2011) particularly across other wind farm areas (BOWind 2008, EMU 2010, CMACS 2013b, Ocean Ecology Limited 2014, Ocean Ecology Limited 2016 and Natural Power 2015).

Table 11 BIOENV test results. Green denotes the subset of variables that best correlate with the ordination of the macrobenthic data sampled during the BBW02 year 2 post-construction benthic survey.

K	Best Variable Combinations	Rho
1	250 µm	0.598
2	354 µm, 250 µm	0.682
3	354 µm, 250 µm, 125 µm	0.725
4	354 µm, 250 µm, 125 µm, Depth	0.733
5	354 µm, 250 µm, 125 µm, 4 µm, Depth	0.736

4.2.4. Spatial Comparison of Macrobenthic Communities (All Years)

To determine whether the construction and operation of BBW02 has led to any significant changes in the macrobenthic communities within the survey area, a uni- and multivariate comparison of the pre-construction and years 1 and 2 post-construction infaunal datasets has been undertaken and presented below.

Figure 15 shows that infaunal mean abundance and biomass did show some station level variability across the pre – and post-construction surveys. Relatively large decreases in abundance averaged per station were observed in year 1 and year 2 post-construction in comparison to pre-construction, particularly at stations 2, 7, 9, 13, 17, and 18. However, Station 1 did show a large increase in N in the year 2 post-construction survey. A two-way ANOVA test identified that abundance differed significantly between years (Table 12) where infaunal abundance was significantly higher in 2015 than in 2017 or 2019 (Appendix XI). Treatment (wind farm, near field, or reference) had no significant effect.

Biomass varied between stations (Figure 15) but to a lesser extent. A relatively large increase in biomass was apparent at Station 13 during the year 2 post-construction period. This is likely due to the occurrence of a relatively high number of larger molluscs, for example, *K. bidentata* and *P. legumen*. Relatively large decreases in biomass at Stations 7, 9, 17 and 18 were observed for the year 1, and to a lesser extent year 2, post-construction period which was attributable to the absence of the large individuals of the sea potato, *Echinocardium cordatum* and *A. echinata*. Overall, biomass did change significantly between survey years (Table 12) where biomass was lowest in 2017. Pre-construction biomass levels were not significantly different from year 2 post-construction levels (Appendix XI).

Species diversity (S) was less variable at each station across survey years (Figure 15). Station 2 showed the greatest change, where there was a large reduction in S between pre- and post-construction surveys. Overall, there was a significant difference in S between survey years (Table 12), however, only pre-construction and year 1 post-construction S differed significantly, where diversity appeared to increase between year 1 and year 2 post-construction surveys. Figures 17 - 19 show the distribution of *N*, *S* and *B* across the BBW02 survey area during pre- and post-construction periods. However, as with the other metrics, treatment area had no significant effect on levels of diversity across the survey area.

Figure 16 illustrates the relative contributions to total abundance (*N*), diversity (*S*) (i.e. the number of taxa) and biomass (*B*) of the major taxonomic groups in the macrobenthic infaunal community sampled across the three treatment areas during pre-construction and years 1 and 2 post-construction surveys. There was a notable increase in the % contribution of crustaceans to total abundances recorded between the construction periods, which was largely accountable to the increase in *D. bradyi.* This increase in % contribution over time was most pronounced within the wind farm and near field areas but was, to a lesser extent, observed in the reference area. In contrast, a decrease in % contribution of annelids (mainly *L. koreni*) to *N* was observed across all three treatment areas between the construction periods with the most pronounced change observed within the wind farm area. The % contribution of echinoderms and ‘other’ taxa across all treatment areas showed a small increase in *N* between the construction periods. The % contribution to *N* of molluscs remained relatively stable within the near-field stations but an increase was observed within the wind farm and reference areas between construction periods.

The % contribution of annelids to total abundance showed a decrease in the year 1 post-construction survey compared to the pre-construction survey though this did increase in the year 2 post-construction survey, particularly at the near field stations. The % contribution of molluscs to abundance, and therefore biomass, has increased post-construction, particularly in the reference area stations in the year 2 post-construction survey. The % contributions of each taxon group to *S* between the pre-construction and post-construction periods did show some variation but remained largely similar between treatment areas over time.

Within the wind farm, biomass results in the year 2 post-construction survey were similar to pre-construction levels, with slightly greater amounts of crustaceans and less echinoderms. Within the near-field area, molluscs showed a decrease in % contribution to *B* when compared to the year 1 post-construction surveys, however there was an increase in annelids and echinoderms meaning that biomass patterns were similar to those observed in the pre-construction survey. The % contribution of each of the taxa groups to *B* in the reference area for the year 2 post-construction survey was also similar to the pre-construction survey. However, the % contribution of crustaceans has reduced.

Table 12. Two-way ANOVA results for abundance, diversity, and biomass by year (2015, 2017, and 2019) and treatment (wind farm, near field, and reference areas). Bold indicates a significant result. Pairwise comparisons can be found in Appendix XI.

		Df	F Value	P value
Abundance	Year	2	10.583	**<0.001**
	Treatment	2	1.972	0.146
	Year * Treatment	4	0.678	0.609
	Residuals	81	-	-
Diversity	Year	2	6.969	**0.001**
	Treatment	2	3.948	0.023
	Year * Treatment	4	0.595	0.668
	Residuals	81	-	-
Biomass	Year	2	5.264	**0.007**
	Treatment	2	0.508	0.603
	Year * Treatment	4	3.224	0.017
	Residuals	81	-	-

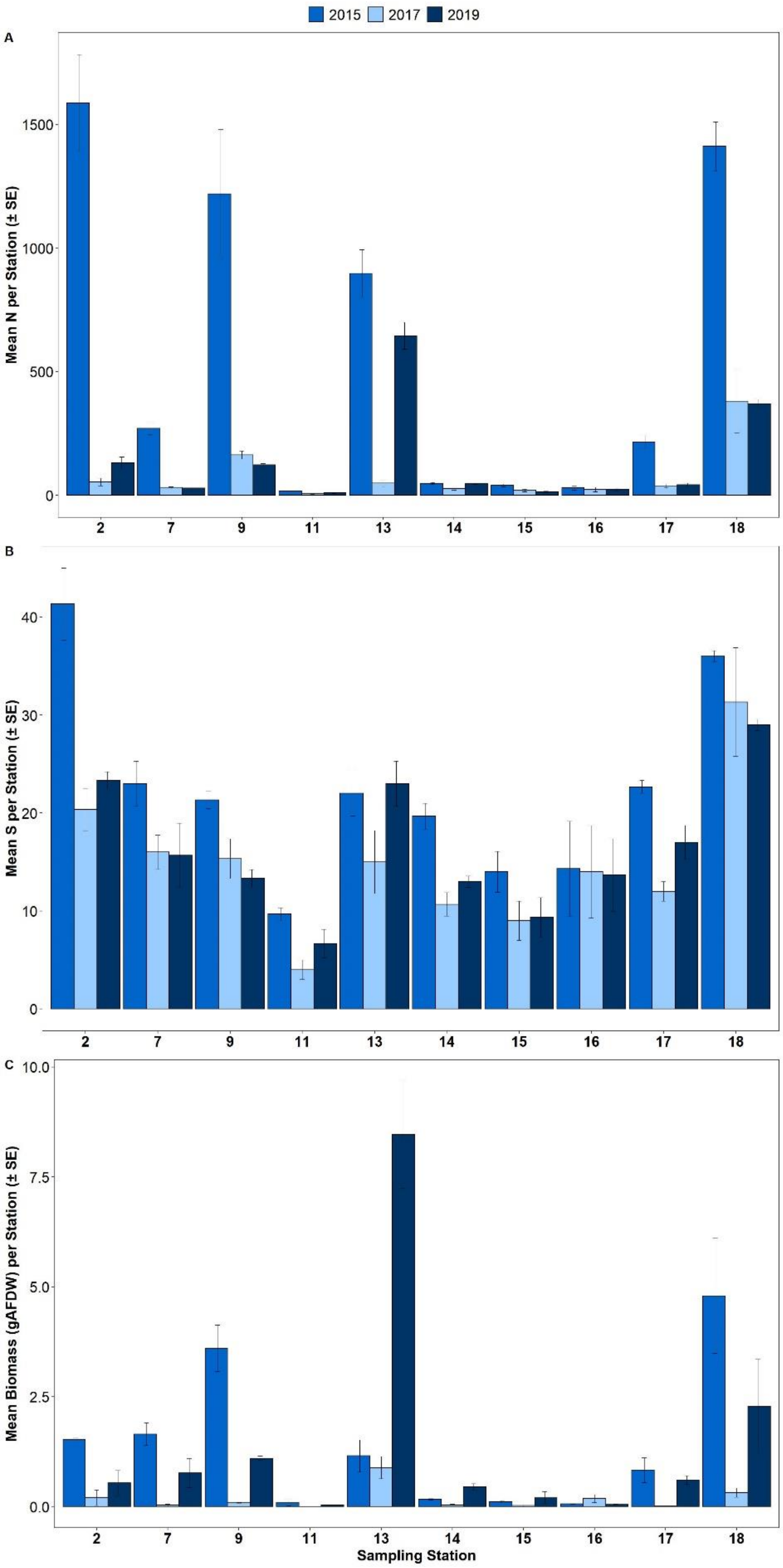


Figure 15. (A) Mean ± SE *N* per station of infauna sampled across the BBW02 survey area during pre- and post-construction surveys. (B) Mean ± SE *S* per station of infauna sampled across the BBW02 survey area during pre- and post-construction surveys. (C) Mean ± SE Biomass per station (gAFDW) of macrobenthic infauna sampled across the BBW02 survey area during pre- and post-construction surveys.

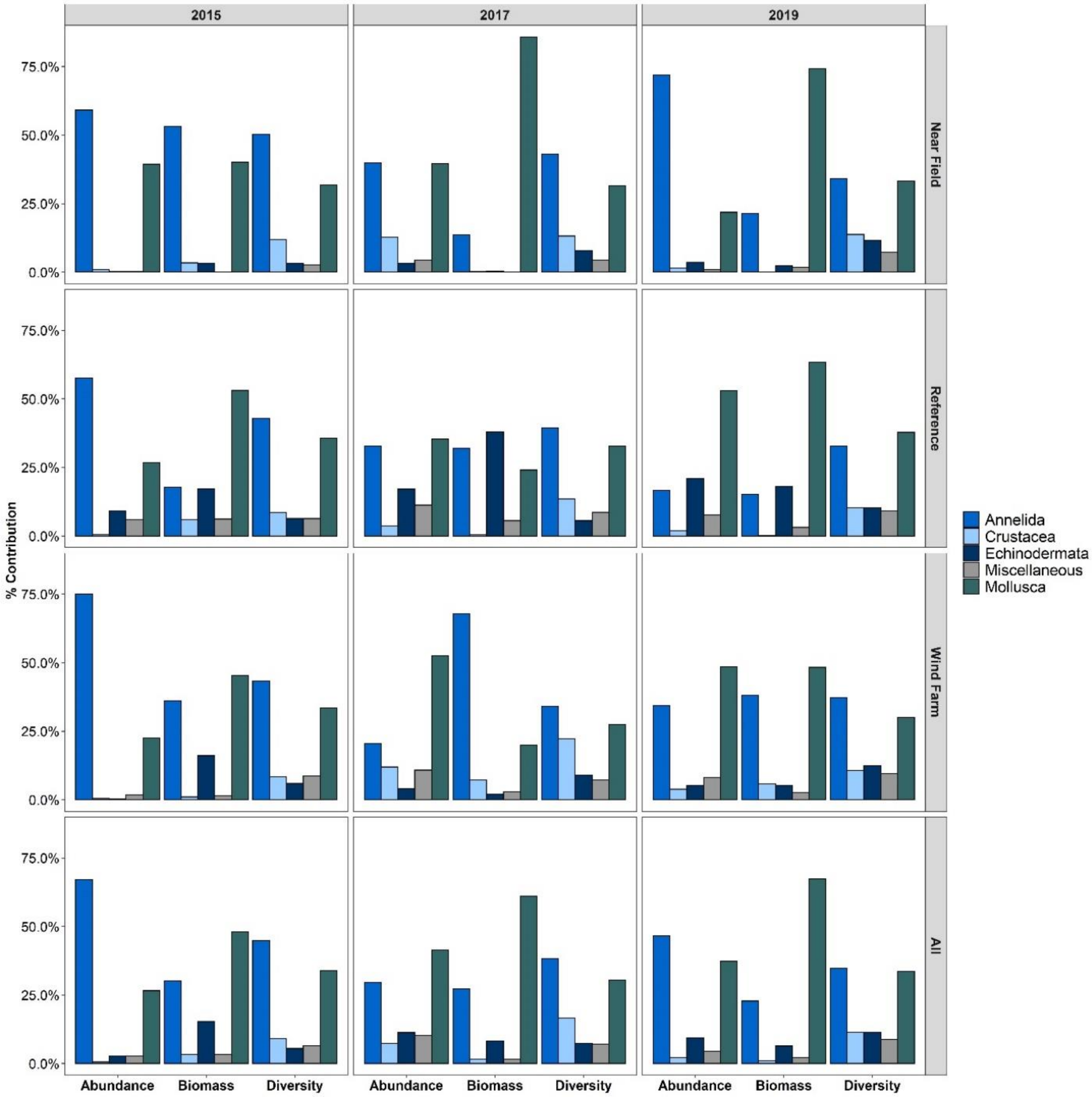


Figure 16. Relative contribution of the major taxonomic groups to *N*, *S* and *B* of infauna sampled during the BBW02 pre- and post-construction benthic surveys. Abundance counts exclude colonial taxa.

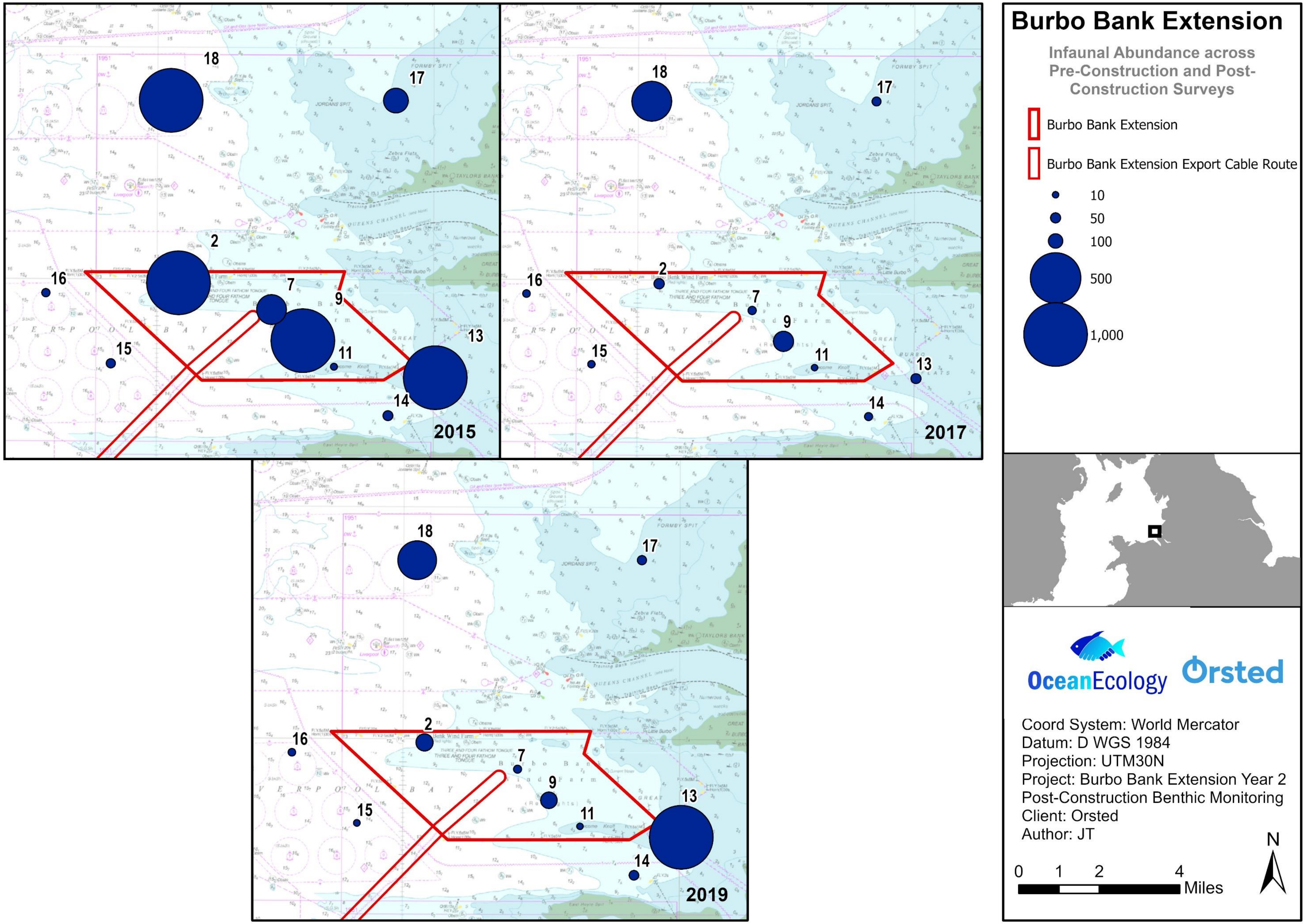


Figure 17. Comparison of infaunal mean abundance per station sampled across the BBW02 survey area during the 2015 pre- and 2017 and 2019 post-construction surveys.

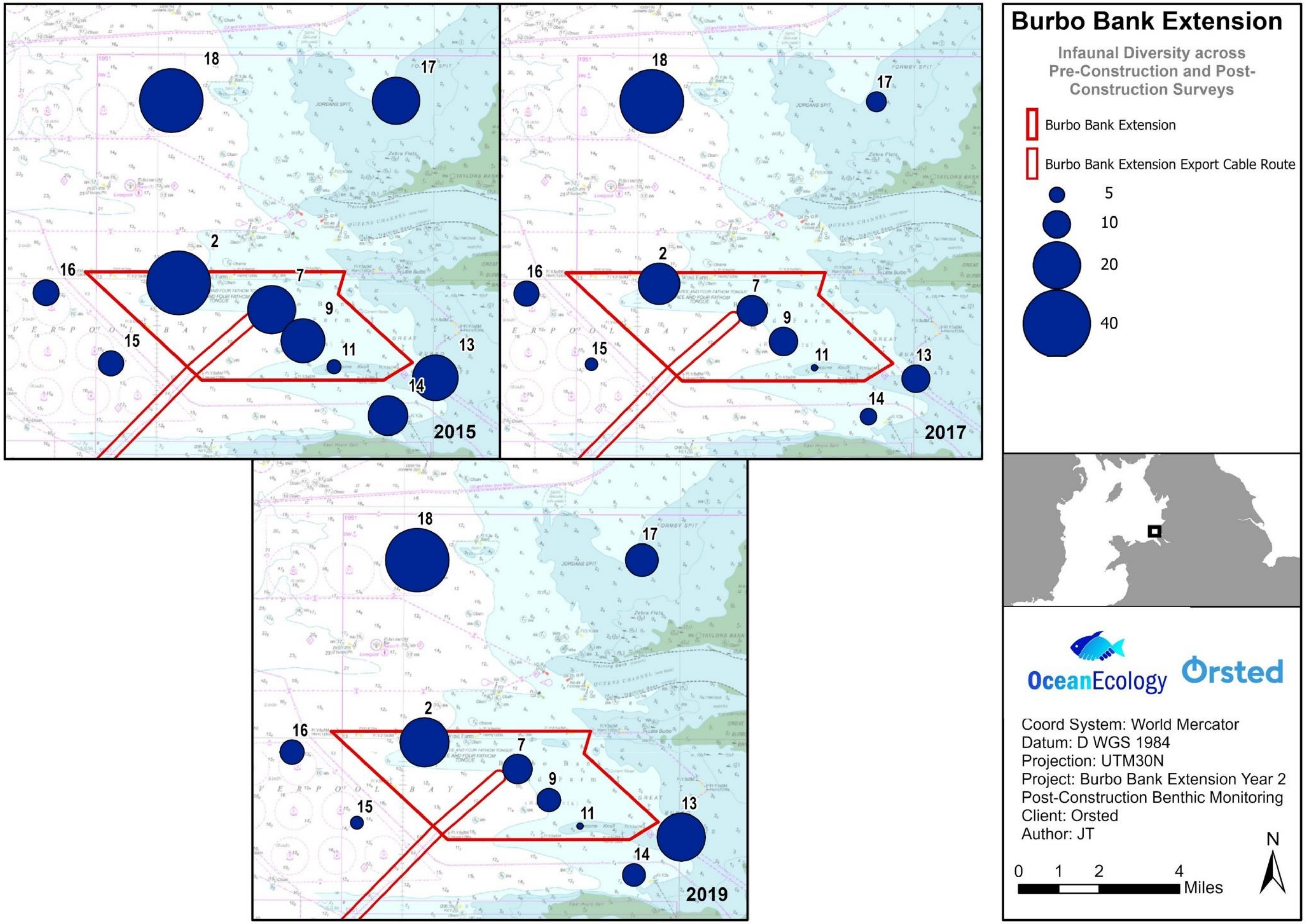


Figure 18. Comparison of infaunal mean diversity per station sampled across the BBW02 survey area during the 2015 pre- and 2017 and 2019 post-construction surveys.

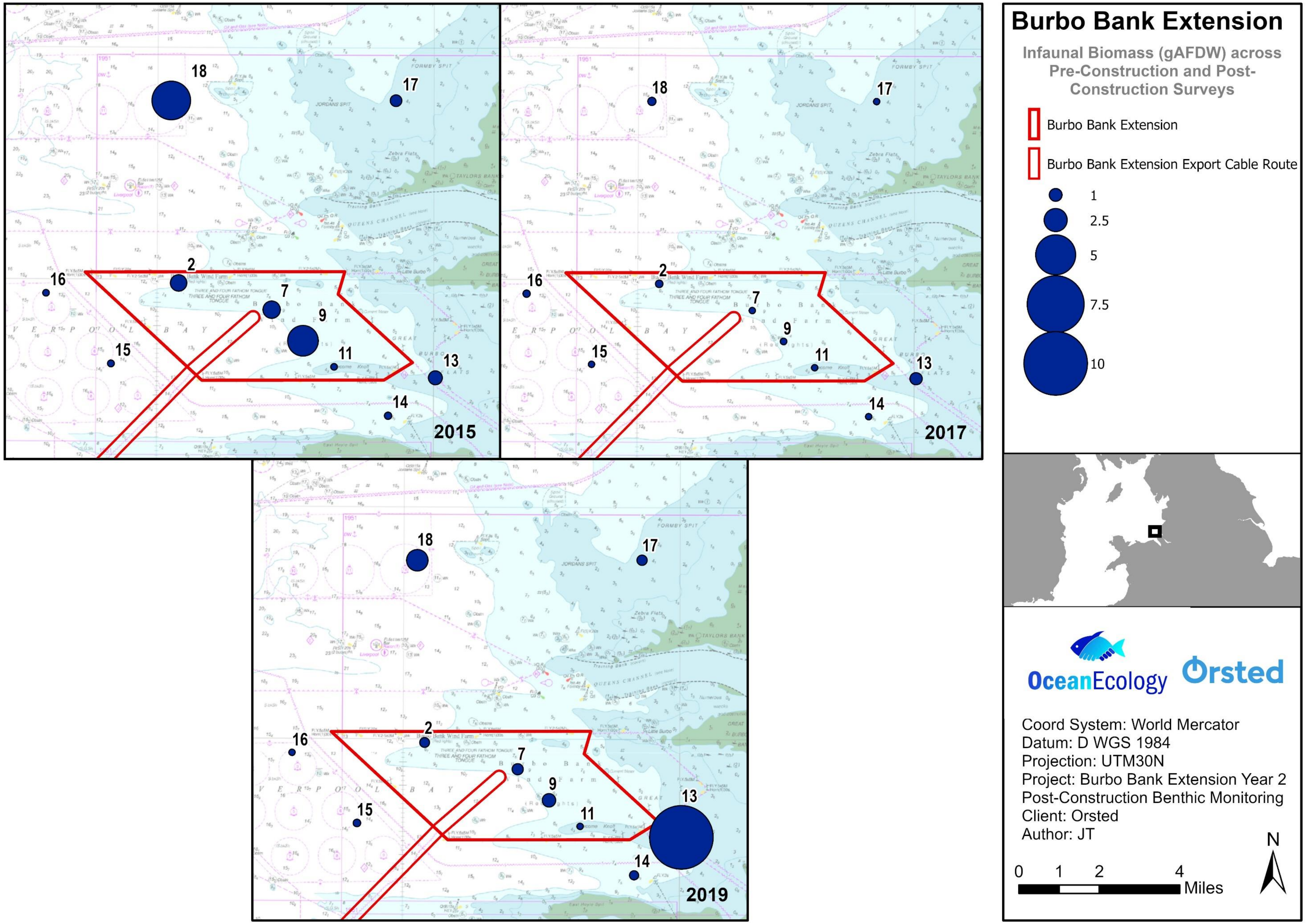


Figure 19. Comparison of infaunal mean biomass (gAFDW) per station sampled across the BBW02 survey area during the 2015 pre- and 2017 and 2019 post-construction surveys.

4.2.5. Multivariate Comparisons of Macrobenthos

4.2.5.1. Locational Differences (Year 2 Post-Construction Only)

A one-way ANOSIM was employed to determine whether differences existed between infaunal data collected across the treatment areas during the year 2 post-construction survey (Table 13). Whilst not statistically significant, the results suggest there was a high level of similarity between infaunal communities across treatment groups (R = -0.29, P = 0.976).

Table 13 ANOSIM results per treatment area for macrobenthic infaunal abundance data collected during the Year 1 BBW02 post-construction benthic survey.

Groups	R Statistic	Significance Level (P)
Global	-0.293	0.976
Wind Farm, Near-Field	-0.185	0.771
Wind Farm, Reference	-0.407	1.000
Near-Field, Reference	-0.407	1.000

4.2.5.2. Construction Period Differences (All data)

The results of the ANOSIM test (Table 14) performed on the infaunal data from each of the ten stations sampled during the pre- and post-construction surveys suggested that there were no significant differences in the infaunal communities between construction phases (R = 0.131, P = 0.112). This is illustrated by the overlap of the pre-construction (squares), year 1 post-construction (triangles), and year 2 post-construction (circles) sample points in Figure 20.

Table 14 ANOSIM results per construction period for macrobenthic infaunal abundance data collected during the BBW02 pre- and post-construction benthic surveys.

Groups	R Statistic	Significance Level (P)
Global	0.131	0.112
Pre-Construction, Year 1	0.127	0.194
Pre-Construction, Year 2	0.262	0.053
Year 1, Year 2	0.029	0.434

4.2.5.3. Locational & Construction Phases (All data)

The MDS ordination plot (Figure 20) illustrates the similarity of the infaunal communities sampled across each of the treatment areas during the pre- and post-construction surveys. The plot shows that while there has been some change at each of the stations across surveys most stations remain reletively clustered, regardless of survey year. Stations 11, 13 and 16 appeared to show the greatest degree of change illustrated by the trajectory lines. Although there were some changes in the infaunal communities between the pre-construction and post-construction surveys, the results of the ANOSIM ($R = 0.049$, $P=0.276$) performed on the treatment area datasets sampled suggest no significant differences occurred between the surveys. Furthermore, no significant differences were detected by further pairwise tests comparing treatment area and construction period also (Table 15).

The results of the SIMPER analysis show that the dissimilarity within the wind farm area between pre-construction and year 1 and year 2 post-construction surveys was mainly attributable to a decrease in *L. koreni*. Changes were also attributable to decreases in *P. pellucidus* and *A. alba.* Within the near field area, dissimilarity was again mainly attributable to a decrease in *L. koreni* and *P. pellucidus* between the pre-construction and post-construction surveys. A decrease in the spionid, *S. bombyx,* was also attributable to the changes observed between the pre-construction and both post-construction surveys. As within the wind farm and near field areas, dissimilarity within the reference area was mainly attributable to a decrease in *L. koreni* between pre-construction and post-construction surveys. Dissimilarity within the reference area was also attributable to decreases in *K. bidentata* and the polychaete *Magelona johnstoni.*

Table 15 One-way ANOSIM and pairwise test results per construction period and treatment for macrobenthic infaunal abundance data collected during the BBW02 pre- and post-construction benthic surveys.

Groups	R Statistic	Significance Level (P)
Global	0.049	0.276
Pre-Construction Wind Farm, Year 1 Wind Farm	0.281	0.143
Pre-Construction Wind Farm, Year 2 Wind Farm	0.385	0.086
Pre-Construction Wind Farm, Pre-Construction Near Field	-0.13	0.686
Pre-Construction Wind Farm, Pre-Construction Reference	-0.241	0.829
Pre-Construction Wind Farm, Year 1 Near Field	0.333	0.143
Pre-Construction Wind Farm, Year 1 Reference	0.389	0.114
Pre-Construction Wind Farm, Year 2 Near Field	0.241	0.171
Pre-Construction Wind Farm, Year 2 Reference	0.315	0.171
Year 1 Wind Farm, Year 2 Wind Farm	-0.031	0.629
Year 1 Wind Farm, Pre-Construction Near Field	0.093	0.371
Year 1 Wind Farm, Pre-Construction Reference	0.056	0.371
Year 1 Wind Farm, Year 1 Near Field	-0.315	0.943
Year 1 Wind Farm, Year 1 Reference	-0.352	0.971
Year 1 Wind Farm, Year 2 Near Field	-0.222	0.943
Year 1 Wind Farm, Year 2 Reference	-0.111	0.714
Year 2 Wind Farm, Pre-Construction Near Field	0.222	0.171
Year 2 Wind Farm, Pre-Construction Reference	0.241	0.229
Year 2 Wind Farm, Year 1 Near Field	0.222	0.229
Year 2 Wind Farm, Year 1 Reference	0.37	0.086
Year 2 Wind Farm, Year 2 Near Field	-0.185	0.771
Year 2 Wind Farm, Year 2 Reference	-0.407	1
Pre-Construction Near Field, Pre-Construction Reference	-0.259	1
Pre-Construction Near Field, Year 1 Near Field	0	0.5
Pre-Construction Near Field, Year 1 Reference	0.074	0.4
Pre-Construction Near Field, Year 2 Near Field	0.222	0.5
Pre-Construction Near Field, Year 2 Reference	0.148	0.2
Pre-Construction Reference, Year 1 Near Field	0.111	0.3
Pre-Construction Reference, Year 1 Reference	-0.074	0.5
Pre-Construction Reference, Year 2 Near Field	0.074	0.4
Pre-Construction Reference, Year 2 Reference	0.037	0.6
Year 1 Near Field, Year 1 Reference	-0.222	0.9
Year 1 Near Field, Year 2 Near Field	0.074	0.5
Year 1 Near Field, Year 2 Reference	0.148	0.2
Year 1 Reference, Year 2 Near Field	0.185	0.4
Year 1 Reference, Year 2 Reference	0.111	0.5
Year 2 Near Field, Year 2 Reference	-0.407	1

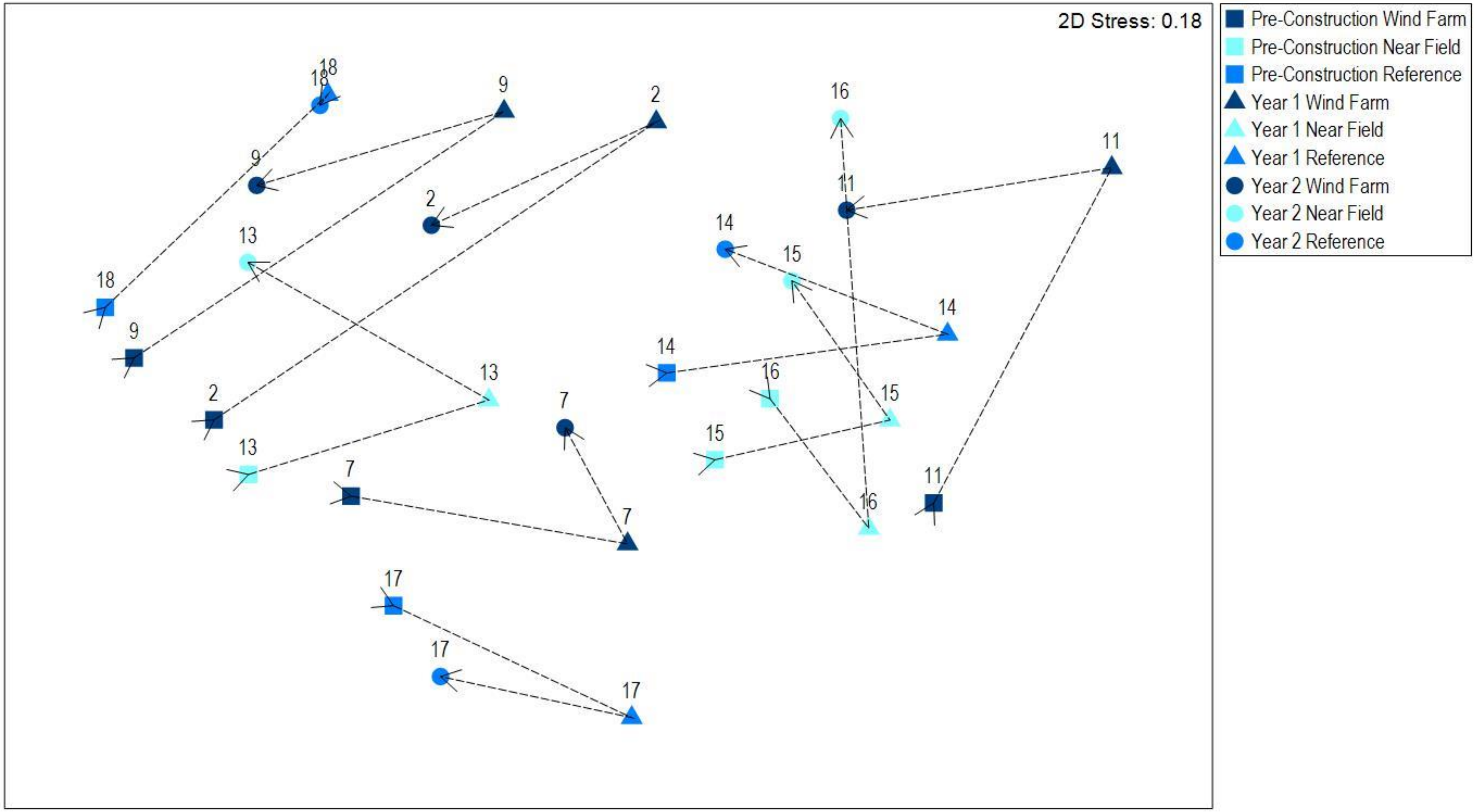


Figure 20. Non-metric MDS ordination plot of the square-root transformed Bray-Curtis similarity infaunal abundance data from stations across all treatment areas during the BBW02 pre- and post-construction benthic surveys. Trajectory lines show change from pre-construction, to year 1, to year 2 post-construction surveys.

4.3. Year 1 Post-Construction Seabed Imagery

4.3.1. Wind Farm, Near-Field and Reference Areas

The seabed imagery collected across the BBW02 survey area during the year 2 post-construction survey was representative of that collected during the pre-construction and year 1 post-construction surveys and further demonstrated the sediment sampled during the benthic grab sampling. The sediment noted in the imagery across the survey area ranged from sandy muds to coarse sediments (visible in Plate 4). Due to an absence of any substantial hard substrate, there was little to no sessile fauna (e.g. hydroid/bryozoan faunal turf) and visible mobile fauna (e.g. decapods and echinoderms) was generally limited to brittlestars (*Ophiura* sp.).

Other infrequently occurring taxa included starfish, Asteroidea and hermit crabs, Paguridae. Within the video footage, the common starfish, *A. rubens* was also noted relatively frequently along with single individuals of the dragonet, *Callionymus* sp. and the lesser-spotted catshark, *Scyliorhinus canicula*. In general, the habitat was relatively devoid of visible epifauna as observed during previous surveys.

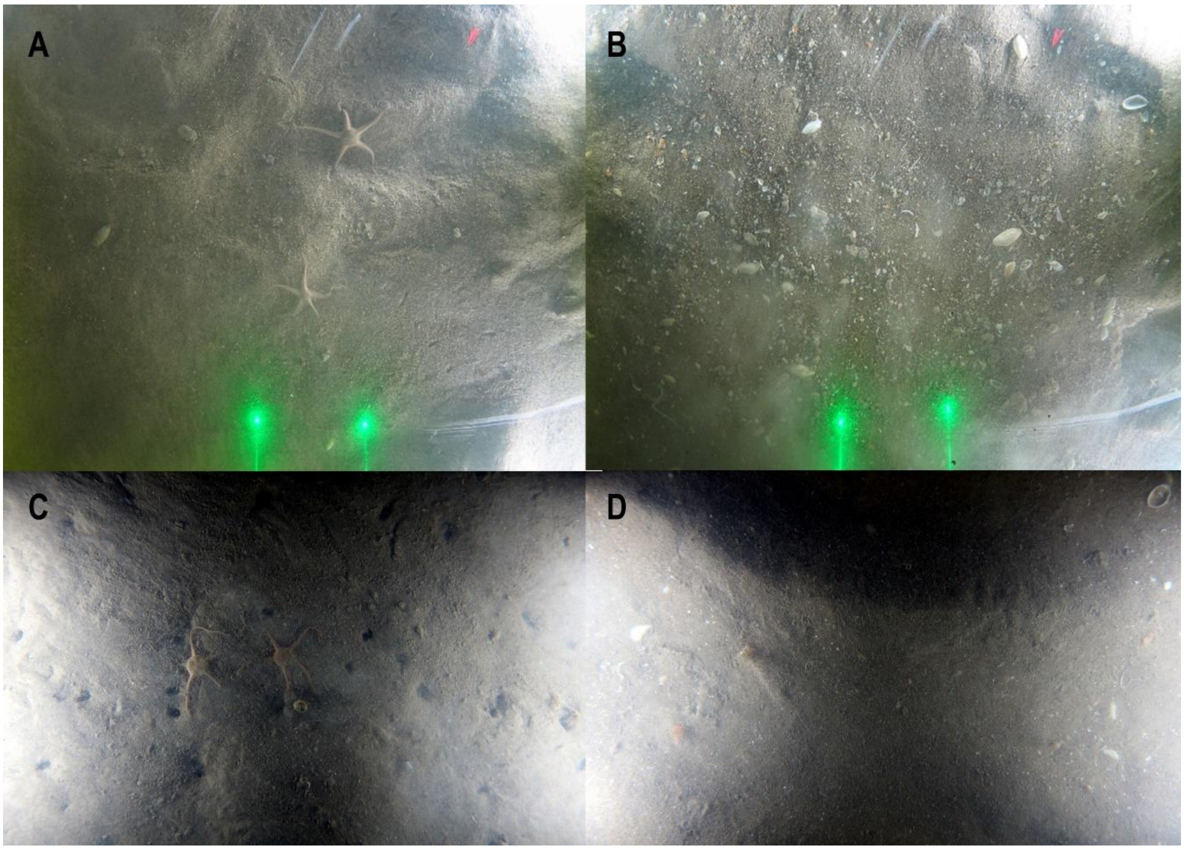


Plate 5. Example seabed imagery collected during the BBW02 year 1 and year 2 post-construction benthic surveys. (A) Brittle stars (Ophiuroidea) at Station 11 during the BBW02 year 1 post-construction benthic survey; (B) Gravelly sand found at Station 19 during the BBW02 year 1 post-construction benthic survey; (C) Brittle stars (Ophiuroidea) at Station 2 during the BBW02 year 2 post-construction benthic survey and; (D) Gravelly sand found at Station 19 during the BBW02 year 2 post-construction benthic survey.

4.3.2. Export Cable Route - Annex I 'Stony Reef' Transects

Analysis of the seabed imagery collected along the four targeted transects during the year 2 post-construction benthic survey showed that a variety of muddy sand and coarse sediment habitats were present within the BBW02 ECR corridor. Areas classified as Annex I 'stony reef' in line with the criteria set out in Section 3.4.1 were recorded along all transects.

In general, the seabed imagery was consistent with that observed during the pre-construction survey (CMACS 2015c) and year 1 post-construction survey (Ocean Ecology Limited 2018) with rocky habitats found along each transect. The rocky habitats were generally considered to be representative of low resemblance Annex I ‘stony reef’ with medium resemblance reef recorded in just a few still images. It was also noted that the rocky habitats representative of Annex I ‘stony reef’ were patchy in nature and were interspersed with areas of coarse sediments or sands and muddy sands akin to the rest of the survey. Cobbles and pebbles often appeared to be partially buried by finer sediments. Observed epibiotal communities were relatively sparse as noted during the previous monitoring surveys suggesting the hard substrate is likely to be subject to regular cycles of smothering, potentially preventing colonisation during periods of exposure above the sediment. Each transect surveyed during the year 2 post-construction survey is discussed in detail below and a temporal comparison is made to the results from the sampling conducted along the same transects during the pre-construction and year 1 post-construction surveys.

3.2.2.1 Transect 03a and 03b

As observed during the pre-construction survey, transects 03a and 03b were characterised by patchy coarse sediments constituted mainly by cobbles and pebbles surrounded by smaller stones and silty sand. Numerous razor clam shells were scattered along the transects with some degree of inundation of cobbles and pebbles by finer sediments also observed. Along Transect 03a, a large area in the centre of the transect was classified as Annex I 'stony reef', mostly recorded as low resemblance 'stony reef' due to the composition of cobble supported by a matrix of some smaller pebbles and finer sediments (Plate 5, Figure 21). There were also occasional patches of medium quality 'stony reef' which consisted of a more stable, consolidated matrix of cobbles. Between areas of stony reef, the seabed was characterised by sediments comprising of muddy sand with a relatively high number of empty razor clam shells and brittlestars (Ophiuroidea). Overall, the areas of hard substrate observed were representative of low resemblance 'stony reef' as recorded in the pre-construction and year 1 post-construction surveys. The extent of the Annex I reef was also very similar to these previous surveys (Figure 21). Transect 3b, perpendicular to Transect 3a, identified burrowed muddy sand at either end of the transect with a distinct boundary between sand and reef areas.

Where hard ground was recorded, the epibiotal community consisted mainly of anemones (mainly the plumose anemone *Metridium senile*) and common starfish (*A. rubens*). This community was also noted during the pre-construction and year 1 post-construction surveys. Other relatively abundant taxa included erect hydroids and bryozoan turf, found mainly on the larger more stable cobbles, with occasional Sabellidae tubes and mobile decapods and fish species also recorded. This area was mostly representative of the circalittoral rock biotope *A4.21 Echinoderms and crustose communities.* In muddy sand areas, the epifaunal community was characterised by high numbers of brittlestars (Ophiuroidea) and *A. rubens*. This area was most representative of the sediment biotope *A5.26 Circalittoral muddy sand*.

Between the pre- and post-construction surveys, there appeared to be little or no distinct change in substrate composition and epibiotal communities. The presence of low resemblance 'stony reef' was consistently observed during each monitoring period, along with a relatively distinct boundary between coarser sediments, 'stony reef' and the surrounding soft sediments (Figure 21).

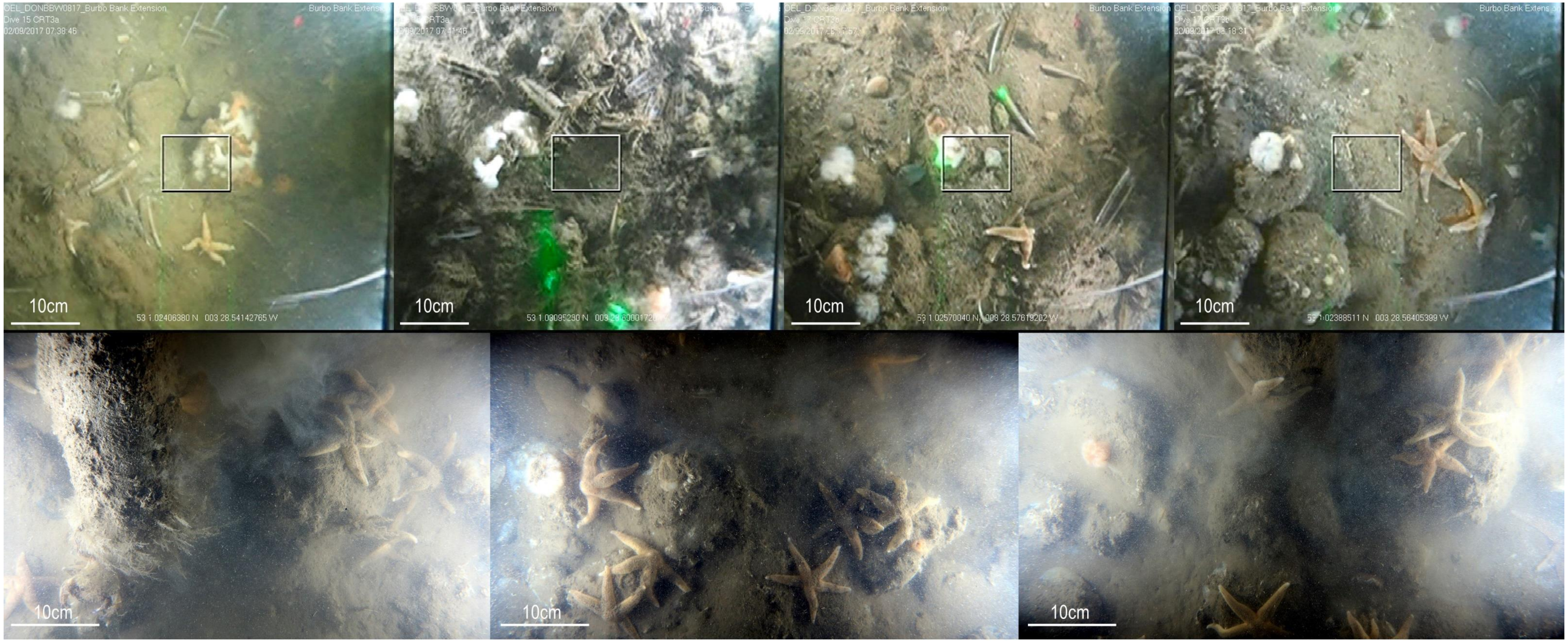


Plate 6. Example images collected along Transects 03a and 03b showing patches of Annex I 'stony' reef during the BBW02 year 1 (top row) and year 2 (bottom row) post-construction surveys.

3.2.2.2 Transect 04a and 04b

The seabed along Transects 04a and 04b consisted of muddy sands with gravel where many brittlestars (Ophiuroidea) and common starfish (*A. rubens*) were observed. There were occasional patches of cobbles and pebbles which were representative of medium and low resemblance 'stony reef', though in comparison to Transects 03a and 03b cobble density was lower (Plate 6, Figure 22). As was noted in the pre-construction and year 1 post-construction surveys, the 'stony reef' areas were patchy, with no obvious boundaries between habitat types. This was reflected in the distribution of 'stony reef' in the year 1 post-construction survey where a mixture of habitat types were observed, including 'reef' and 'not-reef', in close proximity (Figure 22). Coarser sediments were reported along Transects 04a and 04b in the year 1 post-construction survey, however, finer sands were reported in the pre-construction survey (CMACS 2015a). The potential extent of the 'stony reef' areas appear to have changed between surveys (Figure 22), however, cobble density was always reported as lower and patchy along these transects, with a silty veneer, so changes may be due to natural sediment movements due to a lack of a defined reef area which has been consistent across surveys.

The epibiotal communities present along Transects 4a and 4b were similar to those observed during transects 03a and 03b with relatively low abundance and diversity. The areas of 'stony reef' were again representative of the biotope *A4.21 Echinoderms and crustose communities* with *M. senile* and *A. rubens* dominant. Also present were erect hydroids and faunal turf patches. In the adjacent areas surrounding the hard ground, the epifaunal community was typical of the biotope *A5.26 Circalittoral muddy sand* with high numbers of brittlestars (Ophiuroidea) and common starfish (*A. rubens*).

The epibiotal communities present along Transects 04a and 04b were consistent with the community identified during the pre-construction survey as was the presence of patchy low resemblance 'stony reef'. A silty veneer overlying cobbles were also noted during the pre- and post-construction surveys, which as for Transects 03a and 03b may be suppressing the diversity of the epibiotal communities that can be associated with Annex I 'stony reef' habitats.

Plate 7. Example images collected along Transects 04a and 04b showing patches of Annex I 'stony reef' during the BBW02 year 1 (top row) and year 2 (bottom row) post-construction surveys.

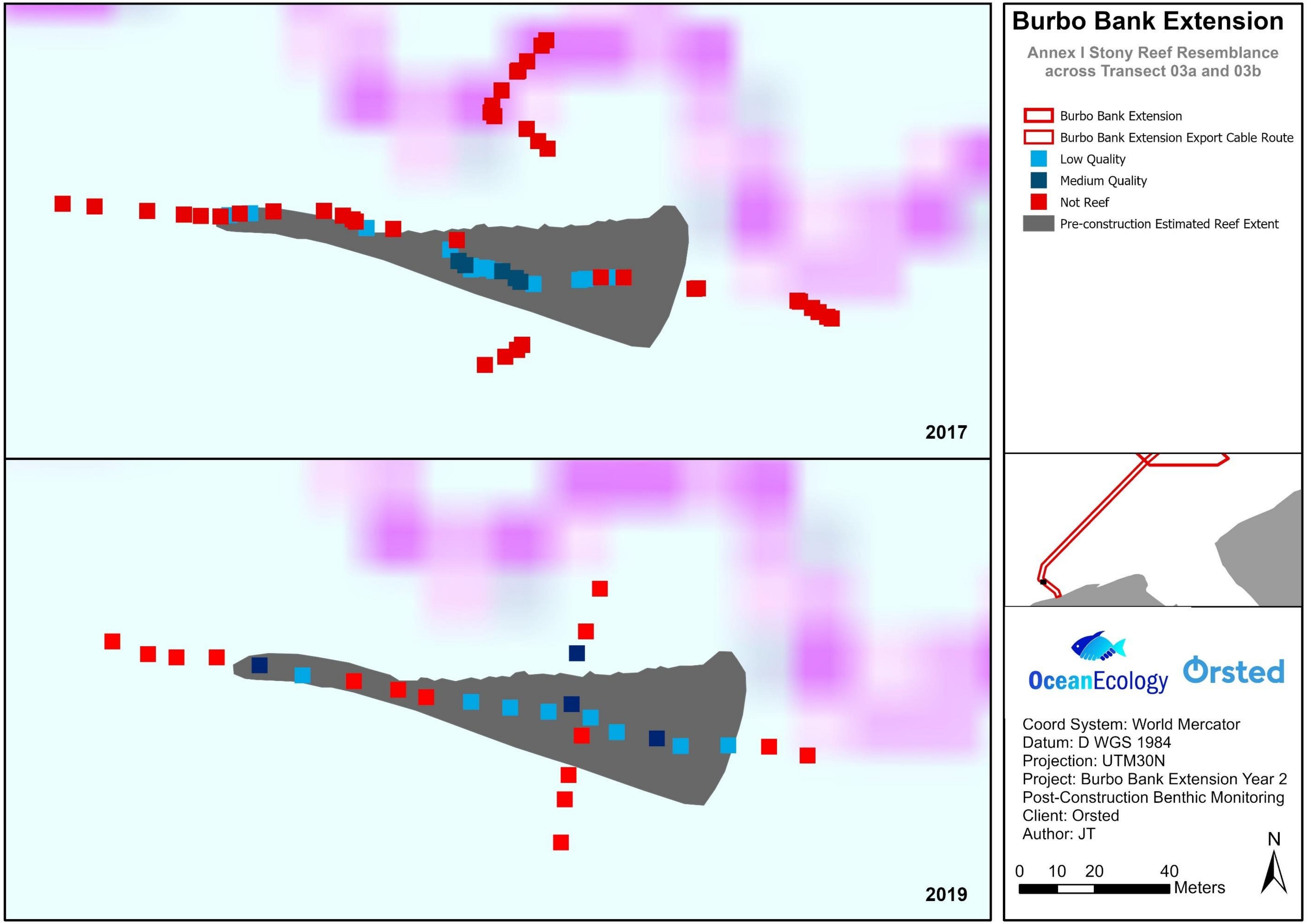


Figure 21 Distribution and classification of potential Annex I 'stony reef' along Transects 03a and 03b sampled during the BBW02 post-construction benthic surveys.

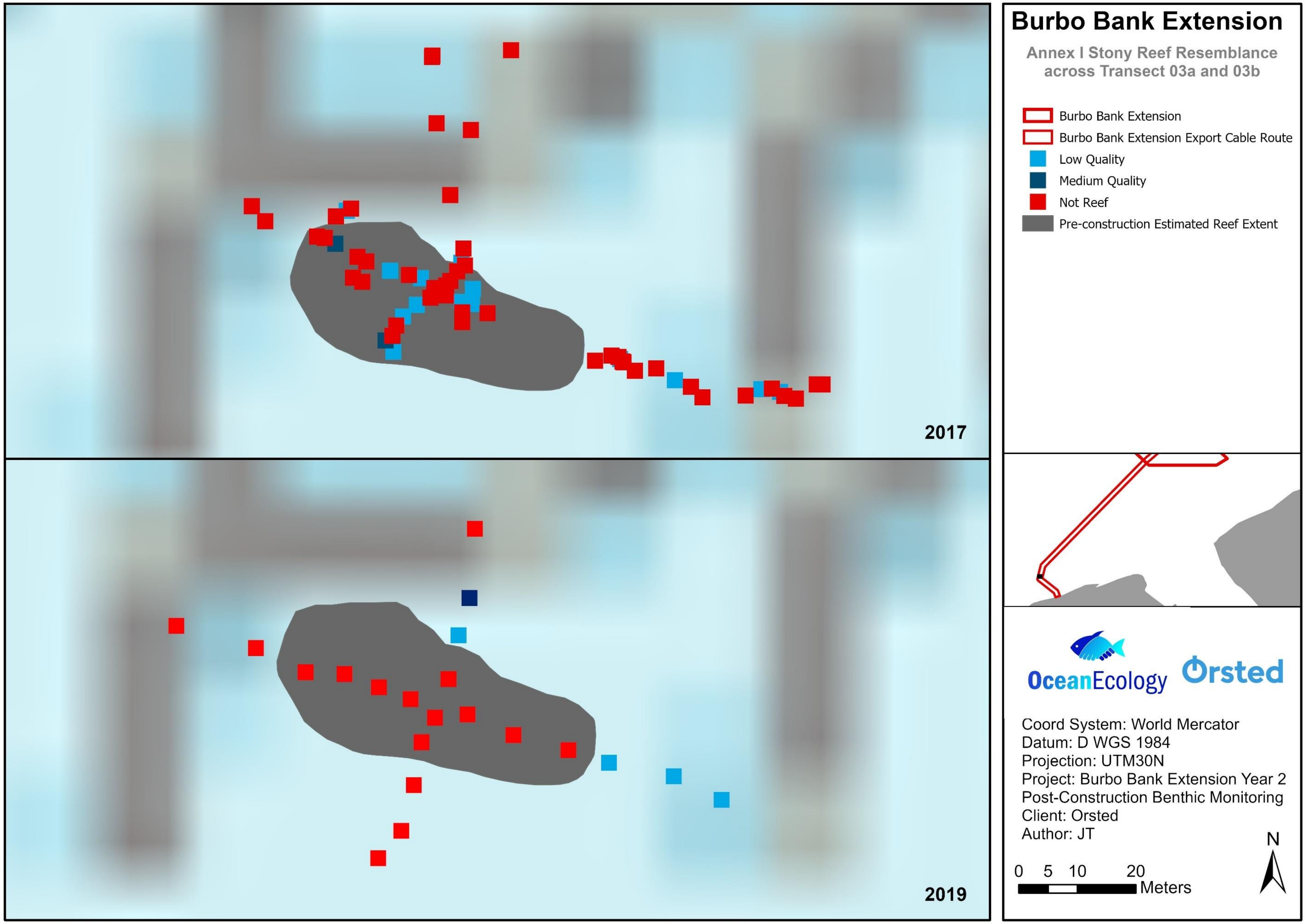


Figure 22 Distribution and classification of potential Annex I 'stony reef' along Transects 04a and 04b sampled during the BBW02 post-construction benthic surveys.

5. DISCUSSION & CONCLUSIONS

5.1. Project Requirements

OEL was commissioned by Ørsted (UK) Ltd to undertake the year 2 post-construction benthic monitoring survey at BBW02 in the summer of 2019 as a repeat of the pre-construction survey undertaken in 2015 and the year 1 post-construction survey undertaken in 2017. These surveys included the acquisition of grab samples and seabed imagery across the wind farm array, near-field and reference areas. The key aim of the year 2 post-construction survey and associated analysis was to collect data relating to the various habitats and features around the wind farm installation and ECR to inform a comparison with the baseline data as a means of validating the predictions made in the ES (Ørsted 2013). The discussion to this report has therefore been focused on presenting the key findings only contextualised through comparison to existing information as a means of either accepting or rejecting the null hypotheses set out in the ES.

5.2. Sediments

The methods used to analyse sediment samples collected during the pre-construction survey in 2015 were different to the standard methods set out in the NMBAQC guidelines. This involved drying all sediments prior to dry-sieving and only laser sizing the <2 mm fraction if >5 % of the whole sample was found to be <63 µm. Oven drying sediment causes the aggregation of particles in muddy sediments (>5 % mud) and for these reasons, such sediments should not be oven dried prior to particle size analysis (Mason 2016).

During analysis of the samples collected during the year 1 post construction survey, a visual assessment of thawed sediment samples was undertaken prior to drying to ensure the optimal analysis technique was used. Due to the notable presence of mud in a large proportion of samples, it was decided that all sediments would be analysed in line with the latest NMBAQC guidelines and the <1 mm fraction analysed using laser sizing, as also undertaken for three Stations (6, 9 and 18) in the pre-construction survey (CMACS 2015d). All samples were, therefore, wet sieved over 1 mm prior to drying to ensure there was no aggregating of fine sediment particles, as per NMBAQC guidance. This represented the most accurate means of analysis for sediment samples of this nature with mud content and very low levels of coarser sediments and ensures consistency of analysis across all treatment areas. This approach was replicated in the year 2 post-construction survey.

A subset of samples, equating to ~50 % of all samples and at all stations where a change in textural group was noted, were re-analysed using the dry sieve method used during the pre-construction phase to allow for comparison of methods. Results showed a marked decrease in % mud content due to the aggregation of mud particles (Plate 8) during the drying process. This further analysis shows that a) the process of oven drying sediments that contain fines (<63 µm) significantly underestimates the actual mud content due to aggregation of fines b) in extreme cases where mud aggregation was particularly prevalent and muddy aggregates were >2 mm in size, elevated levels of 'gravel' were falsely recorded and c) the standardised NMBAQC methodology should be used for sediments of this nature that contain high mud content and little to no gravel content.

Plate 8 Dried aggregations of mud as a result of pre-drying fine sediments before dry sieving.

Sediments sampled during the year 2 post-construction grab survey within and around the BBW02 wind farm area were homogeneous at triplicate sampling stations and showed relatively limited variation across the survey area. Sediments consisted primarily of sand and muddy sands with low gravel content, typical of circalittoral muddy sand and circalittoral sandy mud biotopes. Muddy sand was the dominant sediment type present with sand the second most frequent sediment type present within the wind farm and near-field areas. The main variation in sediment types across the site were due to varying percentages of mud fractions, where the percentage contribution of gravel was only > 1 % at 5 stations. Grab data was corroborated by seabed imagery which further demonstrated the area to be characterised by circalittoral fine sediments with little (<5 %) gravel content.

Comparison of sediment data collected during the pre-construction and the year 1 and year 2 post-construction surveys showed a small variation in sediments over time although the changes observed were not identified as statistically significant in the ANOSIM comparisons. When comparing the results of the year 2 post-construction surveys to previous years, a slight overall decrease in mean grain size was observed with the composition of mud becoming more prominent in sediments across the survey area (e.g. sands shifting to muddy sands). This increase in mud was less pronounced between the year 1 and year 2 post-construction surveys and so likely represents that the initial difference was due to the methods used, as described above. The most prominent change in sediment composition over the years has occurred at reference station 18. This station was initially classed as muddy sand in 2015, where an increase in gravel resulted in a classification of slightly gravelly muddy sand in 2017. Finally, in this survey the proportion of mud has almost doubled compared to previous years, which resulted in a classification of sandy mud. Within this context, there has been very limited change across the rest of the survey area. The only station to show a change in textural group classification in the same direction (an increase in finer particles) was station 13 in the near-field area. All stations in the wind farm area have shown no change in textural group (5 out of 12 stations), or only one change (7 out of 12 stations) across both post-construction surveys.

Despite these small changes, multivariate analysis eluded no significant differences between the composition of sediments sampled during the pre- and post-construction surveys. Further analysis run on all data (construction phase and treatment area) also showed no notable differences within all treatment areas between the pre- and post-construction surveys. Stations occasionally fell in different SIMPROF groups between survey years; however, this may be due to the increased gravel content in the pre-construction surveys, probably as a result of the methods used. Most of the time, all stations fell in the same SIMPOF group in all surveys.

An increase in finer suspended sediment particles may be associated with construction activities, such as pile driving and cable laying, as predicted in the ES. The amount of finer sediments did increase slightly in the year 2 post-construction survey; mean grain size reduced, and sediments became finer by a textural group at five of the 18 stations when compared to the year 1 post-construction results. However, these changes occurred at reference, near-field, and wind-farms stations, with no obvious trend apparent. These small variations are more likely to be in line with natural variation in sediment movements, attributable to natural stochastic events (e.g. storms) and changes to hydrological processes (e.g. wave action and tidal flows). Additionally, it is almost certain that the elevated mud content when compared to the pre-construction results, is due to different methods of analysis used between years. If construction activities are the cause of an increase in finer particles then the impacts appeared to be negligible across the BBW02 survey area given no significant changes have occurred in sediment composition, which has been observed in other areas (Van Den Eynde et al. 2010).

In light of the findings presented above, the null hypotheses relating to changes in sediment composition ("*There is no significant difference in sediment particle size distribution / infaunal community between wind farm, near-field and reference areas"* and *"There is no significant difference in sediment particle size distribution / infaunal community between survey years.")* can provisionally be accepted based on the results of the post-construction monitoring conducted to date. Full acceptance will be based on the condition that similar results are observed during further post-construction monitoring in 2021 by ruling out potential changes to sediment composition over extended time periods as a result of the continued operation of BBW02. It is recommended that the NMBAQC methods of sediment analysis used in the year 1 and year 2 post-construction surveys are used as a benchmark going forward to ensure maximum comparability between years at BBW02.

5.3. Infaunal Communities

The macrobenthic infaunal assemblage identified across the BBW02 survey area during the year 2 post-construction monitoring survey was relatively diverse with 111 taxa recorded and a mean abundance of 143.0 individuals per sample. As observed during the pre-construction survey, mollusc and annelid taxa dominated the infaunal communities in terms of biomass and diversity respectively. Patterns in abundance, diversity, and biomass were largely similar to the pre-construction survey results, though echinoderms contributed more to abundance in the post-construction surveys. This pattern was consistent across treatment areas, although near-field biomass was dominated by molluscs, as observed in the year 1 post-construction survey. This was mainly due to larger numbers of *P. legumen* and *Kurtiella bidentata* found at station 13.

When broadly comparing the pre-construction and post-construction infaunal datasets, a marked area wide change in abundance was observed. Decreases in the numbers of infaunal taxa that characterised the pre-construction communities were observed, particularly the polychaete *L. koreni* that was found in densities of up to 14,520 per m^2 during the pre-construction survey compared to 90 per m^2 and 5,310 per m^2 in 2017 and 2019 respectively. *L. koreni* was only observed at pre-construction abundance levels at Station 13 . Densities of *L. koreni* can vary greatly over time ranging from thousands of individuals per square metre to very few. These changes can be linked to mass mortality after winter storms due to the destabilisation of sediments through bioturbation (Eagle 1973) but can also be linked to corresponding decreases in other characterising taxa that have been shown to display linked population dynamics in this area (Rees & Walker 1983). *L. koreni* populations are capable of tolerating sudden increases in the deposition of sediment and often dominate such areas following such an event suggesting that a major deposition of sediment may have occurred shortly before the pre-construction survey rather than as a result of the wind farm construction activities that followed.

To investigate further, the post-construction datasets were examined in more detail both separately and in combination with pre-construction datasets. Further statistical analysis, on a treatment scale basis, revealed no significant changes in infaunal composition across all treatment areas between construction periods, including reference areas. This suggests that whilst there had been changes to the abundances of some key taxa, the composition of the communities remained relatively similar. Some small variations were observed, however these were not considered to be greater than changes to be expected as a result of natural fluctuations in infaunal assemblages typical of this type of environment. The changes in abundance and diversity correlated well with the patterns of change in the sediment type (as a result of mean grain size), further corroborating the findings that sediment and depth were governing the infaunal communities as observed at other offshore wind farm areas in the Irish Sea and elsewhere around the UK (BOWind 2008, EMU 2010, CMACS 2013b, Ocean Ecology Limited 2014, Ocean Ecology Limited 2016 and Natural Power 2015). As the pre- and post-construction surveys were both conducted during the summer/early autumn months (pre-construction in July, year 1 post-construction in August/September, and year 2 post-construction in September) seasonal influences on communities were considered to be small. However, the earlier timing of the pre-construction surveys may have led to higher abundances of taxa such as *L. koreni*.

In light of the findings presented above, the null hypothesis relating to changes in the infaunal communities cannot be accepted. In order to test this hypothesis in a robust manner, further post-construction monitoring data is required. This will help to establish whether the fluctuations in key characterising taxa observed are attributable to the natural variability of the site and whether the construction and operation of BBW02 is responsible for any longer-term changes to the composition of the infaunal communities that are not yet detectable.

5.4. Annex I 'Stony Reef'

In line with the findings of both the pre-construction and year 1 post-construction surveys, low resemblance Annex I 'stony reef' was identified along the BBW02 ECR during the year 2 post-construction survey. Transects 04a and 04b revealed small patches of low resemblance 'stony reef' supported by a matrix of smaller pebbles, sand and empty shell interspersed with areas of finer sand and mud. Instances of 'stony reef' along these transects did not appear to correlate well with the predicted extent of the previous surveys. Instances of 'stony reef' along these transects did not appear to correlate well with the predicted extent of the previous surveys indicating smothering of some areas but exposure of others. While an increase in finer sediments may be associated with the cable installation, these effects are expected to be of much lower magnitude compared to the high levels of natural siltation and periodic inundation by finer sediments in the area. The presence of fine sediments in the water column and the partial burial of hard substrate by finer sediments was observed and evidenced in the video footage and stills suggesting natural siltation is the likely cause of increased fines within the area. The surficial sediments in and around the BBW02 area have been noted to be mobile owing to destabilisation by feeding activity of deposit feeders, localised wave action following winter gales and the influence of the two large estuaries of the River Mersey and River Dee (Ørsted, 2013). Changes in fluvial flow are thought to be contributory factors to changes in siltation in the area and may be linked to the apparent changes observed. A further consideration for this is that dredging for shipping has been known to remove approximately 0.7 to 1.4 x 106 m^3 of sediment (mainly fines) from the Mersey outer estuary per annum which is disposed of in Liverpool Bay (Van der Wal and Pye, 2000).

Where present, hard ground identified along Transects 03a and 03b identified a more contiguous cover of cobble with supporting pebbles, sand and shell with areas of both low resemblance and medium resemblance Annex I 'stony reef'. 'Stony reef' observed along transects 03a and 03b had a more distinct boundary than along Transects

04a and 04b and was surrounded by burrowed muddy sand. This distinct boundary was also noted during the pre-construction survey; however, the surrounding substrate was predominantly fine sand with shell fragments and little mud content, potentially suggesting an increase in finer sediment in areas adjacent to this section of the ECR. An apparent increase in fine sediments was also observed along Transect 03a between pre- and year 1 post-construction surveys. Patches of 'stony reef' observed in this survey were also separated by areas of silty sand, potentially representing increased sediment suspension associated with construction activities, although, as explained above, probably fall in line with natural variation.

A low abundance and diversity of epibiotic fauna was recorded in areas of Annex I 'stony reef' similar to that observed during the pre-construction and year 1 post-construction survey. Communities were representative of the habitat types observed, and characteristic of areas that undergo periodic smothering and burial of the cobble substrate by the surrounding finer sediment areas which prevents colonisation during periods of exposure above the sediment. Despite this, the epibiotic assemblages observed between the three periods were similar in their makeup suggesting minimal impact from the installation of the BBW02 export cable and the null hypotheses relating to Annex I Habitats ("*The establishing of BBW02 Offshore Wind Farm and export cable routes does not lead to a significant impact on Annex I Habitat(s))* can provisionally be accepted.

5.5. Conclusions and Validation of the ES

The predicted impacts of the BBW02 development, as reported in the ES, are summarised below with predicted impact level highlighted for each impact. Predicted impact levels are assessed to be either ***None*** or ***Minor***.

Disturbance from vessels/machinery, change in sediment transport or scour leading to habitat change, increases in suspended sediments and/or deposition of sediments and the loss of seabed habitat as a result of turbine installation and cable laying were all deemed to be unavoidable ***minor*** impacts of the development.

Whilst the changes to sediments observed to date appear to reflect the impact level predictions made (***minor***), it is difficult to necessarily attribute these solely to either the BBW02 development or natural variation. As identified previously, change to recorded fine content within the benthic grab samples may be largely attributable to differences in laboratory analysis between years. With no statistically significant changes in sediment type across the area noted between all three construction phases, it cannot be concluded that the minor changes are a result of construction but more likely a combination of both construction activity and natural variation in sediment loading within Liverpool Bay. This has been corroborated in the infaunal data which also exhibited some changes, but none of which were significant on a treatment scale or across monitoring periods when considering the composition of the communities observed.

Determining ongoing impacts and how infaunal communities are impacted over longer time periods is complex due to a combination of natural and anthropogenic stressors. Having only assessed change across four years (2015-2019) the results presented here must be interpreted with caution and will not be suitable for validating the predictions made in the ES until augmented by further post-construction data.

Description of Impact	Magnitude of Impact	Importance of Receptors	Sensitivity of Receptors*	Significance of Effect	Potential Mitigation Measures
Construction/Decommissioning Phase					
Increases in suspended sediment concentration	**Minor**	Low to medium	Not/very low to moderate	Negligible to minor	None
Increases in sediment deposition	**Minor**	Low to medium	Not/very low to moderate	Negligible to minor	None
Release of contaminants	**None**	Low to medium	Low to moderate	Negligible	None
Release of pollutants	**None**	Low to medium	Low to moderate	Negligible	None
Disturbance from vessels/machinery	**Minor**	Low to medium	Very low to low	Negligible to minor	None
Noise	**Minor**	Low to medium	Not to low	Negligible to minor	None
Operation Phase					
Loss of seabed habitat	**Minor**	Low to medium	Low to moderate	Minor or moderate positive to minor adverse	None
Scour leading to habitat change	**Minor**	Low to medium	Very low to moderate	Negligible to minor	None
Change in sediment transport leading to habitat change	**Minor**	Low to medium	Low to moderate	Negligible	None
Colonisation of structure leading to increased biodiversity	**Minor**	Low to medium	Not to low	Minor to moderate positive to minor adverse	None
Colonisation of structures by invasive species	**Minor**	Low to medium	Not, unknown or low	None to negligible (some uncertainty)	Risk assessment, follow IMO best practice guidelines
Electromagnetic fields (EMF)	**Minor**	Low to medium	Not, unknown or low	Negligible to minor	None
Cable heating	**Minor**	Low to medium	Not/very low to low	Negligible	None

*as determined by comparing intolerance with recoverability to each import

6. REFERENCES

BOWind (2008) Barrow Offshore Wind Farm. Post Construction Monitoring Report. January 2008.

Clarke K., Gorley RN (2015) PRIMER v7: User Manual/Tutorial.

Clarke RK, Tweedley J, Valesini F (2013) Simple shade plots aid better long-term choices of data pre-treatment in multivariate assemblage studies. J Mar Biol Assoc UK:23.

CMACS (2015a) Burbo Bank Extension Offshore Wind Farm Benthic and Annex I Habitat pre-construction monitoring proposals.

CMACS (2015b) Burbo Bank Extension Offshore Wind Farm Benthic and Annex I Habitat Screening Exercise.

CMACS (2015c) Burbo Bank Extension Offshore Wind Farm Pre-construction Annex I Habitat Evaluation Report.

CMACS (2015d) Burbo Bank Extension Offshore Wind Farm Pre-construction Benthic Monitoring Technical Report.

CMACS (2013a) The proposed Burbo Bank Extension offshore wind farm development. Subtidal and intertidal benthic characterisation survey technical report.

CMACS (2013b) Walney Extension Offshore Wind Farm benthic characterisation survey technical report (2011-12 survey). Report to Walney Extension Offshore UK/DONG Energy.

Cooper KM, Curtis M, Wan Hussin WMR, Barrio Froján CRS, Defew EC, Nye V, Paterson DM (2011) Implications of dredging induced changes in sediment particle size composition for the structure and function of marine benthic macrofaunal communities. Mar Pollut Bull 62:2087–2094.

DONG Energy (2013) Burbo Bank Extension Offshore Wind Farm. Environmental Statement Volume 2 - Chapter 12: Subtidal and Intertidal Benthic Ecology. Document Reference 5.1.2.12 APFP 5(2)(a).

Eagle RA (1973) Benthic studies in the south east of Liverpool Bay. Estuar Coast Mar Sci 1:285–299.

Eleftheriou A, Basford D. (1989) The macrobenthic infauna of the offshore northern North Sea. J Mar Biol Assoc 69:123–143.

Ellingsen KE (2002) Soft-sediment benthic biodiversity on the continental shelf in relation to environmental variability. Mar Ecol Prog Ser 232:15–27.

EMU (2010) London Array Phase 1 Pre-Construction Baseline Benthic Ecology Study. A report to London Array. Report No. 10/J/1/03/1544/1077.

Van Den Eynde D, Brabant R, Fettweis M, Francken F, Melotte J, Sas M, Lancker V Van, Van den Eynde D, Van Lancker V (2010) Monitoring of hydrodynamic and morphological changes at the C-Power and the Belwind offshore wind farm sites: A synthesis.

Folk R. (1954) The distribution between grain size and mineral composition in sedimentary rock nomenclature. J Geol 62:344–359.

Hitchin R, Turner J, Verling E (2015) Epibiota Remote Monitoring from Digital Imagery: Operational Guidelines. NMBAQC JNCC.

Holstein J (2018) Worms: Retriving Aphia Information from World Register of Marine Species. package ve.

Irving R (2009) The identification of the main characteristics of stony reef habitats under the Habitats Directive. Summary report of an inter-agency workshop 26-27 March 2008. JNCC Rep No 432:44.

Long D (2006) BGS detailed explanation of seabed sediment modified folk classification. Folk.

Mason C (2016) NMBAQC’s Best Practice Guidance - Particle Size Analysis (PSA) for Supporting Biological Analysis.

Natural Power (2015) London Array Offshore Wind Farm Year 1 Post Construction Benthic Monitoring Report. 109.

NIRAS Consulting (2017) Burbo Bank Extension Post-construction Benthic Ecology Monitoring Plan.

Ocean Ecology Limited (2018) Burbo Bank Extension Offshore Wind Farm: Year 1 Post-Construction Benthic Monitoring Report 2017. Report No. ORDBBA0817_TCR.

Ocean Ecology Limited (2014) Kentish Flats Extension Pre-Construction Benthic Report. Report No. VATKFE0914.

Ocean Ecology Limited (2016) West of Duddon Sands Offshore Wind Farm Year 2 Post-Construction Benthic Monitoring Report 2016.

R Core Team (2019) R: A Language and Environment for Statistical Computing.

Rees EIS, Walker AJM (1983) Annual and spatial variation in the Abra community in Liverpool Bay. Oceanol Acta:165–169.

Turner J., Hitchin R, Verling E, van Rein H (2016) Epibiota remote monitoring from digital imagery: Interpretation guidelines.

Ware SJ, Kenny AJ, Curtis M, Froján CB, Cooper K, Reach I, Bussell J, Service M, Boyd A, Sotheran I, Egerton J, Pearce LSB (2011) Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites. Mar Aggreg Levy Sustain Fund 2:80.

Wentworth C. (1922) A scale of grade and class terms for clastic sediments. J Geol 30:377–392.