Bellrock Offshore Wind Farm

Wind Farm Development Area

Appendix 7.2: Bellrock Wind Farm Development Area Environmental Baseline Survey 2023 Report

Date: March 2026

Document Number: RHDV_BEL_CST_REP_0004_024

Revision Number: 1

Classification: Public

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Bellrock Offshore Wind Farm Wind Farm Development Area Environmental Baseline Survey Report 2023

OEL_TERBEL0922_TCR
2023-002-OP-REP-0066

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Details

Version	Date	Description	Author(s)	Reviewed By	Approved By
V01	20/10/2023	Draft	Dr Ana Corrochano, Samuel Spode	Dr Elena Cappelli	Ross Griffin
V02	12/12/2023	Revision following client review	Josh Baker	Dr Elena Cappelli	Ross Griffin
V03	22/05/2025	Final	Daniel Hendy	-	Samuel Holmes

Updates

Section	Description	Page
Several	Updated Project terminology throughout	Throughout

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Abbreviations

BIIGLE	Bio-Image Indexing and Graphical Labelling Environment
BSH	Broadscale Habitat
DDC	Drop-Down Camera
eDNA	Environmental DNA
EUNIS	European Nature Information System
HA	Habitat Assessment
HD	High Definition
HOCI	Habitat of Conservation Importance
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee
LED	Light-Emitting Diode
MBES	Multibeam Echosounder
MCZ	Marine Conservation Zone
MP	Megapixel
MPF	Marine Protected Feature
MPA	Marine Protected Area
MD-SEDD	Marine Directorate Science Evidence Data Digital
MW	Mega Watt
OEL	Ocean Ecology Ltd
OTU	Operational Taxonomic Units
PSD	Particle Size Distribution
SAC	Special Area of Conservation
SOCI	Species of Conservation Interest
SPA	Special Protection Area
SSS	Side-Scan Sonar
UPS	Uninterruptable Power Supply
USBL	Ultra-Short Baseline
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
VRU	Vapor Recovery Units

Non-Technical Summary

Introduction

Ocean Ecology Limited (OEL) were commissioned by Terrasond to undertake a benthic characterisation of the Bellrock Offshore Wind Farm Wind Farm Development Area (Bellrock WFDA). The Bellrock WFDA is located in the Central North Sea, approximately 120 km east of Stonehaven. The area is approximately 279 km^2 and is intended to accommodate a 1,800 MW capacity of floating offshore wind. Eight marine protected areas (MPAs) surround but do not overlap the WFDA. The nearest of these is the East of Gannet and Montrose Fields Nature Conservation Marine Protected Area (NCMPA) which lies 45 km to the northeast of the WFDA.

Survey Strategy

A total of 113 combined Drop-Down Camera (DDC) and grab sampling stations were sampled across the Bellrock WFDA (the 'survey area') based on an estimated density of 1 station per 10 km^2. Water samples for environmental DNA (eDNA) analysis were collected at three different depths at 10 sampling stations. The sampling was undertaken during periods of favourable weather aboard the vessel DSV Curtis Marshall between the 5th and 28th of July 2023.

Sediments

Despite some variation in sediment type between stations, most stations were dominated by sand and classified as Broad Scale Habitat (BSH) A5.2. Mud contribution to sediment increased with increasing water depth and was substantial at three stations (ST0038, ST0102, and ST0103), where it represented more than 25% of the total composition; these stations were assigned to BSH A5.3 (Sublittoral mud). In contrast, gravel content was comparatively low at most stations, contributing on average to less than 1 % of the total sediment. Considering the water depth at which all grab samples were collected, these sublittoral sediment types were deemed to be representative of the 'offshore deep sea muds' and 'offshore subtidal sands and gravels' Priority Marine Feature (PMF) habitats in Scottish waters and therefore of conservation importance. To note that these habitats are among the most common habitats found in offshore deep waters around the coast of the UK.

Contaminants

The examined contaminants included heavy and trace metals, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated biphenyls (PCBs), organotins and Total Hydrocarbon Content (THC). None of the analysed metals, PAHs and THC exceeded any of the reference levels while the concentrations of PCBs, and Organotins were found Below the Detection Limits (BLD) at all stations.

Macrobenthos

A diverse macrobenthic assemblage was identified across the survey area from 113 samples collected, with a total of 9,194 individuals and 283 taxa recorded. The most abundant taxon with the greatest average density per sample was the heart urchin *Spatangoida* (juveniles) and the most frequently occurring taxon was the polychaete *Scoloplos armiger*. Annelida taxa dominated abundance and diversity while biomass was dominated by Echinodermata. One notable species was identified across the survey area: the Ocean quahog *Arctica islandica*. This species is included in the OSPAR List of Threatened and/or Declining Species and Habitats (2008) and is also a PMF species in Scottish waters. Most of the individuals recorded were juveniles, with only three adults noted across the survey area.

EUNIS Habitats/Biotopes

An integrated analysis of data collected across the survey area indicated that the primary biotopes present were "A5.272 *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand" dominating the survey region, and a mosaic of biotopes "A5.371 *Ampharete falcata* turf with *Parvicardium ovale* on cohesive muddy sediment near margins of deep stratified seas" and "A5.*376 Paramphinome jeffreysii, Thyasira spp*. and *Amphiura filiformis* in offshore circalittoral sandy mud" to the east of the survey area, and as linear (north to south) features occurring at regular intervals laterally across the Bellrock WFDA (east to west). The findings closely aligned with existing predictive habitat mapping. Macrobenthic data helped assign sandy stations to A5.272 and muddy stations to a mosaic of A5.371/A5.376. The burrowed mud PMF habitat was identified based on seabed imagery analysis associated with EUNIS habitat "A5.37 Deep circalittoral mud" in the east of the survey area where burrow density was comparably higher than across the rest of the survey area. However, there was no spatial relationship between burrow density and the presence of seapens, the most common epifauna. Macrobenthic analysis did not reveal any species qualifying as biotope components of the burrowed mud PMF habitat. It is likely that this area represents a combination of the two PMF habitats burrowed mud and offshore deep sea muds. Additionally, the offshore subtidal sands and gravels PMF habitat was identified in correspondence of biotope A5.272.

eDNA

The eDNA analysis conducted within the survey area revealed the presence of three IUCN Red List fish species: the Atlantic cod, haddock, and Atlantic Horse Mackerel. Additionally, 10 PMF fish species and 18 fish species of commercial importance were also recorded across the survey area. Of note, the detection of the Atlantic Salmon which is a species of notable ecological and cultural significance. A number of other fish species were detected outside of what is thought to be their typical ranges including Boarfish.

The eDNA analysis also confirmed the presence of various marine mammals such as Minke Whale, Harbour porpoise, and dolphins from the genus *Lagenorhynchus*. Several bird species were also detected, in line with bird records for the northeastern region of Scotland. The

persistence of eDNA in water relies on environmental factors and DNA type, with its detectability lasting from hours to months, subject to degradation rates influenced by UV radiation, temperature, and enzymatic activity. Sampling eDNA at different depths provides insights into genetic material distribution; for example, the Atlantic Salmon as recorded across all depths with a stronger DNA signal in the top layer, while other species like Haddock and Dab were absent in the top layer while giving stronger DNA signals in the middle and bottom layer of the water column.

1. Introduction

1.1. Project Overview

The Bellrock Offshore Wind Farm Wind Farm Development Area (Bellrock WFDA) is in the north-east corner of the E1 ScotWind Plan Option (PO) in the Central North Sea, approximately 120 km east of Stonehaven (Figure 1). The area is approximately 279 km^2 and is intended to accommodate 1,800 MW capacity (Figure 1). Water depths across the WFDA range from approximately 110 m below Lowest Astronomical Tide (LAT) to approximately 70 m below LAT. Information available from EMODnet (EMODnet 2021) suggest the surface and shallow sub-surficial sediments of the Bellrock WFDA comprise deep circalittoral sand and deep circalittoral mud.

1.2. Background Information

Ocean Ecology Limited (OEL) were contracted to undertake a benthic characterisation survey to provide a description of the biological and physico-chemical nature of the seabed across the proposed Bellrock WFDA.

This report provides a summary of the survey methodologies employed during the survey, presents mapping of the habitats/biotopes encountered and sets out a detailed description of the biological and physio-chemical status of the substrates encountered across the survey area. This was achieved through detailed interpretation of Drop-Down Camera (DDC) imagery combined with information on the macrobenthic and physio-chemical characteristics of sediments sampled via grab sampling. This information was considered alongside high-resolution Multibeam Echosounder (MBES) and Side-Scan Sonar (SSS) data collected by TerraSond to allow for the creation of full coverage habitat and biotope mapping across the survey area including the delineation of important and environmentally sensitive features (e.g., Annex I habitats and PMFs).

It should be noted that the findings of this report are based on finalised geophysical data and therefore supersede the findings of the Bellrock Habitat Assessment Report (REF: OEL_TERBEL0922_HA 2023-002-OP-REP-0071) which were made on the preliminary data available at the time of writing.

1.3. Aims and Objectives

The primary aim of this survey and subsequent analysis and reporting was to provide a comprehensive characterisation of the benthic environment across the Bellrock WFDA suitable to inform the Bellrock WFDA Environmental Impact Assessment (EIA).

The key objectives of the technical report were to:

- Provide an initial description of the seabed habitats within the Bellrock WFDA (the 'survey area'). This was achieved using DDC and sediment grab sampling followed by subsequent laboratory analysis to provide accurate ground–truthing of geophysical data collected by Terrasond;
- Describe the benthic communities present within the Bellrock WFDA, including biotopes, biodiversity, abundance, extent, species richness, representativeness, rarity and sensitivity. This covered the range of water depths across the Bellrock WFDA and included both infaunal and epifaunal communities;
- Identify and assess the status of species and habitats of conservation importance, including Priority Marine Features (PMFs), Annex I protected species and habitats, and Annex V species[1] of the Habitats Regulations, species listed under Schedule 5 of the Wildlife & Countryside Act[2], OSPAR species and habitats[3] and designated features of the MPA network (e.g., SAC and Nature Conservation MPA);
- Confirm the presence/ absence of any invasive non-native species (INNS), and species non-native to the local habitat types (e.g., hard- substrate specialists in a wider sedimentary habitat);
- Develop understanding of biodiversity in the Bellrock WFDA and identification of potential indicators of ecosystem health following Marine Directorate Science Evidence Data Digital (MD-SEDD) advice by introducing water eDNA sampling.

[1] https://jncc.gov.uk/our-work/article-17-habitats-directive-report-2019-species/
[2] https://www.legislation.gov.uk/ukpga/1981/69/schedule/5
[3] https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-species-habitats

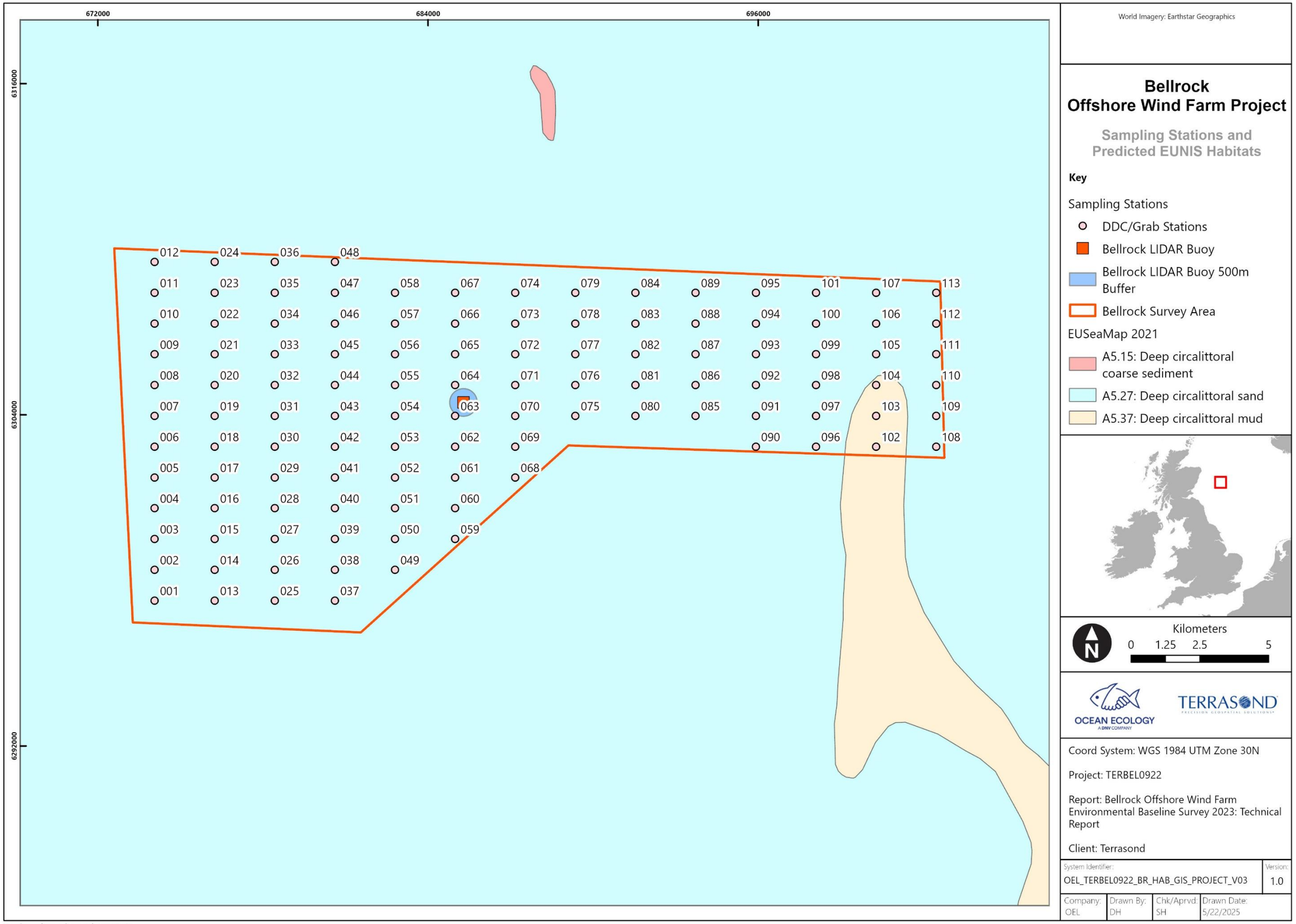

Figure 1 DDC and grab stations sampled during the survey overlain on predicted EUNIS habitat type (EMODnet 2021).

2. Current Understanding

2.1. Existing Habitat Mapping

The 2021 EUSeaMap broad-scale predictive model classifies and maps intertidal and subtidal habitats according to the European Nature Information Systems (EUNIS) classification criteria. The system is able to identify keystone species that have been evidenced to inhabit areas with certain environmental conditions and can therefore act as an indicator, allowing inferences of overall community composition. The EUSeaMap data indicated that the habitats present across the proposed survey area primarily consisted of Deep circalittoral sand (A5.27) and Deep circalittoral mud (A5.37), as mapped in Figure 1 (EMODnet 2021).

2.2. Relevant Conservation Legislation

European Commission Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora, commonly known as the 'Habitats Directive' ensures the conservation of a wide range of rare, threatened endemic animal and plant species as well as habitats. The EU Habitats Directive (1992) was transposed into UK law by The Conservation of Habitats and Species Regulations 2017 within 12 nautical miles (nm), and The Conservation of Offshore Marine Habitats and Species Regulations 2017 between 12 nm out to 200 nm or the UK Continental Shelf. Under these regulations, a network of Special Protected Areas (SPA) and Special Areas of Conservation (SAC) have been established to grant protection and conservation to rare and threatened habitats and species.

The Marine (Scotland) Act 2010 provides the legal mechanism to assist in the conservation and enable the recovery of protected wildlife and habitats within nature conservation MPAs.

Designated Sites

The survey area lies central to, but does not overlap, several designated MPAs. The nearest of these is the East of Gannet NCMPA which lies 45 km to the northeast of the survey area. Figure 2 illustrates all designated sites present in the wider region surrounding the Bellrock WFDA while below is a summary of the sites occurring within a 115 km radius from the survey area.

East of Gannet and Montrose Fields NCMPA

This NCMPA lies approximately 45 km northeast of the Bellrock WFDA and is designated for the protection of the ocean quahog *A. islandica* and the habitat offshore deep-sea muds.

Turbot Bank NCMPA

This NCMPA is situated approximately 60 km northwest of the survey area and is designated for the protection of sand eels as a commercially important species and important prey species for bird species such as Atlantic puffin *Fratercula arctica* and black-legged kittiwake *Rissa tridactyla*.

Firth of Forth Banks Complex NCMPA

This MPA complex is comprised of three MPAs and the Bellrock WFDA is approximately 64 km from the complex, which covers an area of 2130 km^2. This MPA complex is designated for the protection of the ocean quahog *A. islandica*, offshore subtidal sands and gravels, shelf banks and mounds and moraines.

Fulmar Marine Conservation Zone (MCZ)

This MCZ is situated 95 km southeast of the survey area and is designated for the ocean quahog *A. islandica* and the habitats subtidal mixed sediments, subtidal mud and subtidal sand.

Swallow Sand MCZ

This MCZ is located approximately 85 km south of the project area and is designated for the protection of the habitat's subtidal coarse sediment and subtidal sand, as well as the geological feature North Sea glacial tunnel valleys such as Swallow Hole.

North East of Farnes Deep MCZ

This MCZ is located 100 km southwest of the survey area and is designated for the ocean quahog *A. islandica* and the habitats subtidal coarse sediments, subtidal mixed sediments, subtidal mud and subtidal sand.

Farnes East MCZ

This MCZ lies 115 km southwest of the survey area and is designated for the ocean quahog *A. islandica* and the habitats moderate energy circalittoral rock, sea-pen and burrowing megafauna communities, subtidal coarse sediments, subtidal mixed sediments, subtidal mud and subtidal sand.

2.2.1. Priority Marine Features

PMFs are habitats and species that are considered to be marine nature conservation priorities in Scottish waters (Tyler-Walters et al. 2016). The following PMF habitats have been recorded within or near to the survey area.

Ocean quahog

The ocean quahog *A. islandica* holds the remarkable distinction of being the longest-lived mollusc on record, with the potential to survive for more than four centuries. This species predominantly inhabits the sandy and muddy sediments found at depths ranging from 10 to 280 m. Its primary habitat spans the maritime expanses surrounding Scotland, particularly offshore in the eastern regions and the northern North Sea. Notably, approximately seventy percent of documented British records of the ocean quahog are concentrated in Scottish waters, a testament to its historical prevalence in these marine environments. However, there is a growing concern as this vulnerable species is now experiencing a decline, prompting increased attention to its conservation.

Burrowed muds

Burrowed muds in Scotland are designated as PMF due to being a home to a diverse range of marine species such as worms, clams, and various types of crustaceans. They provide essential ecosystem services playing a crucial role in nutrient cycling and water purification. Burrowed mud habitats can store significant amounts of carbon in the form of organic matter. The burrows created by mud-dwelling organisms create complex physical structures in the seabed, providing shelter and foraging opportunities for a variety of other species, including those that are not directly associated with the mud habitat enhancing the overall resilience and stability of the marine ecosystem. Burrowed mud habitats are sensitive to disturbance from human activities such as bottom trawling, dredging, and pollution. These activities can damage or destroy the habitat and disrupt the communities living within it. Designating burrowed mud as PMFs helps raise awareness of their importance and provides a basis for conservation efforts and regulations to protect them.

Offshore deep sea muds

Offshore deep sea muds in Scotland are designated as PMFs due to their unique and rare status as habitats in the marine environment. These muds possess distinct geological formations and sediment types that are not commonly found elsewhere. Within these offshore deep sea muds, a diverse and abundant array of marine life thrives, including notable species such as polychaete worms, bivalve molluscs, sea cucumbers, and soft corals. These muds are delicate ecosystems that are highly vulnerable to disturbances, including activities like seabed mining and bottom trawling. Such disturbances can have severe consequences for the intricate balance of these ecosystems, underscoring the need for their protection and recognition as PMFs. Furthermore, these offshore deep sea muds serve as crucial nursery and feeding grounds for commercially valuable fish

species. They provide essential habitats where these fish can reproduce and find sustenance, supporting the sustainability of fisheries and the long-term health of fish populations.

Offshore subtidal sands and gravels

Offshore subtidal sands and gravels in Scotland are designated as PMFs due to their ecological significance and the valuable habitats they provide. These habitats encompass diverse sandy and gravelly seabed areas that support a wide range of marine organisms. They serve as biodiversity hotspots, providing shelter, food, and breeding grounds for various species including sand eels, flatfish, brittle stars, and burrowing anemones. These habitats are essential as nursery grounds for many fish species, supporting the growth and development of juvenile fish before they move into other habitats.

They also serve as important feeding areas, sustaining bottom-dwelling organisms and filter feeders. The organic matter and nutrients present in these habitats support the survival and growth of many marine organisms. Offshore subtidal sands and gravels play a crucial role in maintaining sediment stability, preventing erosion, and providing a stable substrate for other organisms such as burrowing species. The conservation of these habitats is vital for maintaining the overall health and functioning of the marine ecosystem.

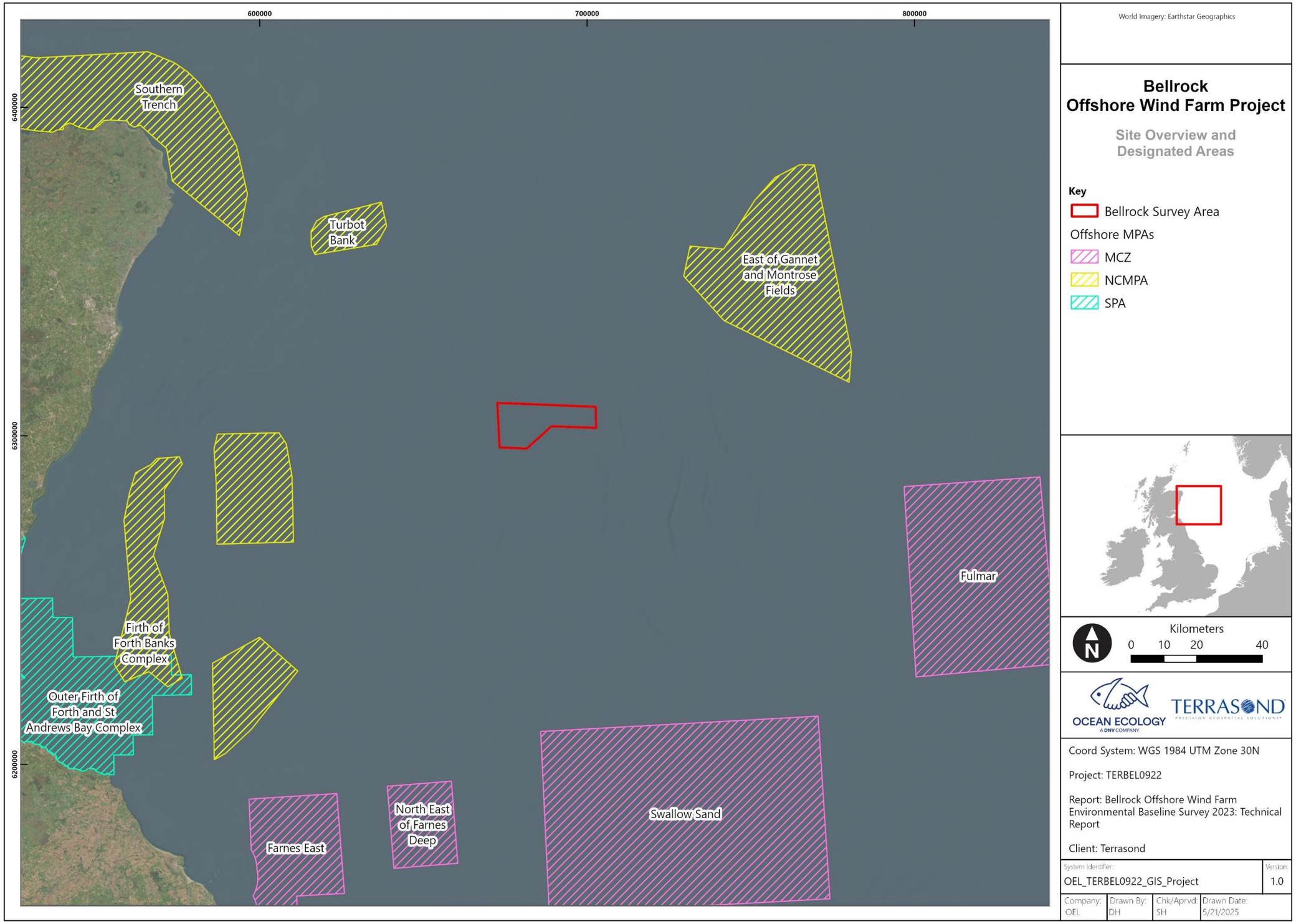

Figure 2. Overview of the Bellrock WFDA benthic characterisation survey area in relation to designated MPAs in the North Sea.

3. Survey Design

3.1. Rationale

A sampling plan was developed to provide adequate spatial coverage throughout the area of interest. In the absence of geophysical datasets at the sampling design stage, consideration was given to the recommendations of best practice guidance (Saunders et al., 2011 and Natural England, 2021) whilst also accounting for all surface, subsurface, and subsea hazards, and their respective exclusion / buffer zones if / where present. To maximise the likelihood that all sediment types within the survey area were adequately sampled and to reduce the likelihood of bias of sampling towards or against regularly spaced features, the number of sampling stations originally proposed based on the assumption of geophysical data being available (75 stations in total) was increased by 50 % (113 stations in total) (Noble-James et al., 2018 and Saunders et al., 2011). Indicative broad scale habitats (BSHs) were inferred from EMODnet datasets (EUSeaMap 2021) to inform micrositing of sampling locations within the grid design.

The sampling array consisted of 113 predetermined sampling stations across the survey area. The sampling stations were placed at 1 km intervals along 14 transects each separated by 2.5 km and orientated in a north to south arrangement. This captured the depth profile of the survey area from 60 m below LAT to 110 m below LAT within the Bellrock WFDA boundary.

3.2. Sampling Approach

At each sampling station, high-resolution seabed imagery (stills and video) was first collected using DDC to i) determine the suitability of the station for grab sampling (i.e., no hazards or sensitive habitat) and ii) provide an indication of the epibiota present at each location. If during this pre-screening exercise the sampling stations were deemed inappropriate for grab sampling (e.g., presence of biogenic reef habitat), the sampling station was repositioned in a nearby area of sediment and revisited with DDC prior to grab sampling. Stations were then sampled with a 0.2 m^2 dual Van Veen (DVV) grab sampler if prior visual inspection deemed the sediment suitable.

3.3. Timing

The sampling was undertaken during periods of favourable weather between the 5th and 28th of July 2023.

4. Field Methods

4.1. Project Parameters

4.1.1. Horizontal Datum

Table 1 Geodetic and projection parameters

Parameter	Details
Name	World Geodetic System 1984 (WGS84)
Ellipsoid	WGS 84
Semi-Major Axis (a)	6378137.000 m
Semi-Minor Axis (b)	6356752.314 m
Inverse Flattening	298.257 223 563
Geodetic parameters EPSG Code	4326
Projection	Universal Transverse Mercator (UTM)
Zone	30 North
Central Meridian	3° West
Latitude of Origin	0°
False Easting	500 000.00 m
False Northing	0.00 m
Scale Factor at Central Meridian	0.9996
Projected coordinate system EPSG code	32630
Units	metres

4.1.2. Datum Transformation Parameters

All data was referenced to WGS84, UTM 30N, with no datum transformation required.

4.1.3. Vertical Datum

All altitude and depth data above seabed shall was referenced to LAT. All depth data below the seabed was referenced to LAT with depth below seabed included in brackets. LAT was derived using a Vertical Offshore Reference Frames (VORF) model.

4.1.4. Unit Format and Conversions

The following have been used throughout this project and are expressed using the following conventions.

Table 2 Project unit format and convention details.

Unit Formats and Conventions	
Geographical Coordinates	Latitude N DD˚MM.mmmmmm' to 6 decimal places. Longitude E/W DD˚MM.mmmmmm' to 6 decimal places.
Grid Coordinates	Meters in the following format: Easting EEE EEE.eee m to 3 decimal places. Northing NNN NNN.nnn m to 3 decimal places.
Linear distances	Meters to 1 decimal places.
Offset measurement sign conventions	Meters in the following format: 'Y' is positive forward. 'X' is positive to starboard. 'Z' values are positives upwards from the waterline.
Time	UTC (GMT).

4.2. Survey Vessel

Sampling was conducted aboard the 26 m MCA Category 1 coded survey vessel 'DSV Curtis Marshall'. The vessel was mobilised from Hartlepool on the east coast of England and operations were performed on a 24-hour basis.

Table 3 Vessel details

Vessel Name	DSV Curtis Marshall
Area of operation	Offshore
Call Sign	2HWN3
MMSI	235107219
Mobilisation Port	Hartlepool
Length	26 m
Beam	7.7 m
Draft	2.8 m

Plate 1 DSV Curtis Marshall.

4.3. Survey Navigation

4.3.1. Surface Positioning

Surface positioning aboard the DSV Curtis Marshall was determined using a Hemisphere V104s Global Positioning System (GPS) compass system. The Hemisphere V104s internal GPS receiver utilises a minimum of 4 GPS satellites, managing the navigation information required to obtain a position within 3 m at 95 % accuracy. The V104s automatically tracks Satellite-Based Augmentation System (SBAS) differential correction to improve position accuracy to > 1 m at 95 % accuracy. The V104s includes an integrated gyro and two tilt sensors to provide an accurate heading for navigation software.

4.3.2. Subsea Positioning

The vessel was equipped with an Easytrak Nexus 2 Lite USBL system and 1329A Omni-directional +/- 90 ° Micro Beacons for subsea positioning of the camera and grab. The Easytrak Nexus 2 Lite is an advanced USBL positioning and tracking system that determines the position of dynamic subsea targets through the transmission and reception of acoustic signals between the submerged transceiver and a target beacon. The USBL was fully calibrated prior to survey operations using a Valeport SWiFT sound velocity profiler (SVP). Readings were obtained daily from both the up-cast and down-cast.

4.3.3. Navigation Software

A vessel-based positioning system was employed utilizing EIVA NaviPac V4.6 software to ensure the accurate positioning of the vessel and subsea positioning of the sampling equipment via the USBL system as well as recording continuous track plots of the sampling equipment and recording sampling fixes. A navigation screen, displaying EIVA Helmsman Display was provided at the helm position of the vessel for the Officer on Watch.

4.3.4. Positional Checks & Calibrations

The GPS has an internal precision calculation which outputs a graphical representation of horizontal accuracy, displaying numerical precision as easting and northing. The accuracy of vessel heading, and reference systems was verified during mobilisation using agreed reference points.

A USBL calibration was undertaken using the inbuilt Easytrak Nexus calibration software package to eliminate any alignment errors of the installation. Offsets were measured dynamically between the Easytrak Nexus Transceiver Head and the external sensors interfaced. This enabled accurate operation of the Easytrak Nexus tracking system when pole-mounted onto a vessel with external Vapor Recovery Units (VRU) and gyro.

4.4. Seabed Imagery Collection

Seabed imagery (simultaneous video and stills) was acquired at each station using OEL's SubC Rayfin PLE camera system, set up to obtain 1080p High Definition (HD) video and 20 Megapixel (MP) still images. The camera system (Plate 2) consisted of a SubC Imaging Rayfin PLE camera mounted in a Clear Liquid Optical Chamber (CLOC) (otherwise known as a 'freshwater lens') filled with fresh water to ensure imagery of suitable quality is obtained regardless of turbidity. The frame included LED strip lamps and a 10 cm point laser scaling array that was projected into the field of view, a 300 m umbilical and topside computer. The camera was powered with the use of an Uninterruptable Power Supply (UPS) to ensure no damage was caused should the vessel have lost power or in case of a power surge. A full redundancy SubC Rayfin PLE camera system was stored onboard for use if required.

The CLOC was height and angle adjustable providing a variety of options for view, lighting, and focal length to maximise data quality with respect to prevailing conditions (e.g., high turbidity).

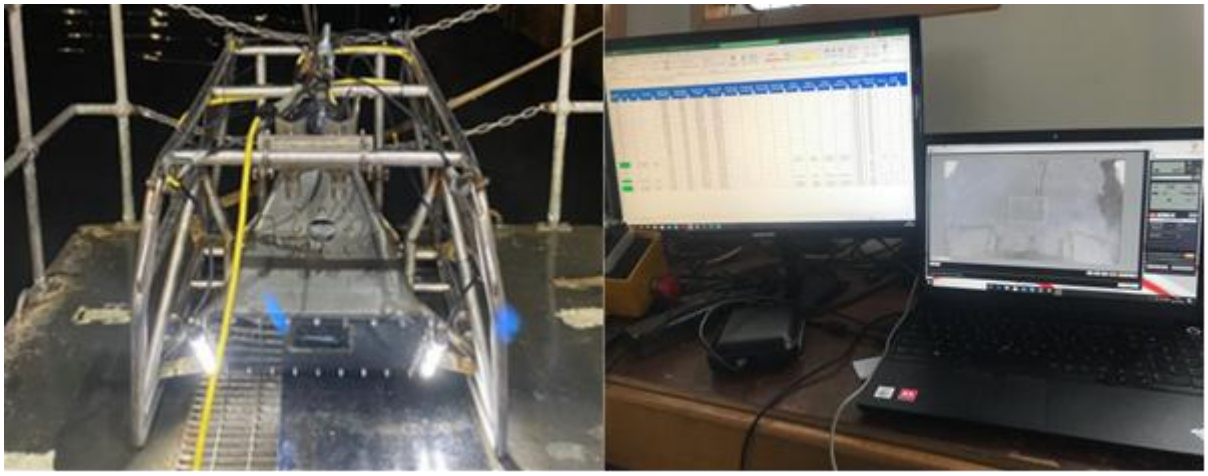

Plate 2 Left: OEL CLOC camera system. Right: The camera system topside setup.

All DDC stations were sampled in consideration of the Joint Nature Conservation Committee (JNCC) epibiota remote monitoring operational guidelines (Hitchin et al. 2015).

The camera system was deployed from the hydraulic 'A' frame on the aft deck of the DSV Curtis Marshall using the following method:

- As the vessel approached the target location, deck personnel began to prepare lifting equipment, camera, and umbilical.
- Deck personnel were alerted by the vessel master once on position, and the camera was raised using the A-frame and deck winch and lowered into the water column. The umbilical was payed out by hand.
- Once the camera system was within 5 m of the seabed, video recording was started, and the camera was gently lowered and landed on the seabed.
- Once any disturbed sediment/ debris had cleared, still images could be taken. Images were taken every 5-10 m using a 'bed-hopping' approach. The vessel was manoeuvred within a 20 m radius of target location, and the camera was raised from the seabed between capturing still images. This ensured broad coverage around the target location.
- Following the capture of the final image, the camera was lifted, video recording was stopped, and the camera could be slowly brought to the surface.
- The winch operator then took the tension on the wire and the deck crew ensured the camera umbilical was free for recovery. The umbilical was reeled in as the camera was lifted.
- Once the vessel master had confirmed sea conditions were suitable, the camera system was recovered aboard and lowered onto the deck.

All footage underwent a preliminary review in situ by OEL's onboard Environmental Scientists. Videos were recorded in a digital format direct to topside hard disk drives (HDDs) and digitally overlaid retrospectively with information including project, date, time, depth, and coordinates.

Detailed notes were taken of visible sediment conditions and seabed features, obvious fauna, and habitat-related features whilst in the field.

4.5. Sediment Sampling

Sediment samples were collected from within 20 m of the target sampling location using OEL's 0.2 m^2 (2 x 0.1m^2) DVV grab sampler. A 0.1 m^2 mini Hamon grab sampler was kept onboard as back up for sampling coarser sediments, although this was not required, and all samples were collected using the DVV (Plate 3).

A single deployment of the DVV yielded two samples of approximately 5-10 L each at each station for macrobenthic and PSD analysis. A sub-sample of the sediment (approx. 0.5 L in volume) was removed from the first sample for characterisation of the physical nature of the substrate (via PSD analysis). The second sample, from the other side of the DVV, was elutriated through a 1.0 mm sieve and retained for macrobenthic analysis.

The grab sampler was deployed from the port side of the DSV Curtis Marshall using the main deck crane.

To ensure consistency in sampling, grab samples were screened by the lead Ecologist and considered unacceptable if:

- Sample replicates were less than 5 L. i.e., the sample represented less than approx. a half of the 10 L capacity of the grab used.
- 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 (beyond 20 m).
- There was obvious contamination of the sample from survey equipment, paint chips etc.

Should a grab have failed, a second and third attempt were conducted at the same site of the first failed attempt. Following three failed attempts, the vessel should move at least 50 m from the initial target station location for a fourth attempt. If the fourth attempt failed, the station may be abandoned. No pooling of samples will take place. However, where samples of less than 5L were continually achieved, these samples were retained and assessed to establish if the sample volume was acceptable to allow subsequent analysis.

Plate 3 Left: OEL's 0.2 m^2 DVV grab sampler. Right: OEL's 0.1 m^2 mini-Hamon grab sampler.

4.6. Water eDNA Sampling

Water samples were taken at 2 m above the seabed, mid-water depth and 2 m below the surface using a 5 L Niskin bottle attached to the deployment cable using bulldog clips and friction tape. When the equipment was at the desired depth a messenger weight was attached to the deployment wire and sent to trip the sampler. When the equipment reached the surface, it was recovered to deck and the sampler removed. A Vampire Pump was attached to the outlet of the Niskin bottle and eDNA sample processed as follows (detailed further in Appendix I):

- The pump was run slowly by pressing the drive unit trigger to fill the hose with water,
- Once the hose was filled, the filter inlet (narrow end) was attached to the hose adapter,
- The pump was run slowly to begin with, while holding the hose securely just behind the adaptor,
- When the flow of water leaving the filter outlet (wide end) slowed, the pump speed was decreased to reduce the build-up of pressure,
- Once all water had passed through the filter, or the filter was fully clogged, the hose was removed from the sample and the pump run until the hose was cleared of any water. The pump was run until no more water exited from the filter, to expel as much water as possible. The filter was then detached from the hose,
- A preservative solution was applied to the filter which was then placed into the specimen bag and seal,
- Samples were frozen immediately.

- The remaining sample (retained for faunal sorting and identification) was emptied onto a 1.0 mm sieve net laid over a 4.0 mm sieve table and washed through using gentle rinsing with a seawater hose.
- This remaining sample was backwashed into a suitably sized sample container and a diluted 10 % formalin solution was added to fix the sample prior to laboratory analysis.
- Sample containers were clearly labelled internally and externally with date, sample ID and project name.

Detailed field notes were taken including station number, fix number, number of attempts, sample volume, sediment type, conspicuous fauna, any sign of protected features, and water depth.

5. Laboratory and Analytical Methods

5.1. Particle Size Distribution (PSD) Analysis

PSD analysis of the sediment samples was undertaken by in-house laboratory technicians at OEL's NMBAQC participating laboratory in line with NMBAQC best practice guidance (Mason 2016).

Frozen sediment samples were first transferred to a drying oven and thawed at 80°C for at least 6 hours before visual assessment of sediment type. 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. A representative sub-sample of the whole sample was then removed for laser diffraction analysis before the remaining sample screened over a 1 mm sieve to sort coarse and fine fractions. The >1 mm fraction was then returned to a drying oven and dried at 80°C for at least 24 hours before dry sieving.

Once dry, the sediment sample were run through a series of Endecott BS 410 test sieves (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 4.

Table 4 Sieve series employed for PSD analysis by dry sieving.

Sieve aperture (mm)												
63	45	32	22.5	16	11.2	8	5.6	4	2.8	2	1.4	1

The sample was then transferred onto the coarsest sieve at the top of the sieve stack and shaken for a standardised period of 20 minutes. The sieve stack was checked to ensure the components of the sample had been fractioned as far down the sieve stack as their diameter would allow.

The sub-sample for laser diffraction was first screened over a 1 mm sieve and the fine fraction residue (<1 mm sediments) transferred to a suitable container and allowed to settle for 24 hours before excess water syphoned from above the sediment surface until a paste texture was achieved. The fine fraction was then analysed by laser diffraction using a Beckman Coulter LS13 320.

The dry sieve and laser data was then merged for each sample with the results expressed as a percentage of the whole sample. Once data was merged, PSD statistics and sediment classifications were generated from the percentages of the sediment determined for each sediment fraction using Gradistat v9 software.

Sediment descriptions are defined by their size class based on the Wentworth classification system (Wentworth 1922) (Table 5). Statistics such as mean and median grain size, sorting

coefficient, skewness and bulk sediment classes (percentage silt, sand and gravel) were derived following the Folk classification (Folk 1954).

Table 5 The classification used for defining sediment type based on the Wentworth Classification System (Wentworth 1922).

Wentworth Scale	Phi Units (φ)	Sediment Types
>64 mm	<-6	Cobble and boulders
32 – 64 mm	-5 to -6	Pebble
16 – 32 mm	-4 to -5	Pebble
8 – 16 mm	-3 to -4	Pebble
4 - 8 mm	-3 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

5.2. Chemical Contaminants Analysis

All chemical contaminant analysis were undertaken by UKAS accredited and Marine Management Organization (MMO) Validated laboratory SOCOTEC UK Limited. Cores were processed and analysed for Total Hydrocarbon Content (THC), Polycyclic Aromatic Hydrocarbons (PAH), Polychlorinated biphenyls (PCB), organotins, and Heavy and Trace Metals. A description of the methods used to test for each chemical determinand is provided in Table 6 and Appendix II.

Table 6 Chemical contaminant analysis methods.

Determinand	Detection Limit	Method/ Instrument
THC (inc. saturates)	100µg/kg (Total) 1µg/kg (Individual alkanes)	Solvent extraction & GC-FID
PAHs (DTI 2-6 ring aromatics + EPA 16)	1µg/kg	Solvent extraction & GC-MS
Metals suite: As(0.5), Cd(0.04), Cr(0.5), Cu(0.5), Pb(0.5), Hg(0.01), Ni(0.5), Zn(2) mg/kg	Detection Limit provided in parentheses in 'Determinand' column,	Aqua Regia extraction and ICPMS
Mercury	0.01mg/kg	Nitric/Peroxide extraction and ICPMS

5.2.1. Hydrocarbons

Indices and ratios were calculated to assess source origin of hydrocarbons in the sediment sampled across the survey area. Generally, there are three sources of hydrocarbons depending on their origin: biogenic, petrogenic and pyrogenic. Hydrocarbons of biogenic origin are the produce of biological processes or early diagenesis in marine sediments (e.g., perylene) (Venkatesan 1988, Junttila et al. 2015). Hydrocarbons of petrogenic origin are the compounds present in oil and some oil products following low to moderate temperature diagenesis of organic matter in sediments resulting in fossil fuels. Hydrocarbons of pyrogenic origin are the product of incomplete combustion of organic material (Fagbote 2013), such as forest fires and incomplete combustion of fossil fuels.

Based on aliphatic hydrocarbons and n-alkanes, if possible, the following index and ratios were calculated:

Pristane / Phytane (Pr/Ph) ratio: values close to one indicate a dominance of petrogenic sources of n-alkanes, values between one and three indicate a biogenic predominance of n-

alkanes with a likely planktonic influence, values higher than three can indicate a terrestrial origin of n-alkanes, while ratios below one indicate a predominance of pyrogenic sources of n-alkanes (Moustafa and Morsi 2012). Pristane is typically found in marine organisms, while phytane is a component of oil (Guerra-García et al. 2003), hence the use of this ratio to assess the source origin of hydrocarbons.

Based on polycyclic aromatic hydrocarbon (PAH) compounds the following ratios were calculated as follows:

Light weight PAHs (NPD) are volatile compounds that break down more easily than their heavier counterparts meaning that elevated NPD can be an indicator of recent sediment contamination. The ratio between NPD and heavy molecular weight (HMW) PAHs is typically used as a proxy to determine the origin source of PAH compounds in sediments, ratios above one indicate a petrogenic source while ratios below one indicate a pyrogenic source. NPD include compounds with 2-3 rings while HMW PAHs include compounds with more than 4 rings (Edokpayi et al. 2016).

Phenanthrene / Anthracene ratio: values lower than 10 indicate a pyrogenic source origin for the hydrocarbons; while values higher than ten account for hydrocarbons of petrogenic origin (Kafilzadeh et al. 2011).

Fluoranthene / Pyrene ratio: for values higher than one, the hydrocarbons are pyrogenic in origin, for values below one, the hydrocarbons are petrogenic in origin (Kafilzadeh et al. 2011).

5.2.2. Heavy and Trace Metals

A total of 8 main heavy and trace metals were analysed from sediments taken across the survey area. These were Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), and Zinc (Zn).

Where available, metal concentrations were compared to the OSPAR Background Assessment Concentration (BAC) (OSPAR et al. 2009), the USA Environmental Protection Agency (EPA) Effect Range Low (ERL) (NJDEP 2009), Centre for Environment, Fisheries and Aquaculture Science (DEFRA 2003)Action Level (AL) 1 and AL 2, and the Canadian sediment quality guideline (CSQG) Threshold Effect Level (TEL) and Probable Effect Level (PEL)(CCME 2001). To note that ERL, TEL and PEL are based on field research programmes based on North American data that have demonstrated associations between chemicals and biological effects by establishing cause and effect relationships in particular organisms(CCME 2001). This means they provide a measure of environmental toxicity compared to the other reference levels which instead provide information on the degree of contamination of the sediments. At levels above the TEL, adverse effects may occasionally occur, whilst at levels above the PEL, adverse effects may occur frequently; concentrations below the ERL rarely cause adverse effects in marine organisms. Additionally, the TEL has been adopted as the International Sediment Quality Guideline (ISQG) (CCME 2001), while ERL has been adopted by OSPAR to assess the ecological

significance of contaminant concentrations in sediments, where concentrations below the ERL rarely cause adverse effects in marine organisms. For these reasons ERL, TEL and PEL are presented here as reference values despite being based on North American data.

BACs were developed to assess the status of contaminant concentrations in sediment within the OSPAR framework with concentrations significantly below the BAC considered to be near background levels for the North-East Atlantic. Cefas ALs are used as part of a 'weight of evidence' approach to assessing dredged material and its suitability for disposal to sea (DEFRA 2003). Contaminant levels in dredged material which fall below AL1 are of no concern and are unlikely to influence decision-making, while contaminant levels above AL2 are generally considered unsuitable for at-sea disposal.

5.3. Macrobenthic Analysis

All elutriation, extraction, identification, and enumeration were undertaken at OEL's NMBAQC scheme participating laboratory in line with the NMBAQC Processing Requirement Protocol (Worsfold and Hall 2010). All processing information and macrobenthic records were recorded using OEL's cloud-based data management application ABACUS that employs MEDIN validated, controlled vocabularies ensuring all sample information, nomenclature, qualifiers, and metadata are recorded in line with international data standards.

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 samples were then re-sieved over a 1 mm mesh sieve to remove all remaining fine sediment and fixative. The low-density fauna was then separated by elutriation with freshwater, poured over a 1 mm mesh sieve, transferred into a Nalgene and preserved in 70 % Industrial Denatured Alcohol (IDA). The remaining sediment from each sample was subsequently separated into 1 mm, 2 mm and 4 mm fractions and sorted under a stereomicroscope to extract any remaining fauna (e.g., high-density bivalves not 'floated' off during elutriation).

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 utilises the live link within ABACUS to the World Register of Marine Species (WoRMS) web services to ensure the most up to date taxonomic classifications are recorded. Colonial fauna (e.g., hydroids and bryozoans) were identified to species level where possible and recorded as present (P). For subsequent data analysis, taxa recorded as P were given the numerical value of 1. A full reference collection was retained including at least one example specimen of each taxon.

Biomass was measured as blotted wet weight in grams to at least 4 decimal places for all countable taxa (i.e., at species level where possible). As a standard, the conventional conversion factors as defined by (Eleftheriou and Basford 1989) was 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%
- Miscellaneous = 15.5

5.3.1. Data Truncation and Standardisation

The macrobenthic taxon list was checked using the R package "*worms*" (Holstein 2018)to check against WoRMS taxon lists and standardise species nomenclature. Once the species nomenclature was standardised in accordance with WoRMS-accepted species names, the species list was examined carefully by a senior taxonomist to truncate the data, combining species records where differences in taxonomic resolution were identified.

5.3.2. Pre-Analysis Data Treatment

All data were collated in excel spreadsheets and made suitable for statistical analysis. All data processing and statistical analysis was undertaken using R v 1.2 1335 (R Core Team, 2022) and PRIMER v7 (Clarke and Gorley 2015) software packages.

In accordance with the OSPAR Commission guidelines (OSPAR 2004) records of colonial, meiofaunal, parasitic, egg and pelagic taxa (e.g., epitokes and larvae) were recorded, but were excluded when calculating diversity indices and conducting multivariate analysis of community structure.

Newly settled juveniles of macrobenthic species may at times dominate the macrobenthos, however the OSPAR (2004) guidelines suggest they should be considered an ephemeral component due to heavy post-settlement mortality and not therefore representative of prevailing bottom conditions (OSPAR 2004). OSPAR (2004) further states that "Should juveniles appear among the ten most dominant organisms in the data set, then statistical analyses should be conducted both with and without these in order to evaluate their importance". As juveniles of the family *Ophiuridae, Amphiuridae* and the heart urchin *Spatangoida* appeared in the top ten of the most dominant taxa across survey area, a 2STAGE analysis was conducted to compare the two data sets (with and without juveniles) which revealed a high level of similarity (~94 %) between the two and therefore juveniles were retained in the dataset for all further analyses and discussion.

In accordance with NMBAQC PRP (Worsfold and Hall 2010), Nematoda were recorded during the macrobenthic analysis and included in all datasets for all further analyses and discussion.

5.3.3. Multivariate Statistics

Prior to multivariate analyses, data were displayed as a shade plot with linear grey-scale intensity proportional to macrobenthic abundance (Clarke et al. 2014) to determine the most efficient pre-treatment (transformation) method. Macrobenthic abundance data from grab samples were square-root transformed to prevent taxa with intermediate abundances from being discounted from the analysis, whilst allowing the underlying community structure to be assessed.

The PRIMER v7 software package (Clarke and Gorley 2015) was utilised to undertake the multivariate statistical analysis on the biotic macrobenthic dataset. To fully investigate the multivariate patterns in the biotic data, macrobenthic assemblages were characterised based on their community composition, with hierarchical clustering and non-metric multidimensional scaling (nMDS) used to identify groupings of sampling stations that could be grouped together as a habitat type or community. SIMPER (similarities-percentage) analysis was then applied to identify which taxa contributed most to the similarity within that habitat type or community. A detailed description of analytical routines is provided in Appendix III.

5.4. Determining EUNIS Classifications

Sampling stations were grouped based on their macrobenthic assemblage composition using hierarchical clustering; the SIMPER routine was then applied to identify key and characterising taxa that contributed the most to the similarity within each group. EUNIS classifications were then assigned to each sampling station based on their macrobenthic group and key, characterising taxa as well as based on their sediment type and composition following the latest JNCC guidance (Parry 2019).

5.5. Environmental DNA

5.5.1. Metabarcoding

eDNA extraction and analysis was conducted by industry specialists Nature Metrics. This employed two metabarcoding assays aimed at detecting the full breadth of marine vertebrates present across the survey area including fish (excluding sharks and rays), marine mammal and marine bird species.

DNA from each filter was extracted using a commercial DNA extraction kit with a protocol modified to increase DNA yields. An extraction blank was also processed for the extraction batch. DNA was purified to remove PCR inhibitors using a commercial purification kit. Purified DNAs were amplified with PCR for a hypervariable region of the 12S rRNA gene to target fish species.

A standard analysis, including 12 replicate PCRs per sample was performed. All PCRs were performed in the presence of both a negative control and a positive control sample (a mock

community with a known composition). Amplification success was determined by gel electrophoresis. PCR replicates were pooled and purified, and sequencing adapters were added. Success was determined by gel electrophoresis. Amplicons were then purified and checked again by gel electrophoresis; these were then quantified using a Qubit high sensitivity kit according to the manufacturer's protocol.

All purified index PCRs were pooled into a final library with equal concentrations. The final library was sequenced using an Illumina MiSeq V3 kit at 10.5 pM with a 20% PhiX spike inside. Sequence data was processed using a custom bioinformatics pipeline for quality filtering, Operational Taxonomic Units (OUT) clustering, and taxonomic assignment.

5.5.2. Bioinformatics

Sequence data was processed using a custom bioinformatics protocol for quality filtering, Operational Taxonomic Unit (OTU) clustering (97 %) and taxonomic assignment. Similar sequences were clustered into an OTU at a defined similarity threshold and these units were approximately equivalent to species and treated as such in analyses. Taxonomic assignments were not always possible, as this depends on the availability of reference sequences and the similarity between closely related species in the amplified marker.

The Global Biodiversity Information Facility (GBIF) taxonomic backbone was used for consistency between databases. Results from both searches were combined and assignments made to the lowest possible taxonomic level where there was consistency in the matches. Conflicts were flagged and resolved manually. Minimum similarity thresholds of 98 %, 95 %, and 92 % were required for species, genus, and higher-level assignments respectively. Any identifications that were based on fewer than three reference matches were also flagged.

5.6. Seabed Imagery Analysis

All seabed imagery analysis was undertaken using the Bio-Image Indexing and Graphical Labelling Environment (BIIGLE) annotation platform (Langenkämper et al. 2017) and in consideration of JNCC epibiota remote monitoring interpretation guidelines (Turner et al. 2016) and the latest NMBAQC/JNCC Epibiota Quality Assurance Framework (QAF) guidance and identification protocols.

A full reef habitat assessment was conducted where appropriate to determine whether habitats met the definitions of Annex I reef habitats as detailed in Table 7 and

Table 8. The annotation label tree used during analysis had major headings for each of reef type. Under each reef type labels were assigned for each of the categories required to determine whether reef habitat was present. The full label tree used in the project can be found in Appendix IV.

Table 7 Characteristics of stony reef (Irving 2009).

Characteristic	'Reefiness'			
	Not a 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		

Table 8 Characteristics of *Sabellaria* spinulosa reef (Gubbay 2007).

Characteristic	'Reefiness'			
	Not a Reef	Low	Medium	High
Elevation (cm)	< 2	2 - 5	5 – 10	> 10
Extent (m^2)	< 25	25 – 10,000	10,000 – 1,000,000	> 1,000,000
Patchiness (% Cover)	< 10	10 - 20	20 – 30	> 30

Analysis of still images was undertaken in two stages. The first stage, "Tier 1", consisted of labels that referred to the whole image being assigned, providing appropriate metadata for the image, these included labels such as image quality, broad scale habitat (BSH), EUNIS habitat assigned PMFs and Invasive Non-Native Species (INNS) in line with Parry (2019). Tier 1 analysis is further explained in Section 5.6.1.

The second stage, "Tier 2", was used to assess presence/absence of conspicuous epibiota and to assign percentage cover of 'reef' types by drawing polygons to inform the habitat assessment process and further explained in Section 5.6.2.

5.6.1. Tier 1 Analysis

The first stage, "Tier 1", consisted of assigning labels that referred to the whole image, providing appropriate metadata for the image. Metadata "Image Labels" include:

- Broadscale Habitat (BSH) type.
- Substrate type (and percentage cover in 10% intervals).
- Bedforms present.
- The presence of any Annex I habitats, PMF species or habitats, and INNS. A detailed evaluation of burrows and seapens was conducted in the survey area.
- The presence of any visible impacts or other modifiers (such as discarded fishing gear or marine litter (as per the Marine Strategy Framework Directive (MSFD) categories), visible physical damage to the seabed, evidence of strong currents, non-native species, etc.).
- Image quality categories (including "Not Analysable" category).

Depending on the presence of reef, this will also include:

- Extent: As it is not possible to fully determine the extent of reef habitats from a single image alone this label will be used to identify areas that are highly unlikely to constitute reef habitats. An example is an image that shows a large boulder being preceded and succeeded by images of unconsolidated sandy sediments.
- Biota: Labels assigned to determine whether epifauna dominate the biological community observed.
- Elevation: Labels assigned depending on reef type. Laser points will be used to assist in the assignment of categories.

5.6.2. Tier 2 Analysis

The second stage, "Tier 2", was used to assess epibiota presence / absence data as "annotations" within each image for visible flora and fauna. This was undertaken as follows:

- Using the BIIGLE Annotation Platform enumeration of visible taxa will be undertaken using point annotation. A single representation of each taxa present was assigned a point to generate presence/absence data outputs.
- To assist the Tier 1 analysis of reef presence, polygons were drawn at the Tier 2 stage to delineate percentage cover of biogenic and geogenic reef features.
- Identification of any INNS and species non-native to UK waters. Information was also included on species non-native to the local habitat types (e.g., hard-substrate specialists in a wider sedimentary habitat).

The substratum observed in each still image was recorded as a percentage cover of CATAMI (Althaus *et al.*, 2015)substratum types where possible. Determination of sediment type (such as coarse, mixed, sand etc.) was facilitated using the adapted Folk sediment trigon (Long, 2006a) incorporated into a sediment category correlation table. Percentage cover of the different substrate types was used to determine and assign EUNIS codes and BSH.

5.7. Determining Habitat Classifications

Habitats were identified and classified in accordance with the EUNIS habitat classification system (under the 2012 EUNIS classification system), in considerations of JNCC guidance on assigning benthic biotopes (Parry 2019). Classifications were assigned based on the combined analysis of seabed imagery and BSH data derived from the PSD, alongside existing habitat maps (EMODnet), and acoustic data. Seabed features were assigned the highest level of classification possible. All habitat / biotope determination was undertaken through consideration of the following:

- Existing habitat mapping (derived from EMODnet)
- Review and interpretation of geophysical data
- Seabed imagery

- PSD

5.8. Habitat Mapping

All mapping processes were conducted in ESRI ArcPro Version 3.1.2. All seabed imagery assigned a EUNIS habitat in BIIGLE was utilised alongside the acoustic information and ground-truthed data from the grab samples to manually delineate the boundaries (polygons) of the various habitats and biotopes encountered across the survey area. Confidence scores were assigned to each polygon to give an indication of their accuracy. A value of 1 (low confidence) or 2 (high confidence) was assigned depending on the following:

- Whether ground-truth data was available within the polygon
- Whether multiple data sources confirmed/suggested the presence of the same habitat/biotope within a polygon
- Whether the boundaries of the habitat/biotope were clearly defined either by seabed imagery, ground-truth or acoustic data

Highest scores were given to polygons where all data sources identified the same habitat/biotope, with distinct boundaries. Lower scores were assigned to polygons where ground-truth data is limited, and boundaries not obvious. In these cases, polygons were drawn based upon expert judgement, given the information available.

6. Results

6.1. Geophysical Data

The SSS and MBES data collected by Terrasond during the geophysical survey campaign covered the entire survey area. These data were interpreted together with the seabed imagery, PSD and macrobenthic data to inform the habitat/biotope mapping process (Figure 3).

The SSS displayed typically uniform reflectivity across the survey area. No features of interest presenting as strong reflectivity signatures in the SSS data were observed that could have been interpreted as potential bedrock and biogenic reefs (Figure 3).

Bathymetry data displayed a largely featureless area with no bedforms such as sand ripples or waves. Water depth gradually increased eastward, moving away from the coast, with three narrow and deep channels presenting as linear north-south features occurring at regular intervals laterally across the Bellrock WFDA (east to west) with the deepest reaching up to 120 m of water depth (Figure 3).

6.2. Seabed Imagery

DDC sampling was successfully conducted at 113 stations, resulting in the collection of 647 high resolution still images and 113 HD videos. Full DDC video logs can be found in Appendix V and stills logs in Appendix VI.

Generally, the seabed imagery correlated well with the geophysical data collected across the survey area. The habitat assessment was conducted using the still images captured during the DDC deployments with the main habitat identified based on the seabed imagery. Findings of the image analysis including BSH description and the EUNIS habitat description are presented in Appendix VII.

One BSH and one EUNIS Level 4 (biotope complex) were identified in the seabed imagery collected across the survey area (Table 9)

Table 9 EUNIS BSH and biotope complexes identified in seabed imagery across the survey area.

BSH	EUNIS Code	EUNIS Description
A5.3	A5.37	Deep circalittoral mud

The most common fauna observed captured in the still imagery included seapens, hermit crabs, and sea urchins (Plate 4). No INNS or species non-native to the local habitat type were observed in the seabed imagery.

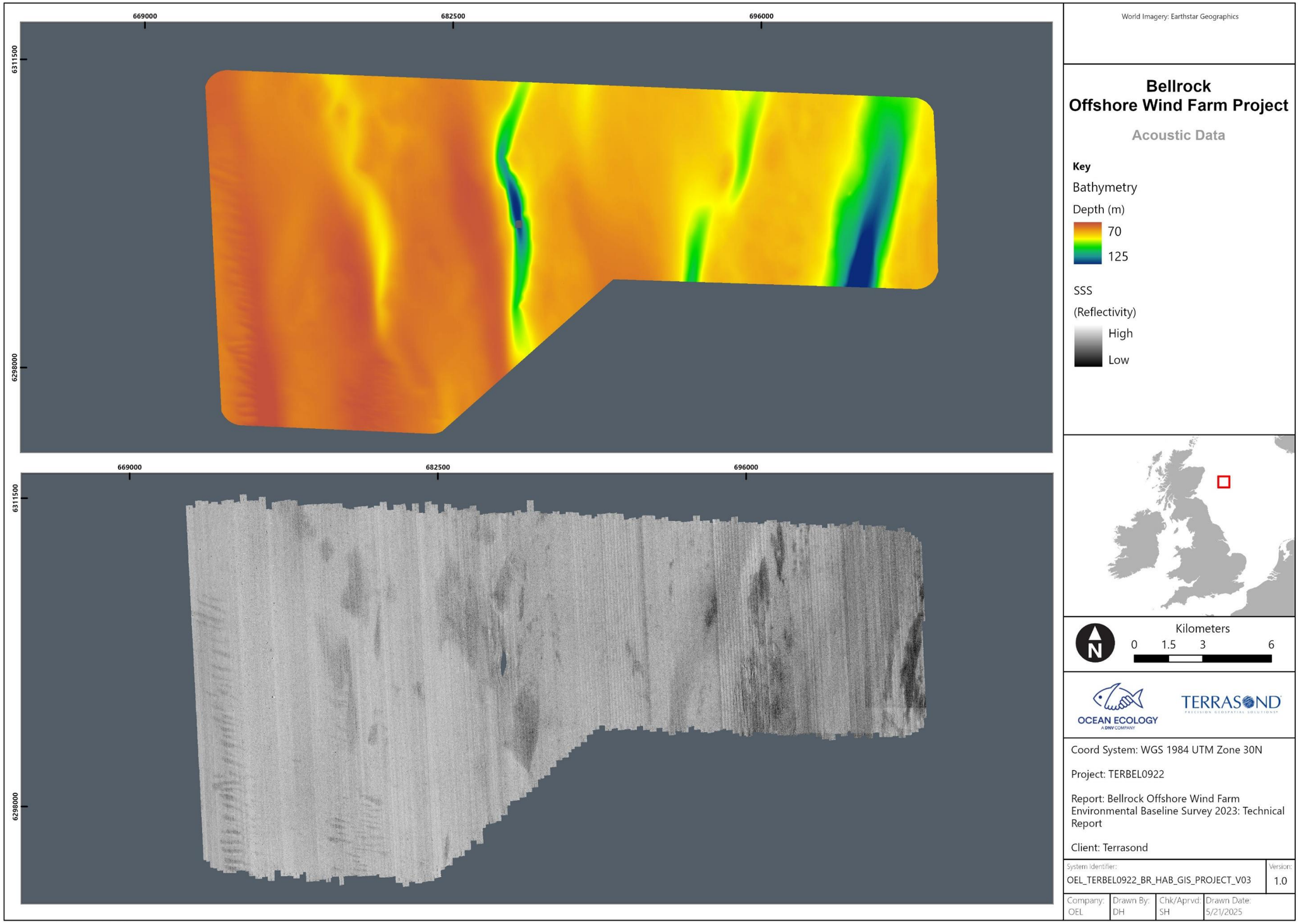

Figure 3 MBES (top) and SSS (bottom) data acquired during the geophysical survey campaign.

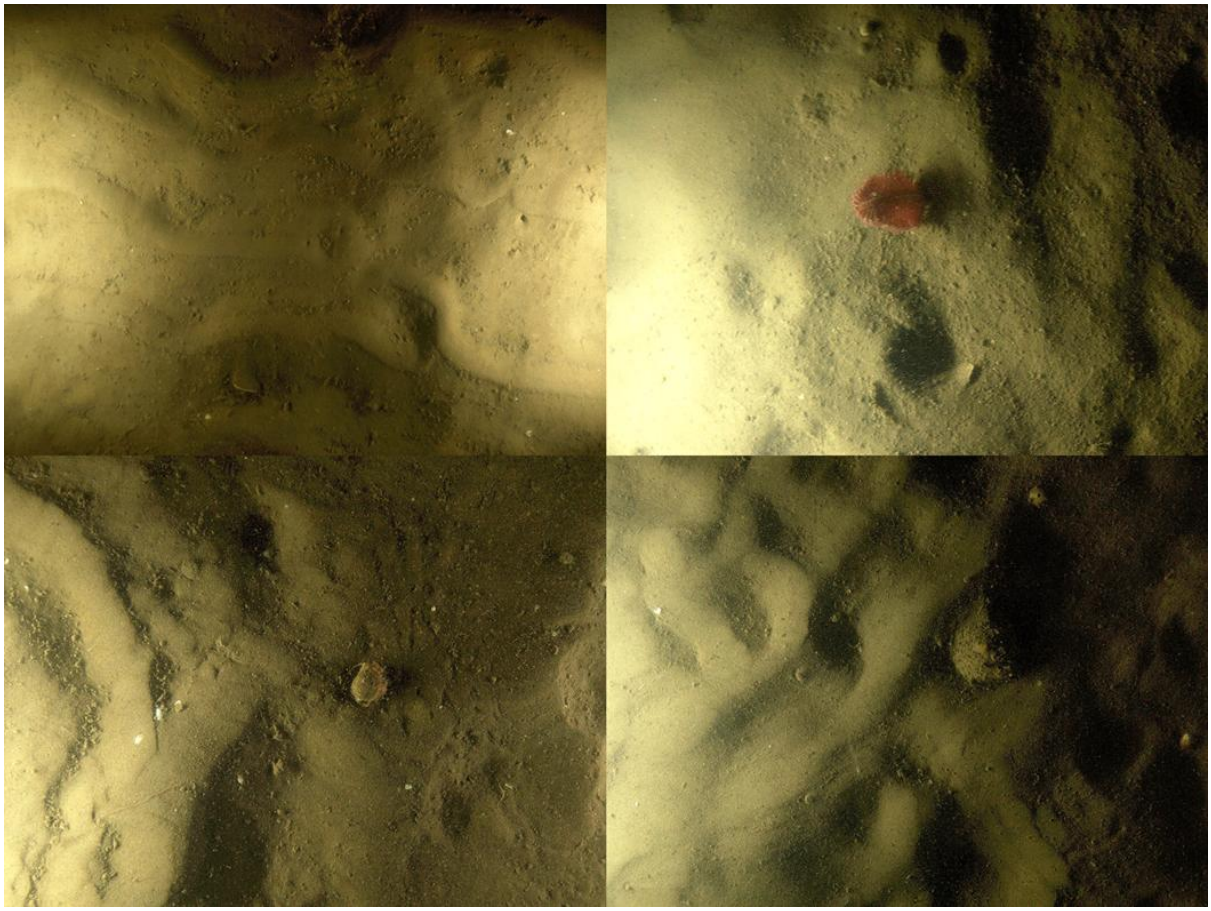

Plate 4 Example seabed imagery collected during the survey. Left to right, top to bottom: Deep circalittoral mud; Seapen *Pennatula phospohorea*; Hermit crab *Paguridae*; Sea urchin *Spatangoida*.

6.3. Other Features of Note

Areas of the PMF habitat burrowed mud were identified in the seabed imagery. An in-depth assessment of this habitat was conducted (Appendix VIII) ultimately determining the average density of burrows per station (Figure 4). Burrows were detected in 59 of the 113 surveyed stations. A further assessment of seapen *Pennatula phosphorea* density was undertaken (Appendix IX), with seapens observed at 16 stations (Figure 5).

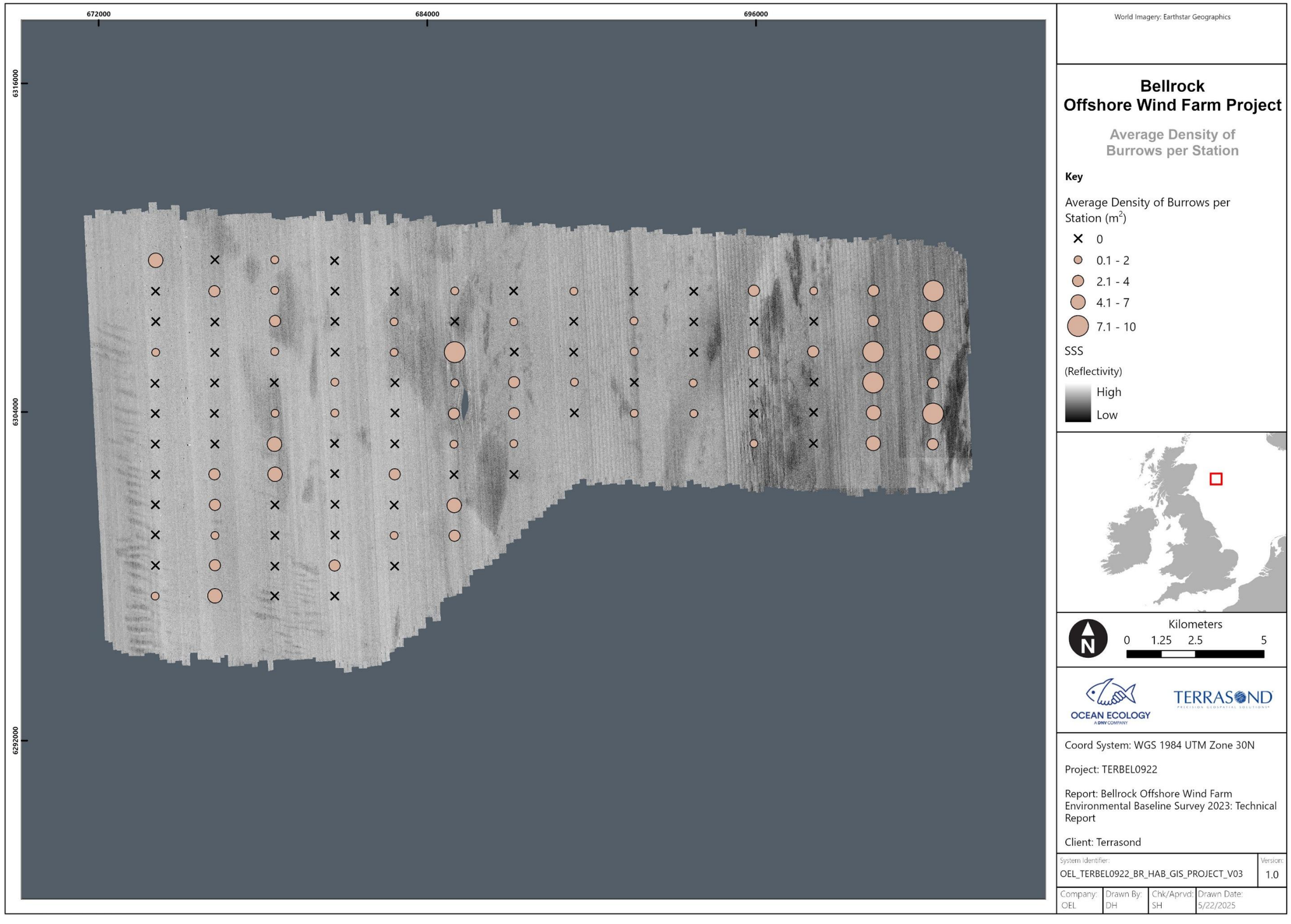

Figure 4 Average density of burrows per station (m^2) across the survey area.

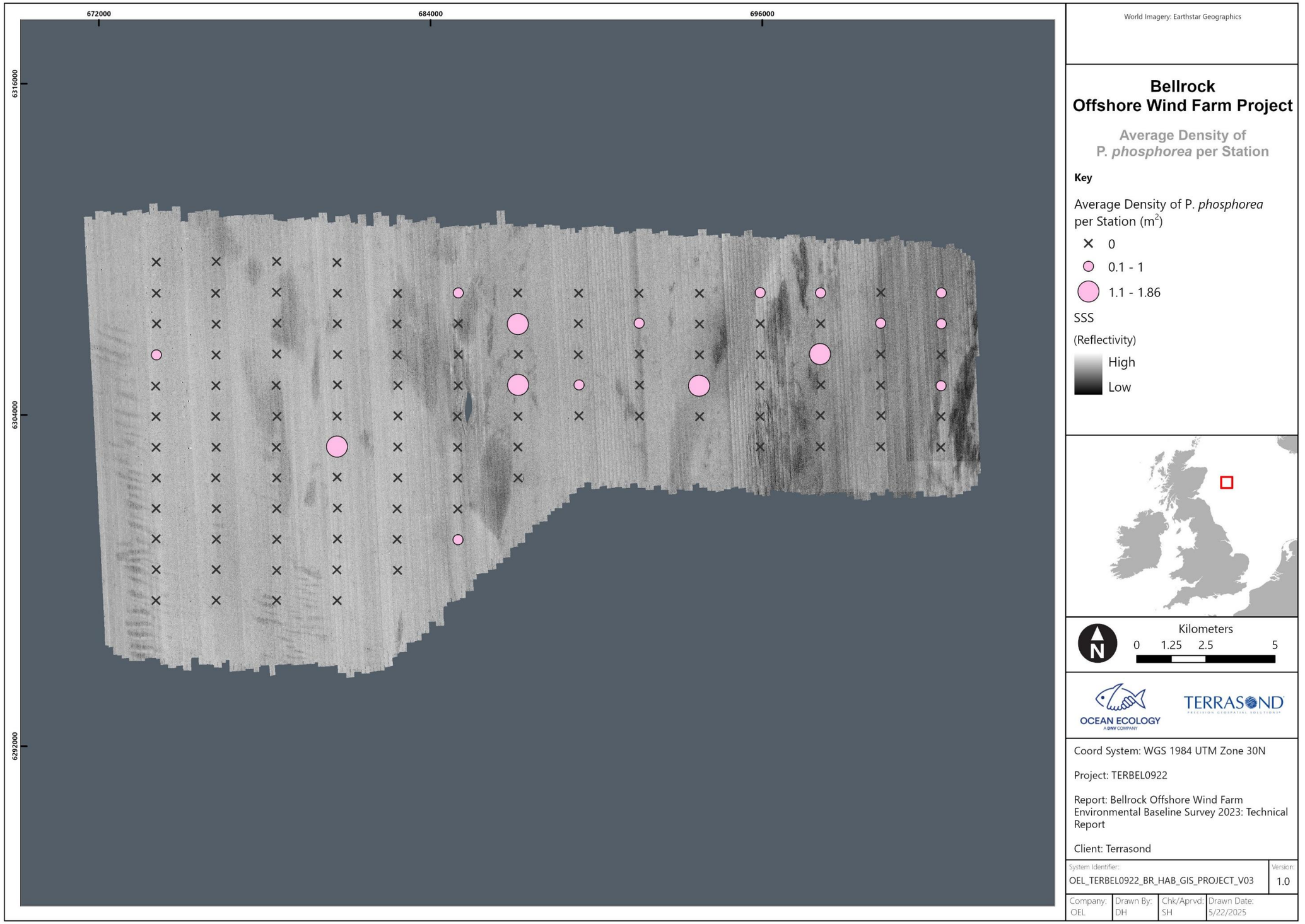

Figure 5 Average density of *P. phosphorea* per station (m^2) across the survey area.

6.4. PSD Analysis

In total, 113 sediment samples were analysed for full particle size classification. Example images of all sampled sediment types are presented in Plate 5 with full particle size data provided in Appendix X and summary data provided in Appendix XI.

6.4.1. Sediment Type

Sediment types, as classified using the Folk triangle (Folk 1954), for each station sampled across the survey area are presented in Figure 6. Each Folk classification was converted to BSH Type (EUNIS Level 3) using the adapted Folk triangle (Long 2006) (Figure 6). Sediments were heterogeneous across the survey area with sand dominating across all stations and variable contributions of mud and gravel. Sediment textural group and BSH are mapped in Figure 7 and Figure 8

Of the 113 sampling stations, 103 stations represented EUNIS BSH A5.2 (Sand and Muddy Sand) including Sand (S), Muddy Sand (mS), Slightly Gravelly Muddy Sand ((g)mS), and Slightly Gravelly Sand ((g)S); 6 stations represented EUNIS BSH A5.3 (Mud and Sandy Mud) including Muddy Sand (mS); and 4 stations represented EUNIS BSH A5.4 (Mixed Sediment) including Gravelly Muddy Sandy (gmS).

6.4.2. Sediment Composition

Sediments across the survey area were characterised predominantly by sand, with varying but generally low gravel and mud content. The percentage of gravels (>2 mm), sands (0.63 mm to 2 mm), and fines (< 63 µm) at each station are presented in Figure 9. The mean proportion (± Standard Error, SE) of sands across all stations was 89 % (± 0.5 %), the mean (± SE) gravel and mud content across the survey area was 0.7 % (± 0.2 %) and 11 % (± 0.45 %) respectively. Spatial trends of sediment composition are mapped in Figure 10.

Plate 5 Sediment types sampled. Left to right: ST0001, Slightly Gravelly Sand. ST0002, Slightly Gravelly Sand .ST0003, Sand. ST0036, Slightly Gravelly Muddy Sand. ST0033, Muddy Sand. ST0031, Gravelly Muddy Sand.

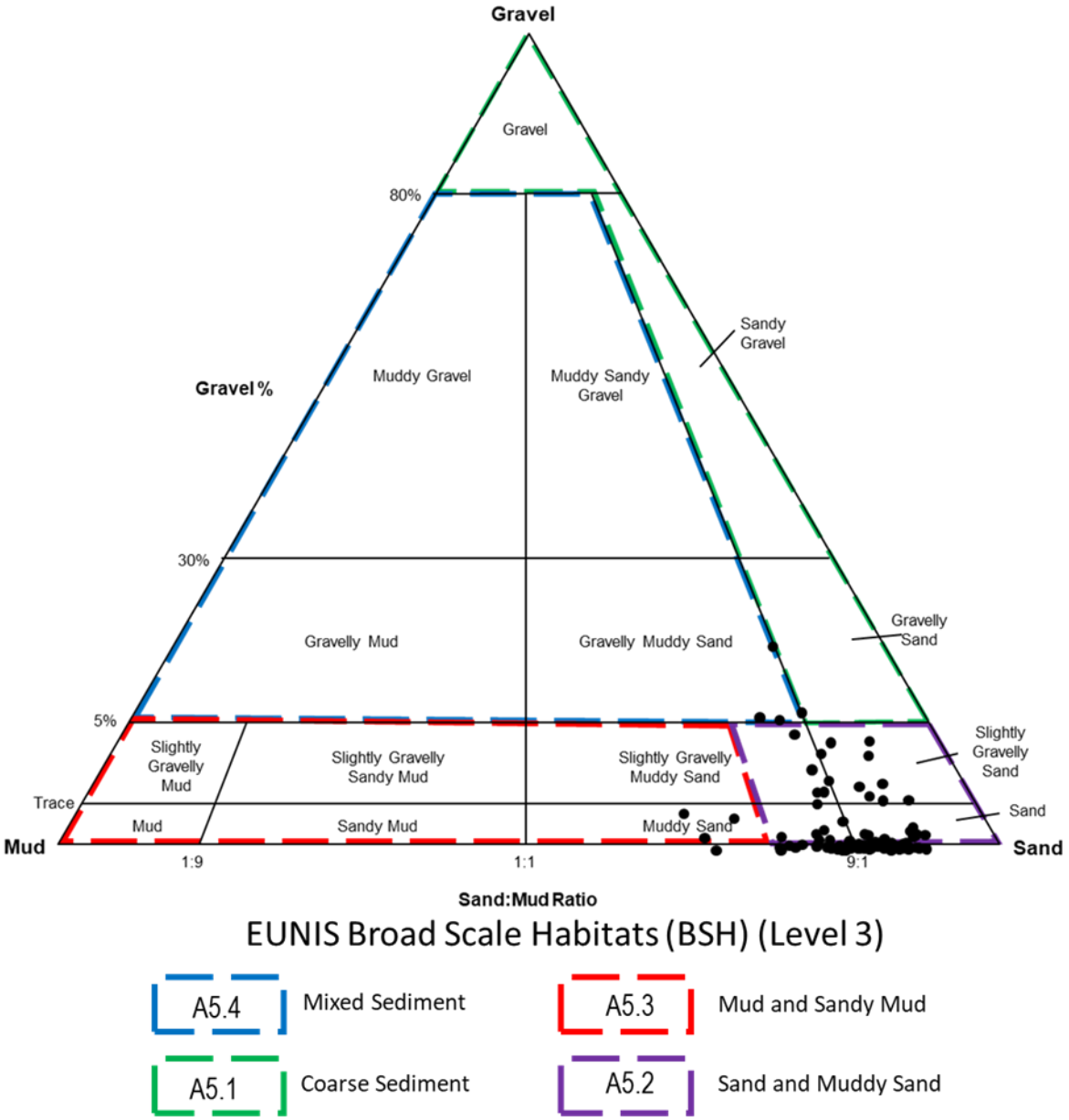

Figure 6 (Folk 1954) triangle classifications of sediment gravel percentage and the sand-to-mud ratio of samples collected during the survey, overlain by the modified Folk triangle for determination of mobile sediment BSHs under the EUNIS habitat classification system (adapted from (Long 2006)).

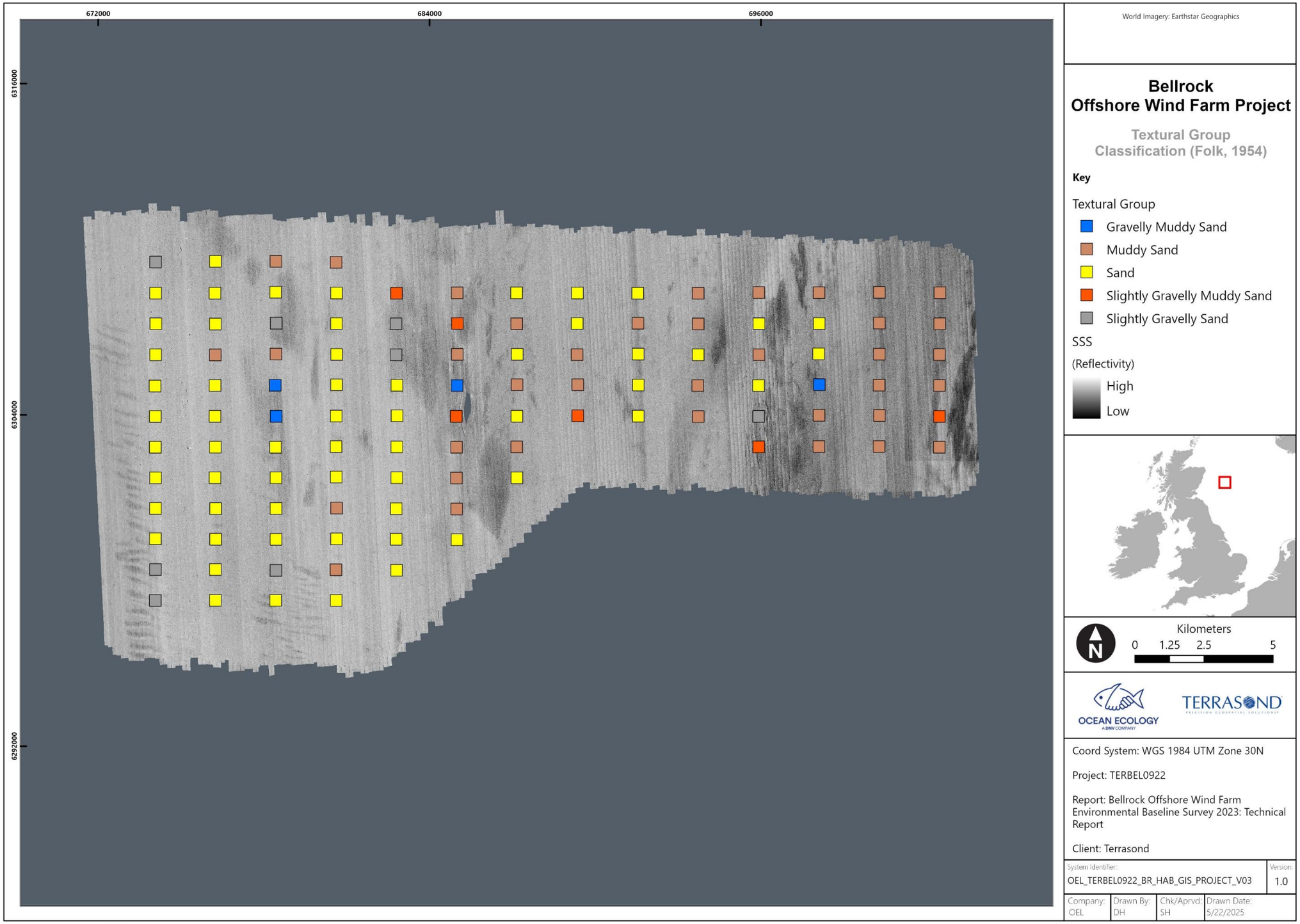

Figure 7 Textural groups as determined from PSD analysis of samples acquired across the survey area.

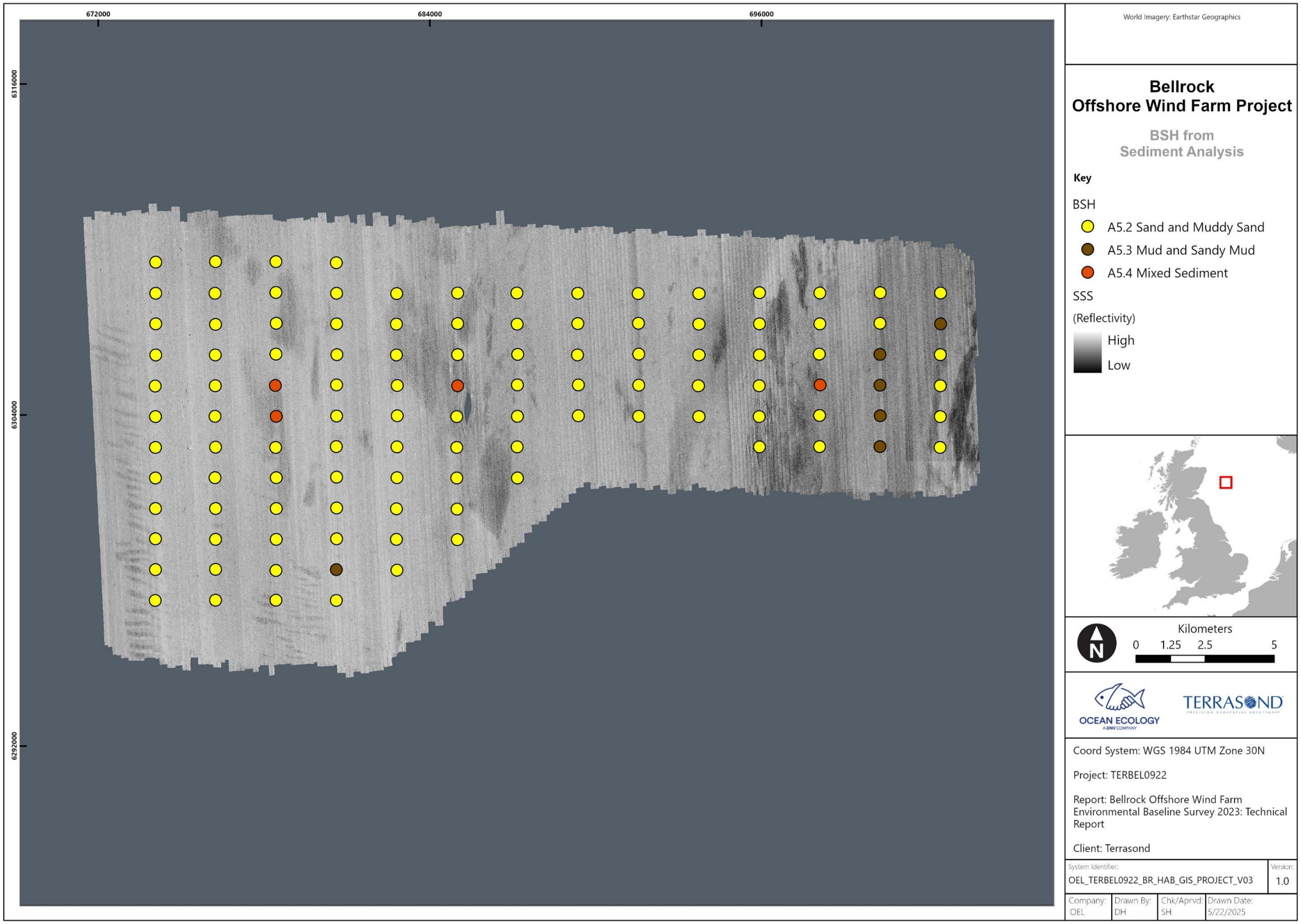

Figure 8 EUNIS BSH classification as determined based on PSD of samples acquired across the survey area.

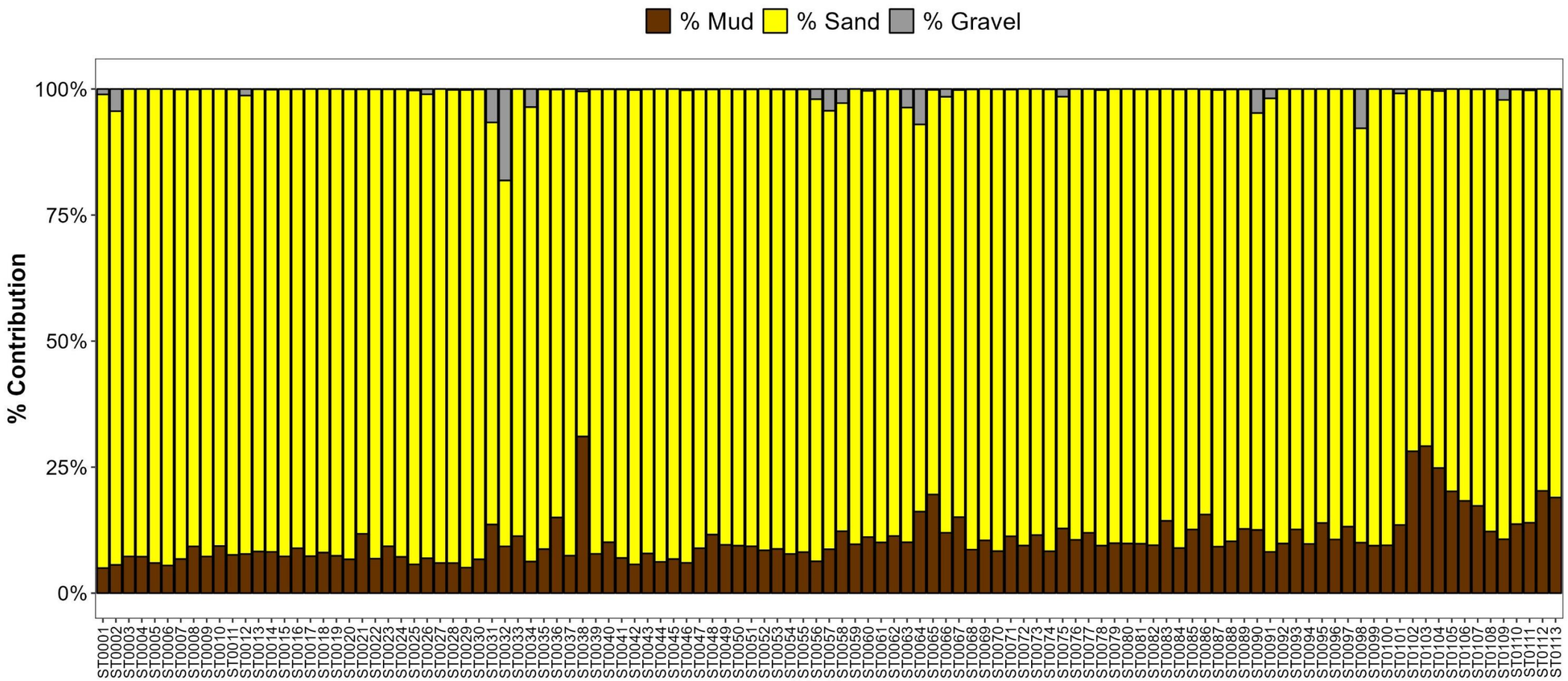

Figure 9 Relative contribution to the volume of sediment at each sampling station across the survey area.

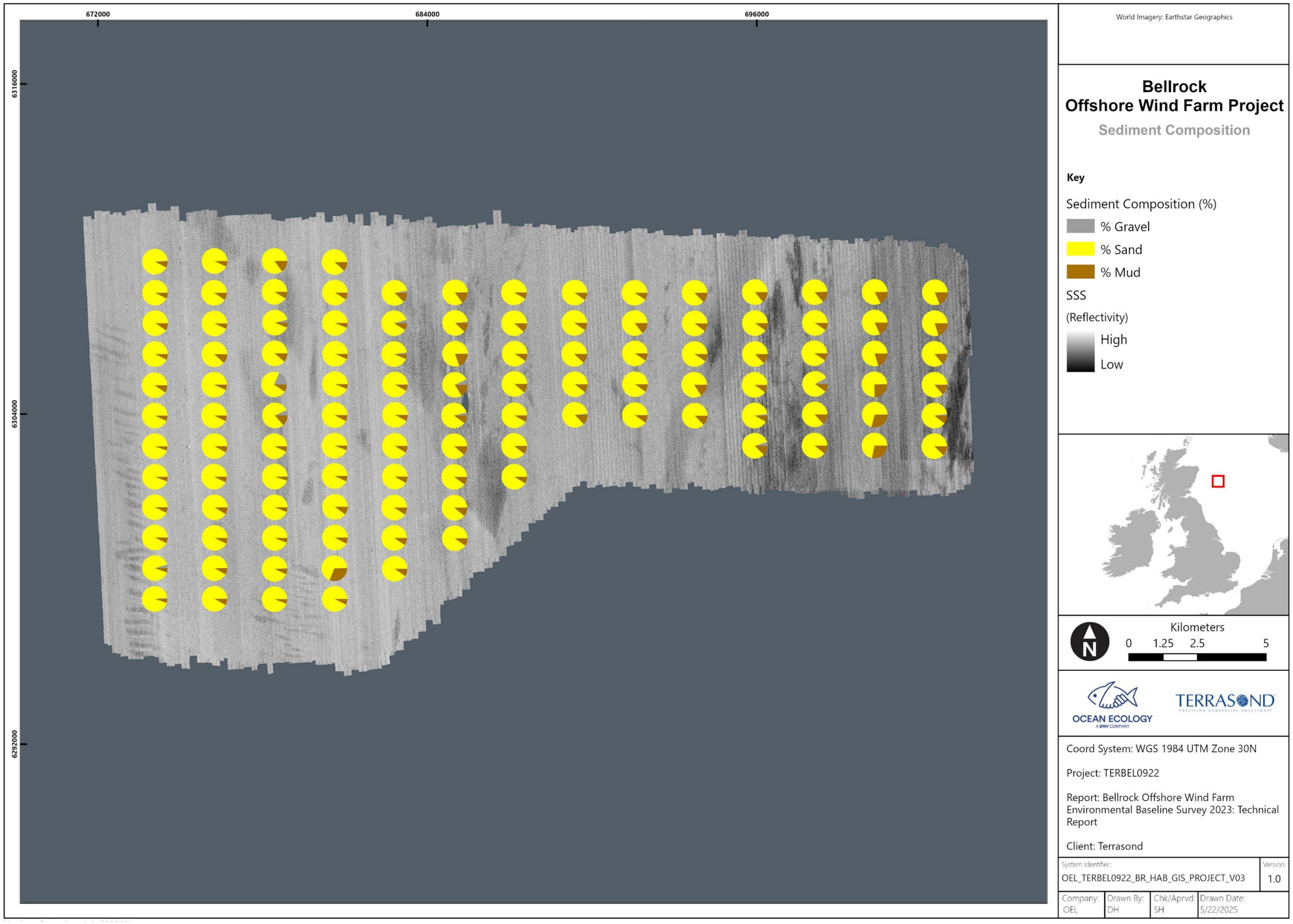

Figure 10 Principal sediment components (gravel, sand, mud) as determined from PSD analysis of samples acquired across the survey area.

6.5. Sediment Chemistry

Sediment samples for chemical contaminant analysis were collected at all stations across the survey area resulting in 15 samples for analysis. Grab samples taken for chemical analyses were analysed for heavy and trace metals, organotins, PHAs, THCs and PCBs. Raw sediment chemistry data are provided in Appendix II.

6.5.1. Heavy and Trace Metals

A total of 8 main heavy and trace metals were analysed from sediment samples and could be compared to national and international reference levels. These were: Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), and Zinc (Zn). Averaged data for the eight main heavy and trace metals (dry-weight concentration, mg kg^{-1}) are shown in Table 10 together with available reference levels. No stations exceeded reference levels for any of the heavy and trace metal analysed.

Table 10 Summary of heavy and trace metal concentrations (mg kg^{1}) in sediments at intertidal stations and reference levels.

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
ST0014	1.60	<0.04	6.80	0.90	0.01	2.50	3.20	8.90
ST0018	2.40	<0.04	8.40	1.10	0.01	3.00	3.60	10.4
ST0022	1.90	<0.04	6.10	0.70	<0.01	2.10	2.50	7.90
ST0038	2.00	<0.04	7.30	0.90	<0.01	2.90	2.80	9.70
ST0042	2.30	0.06	19.2	3.60	0.03	12.9	3.80	23.1
ST0046	2.20	<0.04	8.00	1.20	<0.01	3.30	3.50	10.5
ST0062	2.30	<0.04	8.30	1.10	<0.01	3.20	3.70	9.60
ST0066	1.90	0.05	8.00	1.40	<0.01	3.60	3.60	10.2
ST0076	2.90	0.05	7.90	1.10	0.05	3.00	3.70	9.40
ST0078	2.90	0.04	8.10	1.10	0.02	3.10	3.40	10.8
ST0086	2.70	0.05	17.0	2.00	0.03	10.1	4.80	18.5
ST0088	2.60	0.04	16.0	1.50	0.02	8.60	3.60	15.3
ST0100	2.50	<0.04	15.0	1.50	0.02	8.70	3.90	16.7
ST00103	2.40	<0.04	16.0	1.60	0.02	9.00	4.20	16.3
ST00104	2.70	0.06	12.0	2.10	0.01	6.00	5.10	15.1
Min	1.60	0.04	6.10	0.70	0.01	2.10	2.50	7.90
Max	2.90	0.06	19.20	3.60	0.05	12.90	5.10	23.10
Mean	2.4	0.1	10.9	1.5	0.0	5.5	3.7	12.8
SE	0.1	0.0	1.1	0.2	0.0	0.9	0.2	1.1
CEFAS AL1	20	0.4	40	40	0.3	20	50	130
CEFAS AL2	100	5	400	400	3.0	200	500	800
OSPAR BAC	25	0.31	81	27	0.1	36	38	122
ERL	8.2*	1.2	81	34	0.2	21*	47	150
TEL	7.24*	0.7	52.3	18.7	0.1	-	30.2	124
PEL	41.6	4.2	160	108	0.7	-	112	271

6.5.2. Polycyclic Aromatic Hydrocarbons (PAHs)

The full range of EPA PAHs was tested for and raw data reported in Appendix II. PAH concentrations were compared to CEFAS AL1 (no CEFAS AL2 available for PAHs), OSPAR BAC levels and ERLs, and TEL and PEL where possible. It should be noted that most of the PAHs analysed were measured below the detection limits (BLD). In instances where PAHs concentrations were measurable, the values remained well below reference levels.

6.5.3. Total Hydrocarbons (THC)

THC concentrations were consistently low across the survey area with 9 stations registering values BDL. The remaining stations exhibited values ranging from 1.07 to 2.12 mg/kg, with station ST0104 recording the highest value.

6.5.4. Organotins

All organotins were BLD at all stations.

6.5.5. PCBs

All PCBs were BLD at all stations.

6.6. Macrobenthos

6.6.1. Macrobenthic Composition

The macrobenthic assemblage identified across the survey area from the samples collected across the 113 grab stations included a total of 9,194 individuals and 283 taxa recorded. The mean (± SE) number of taxa per station was 29 ± 1, mean (± SE) abundance per station was 81 ± 5 and mean (± SE) biomass per station was 0.3858 ± 0.1099 gAFDW.

The full abundance matrix is provided in Appendix XII. The biomass (gAFDW) of each major taxonomic group (Annelida, Crustacea, Mollusca, Echinodermata, and Miscellaneous) in each sample collected is presented in Appendix XIII.

Figure 11 shows the main macrobenthic taxa characterising the stations. Juveniles of the heart urchin *Spatangoida* were the most abundant accounting for 20 % of all individuals recorded. It accounted for the maximum average density per sample. However, the most frequently occurring taxon across the survey area was the polychaete *Scoloplos armiger* occurring in 96% of the samples. The polychaete *Galathowenia oculata* accounted for the maximum abundance per sample.

Figure 12 illustrates the relative contributions to total abundance, diversity, and biomass of the major taxonomic groups in the macrobenthic community sampled across the survey area. Annelida taxa dominated abundance as they accounted for 38% of all individuals recorded, as

well as for diversity as they accounted for the 44% of all taxa recorded. Biomass was dominated by Echinodermata, contributing to 39% of the total biomass.

Figure 13 represents total abundance, diversity, and biomass across the survey area. Stations ST0064 and ST0066 exhibited the highest abundance and diversity, recording 264 and 287 individuals, and 46 and 61 taxa, respectively. Addinitonally, station ST0013 had the highest recorded biomass at 7.5249 gAFDW. Of notice was station ST0057 which was barren.

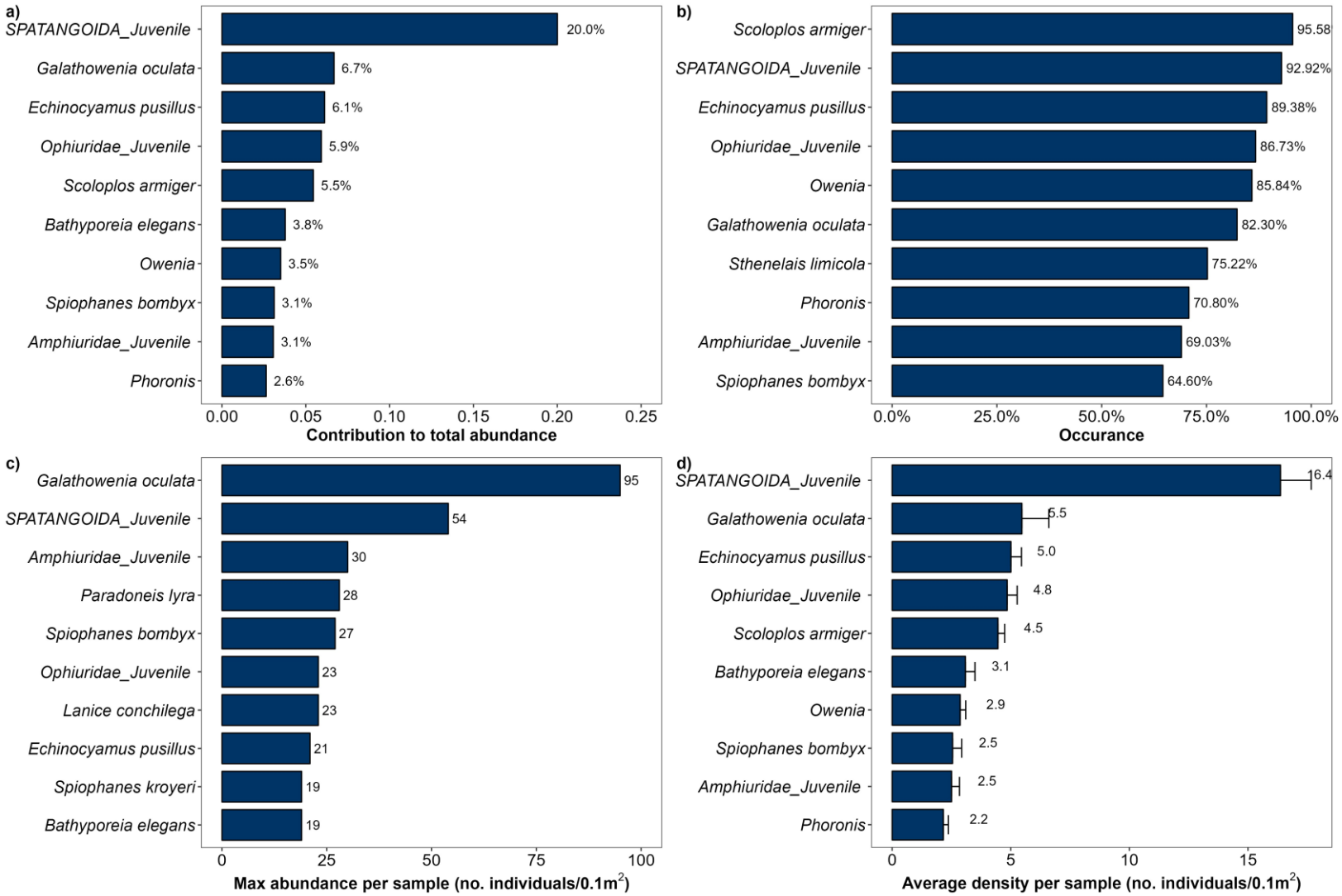

Figure 11 Percentage contributions of the top 10 macrobenthic taxa to total abundance (a) and occurrence (b) from samples collected across the intertidal stations. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

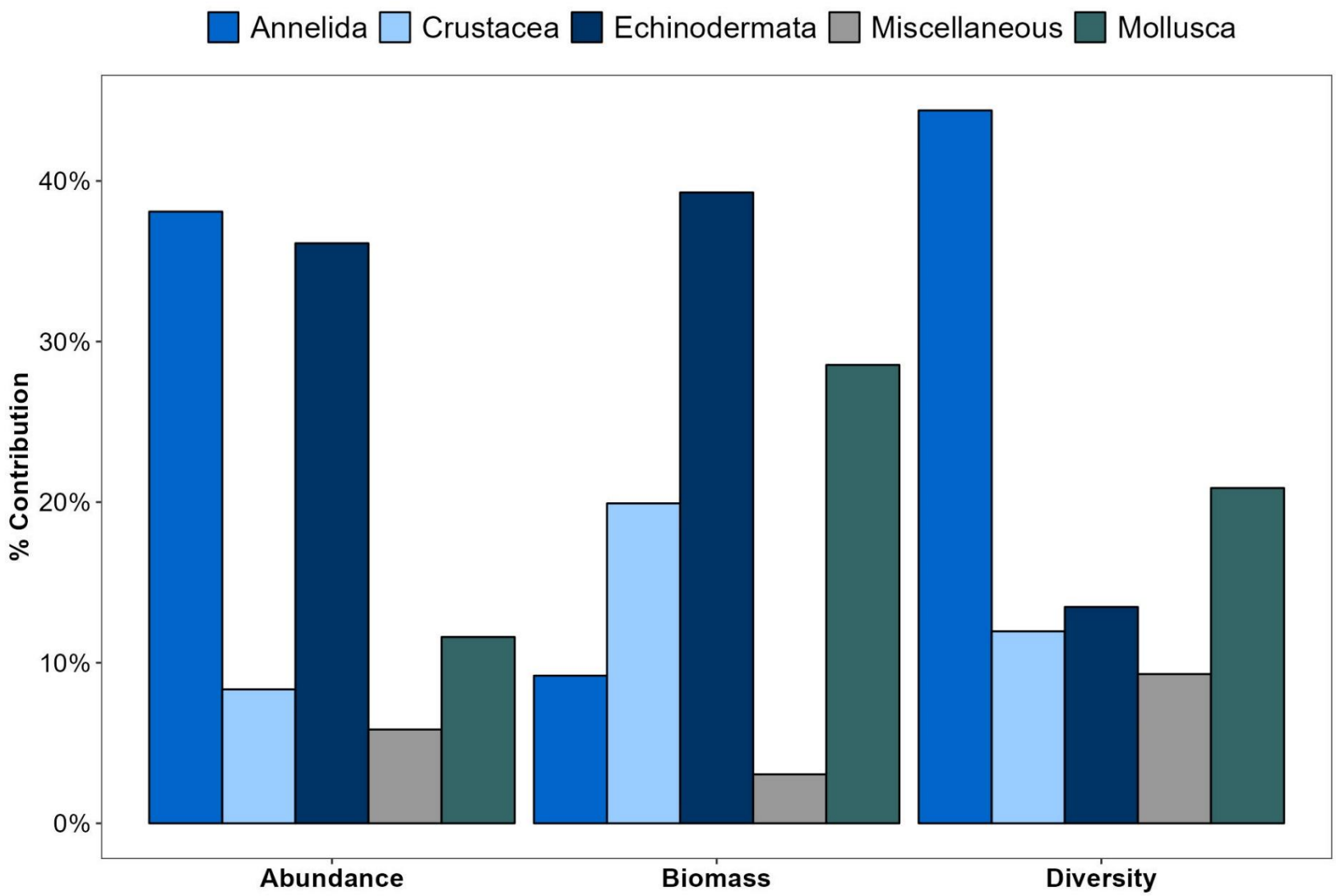

Figure 12 Relative contribution of the major taxonomic groups to the total abundance, diversity and biomass of the macrobenthos sampled across the survey area.

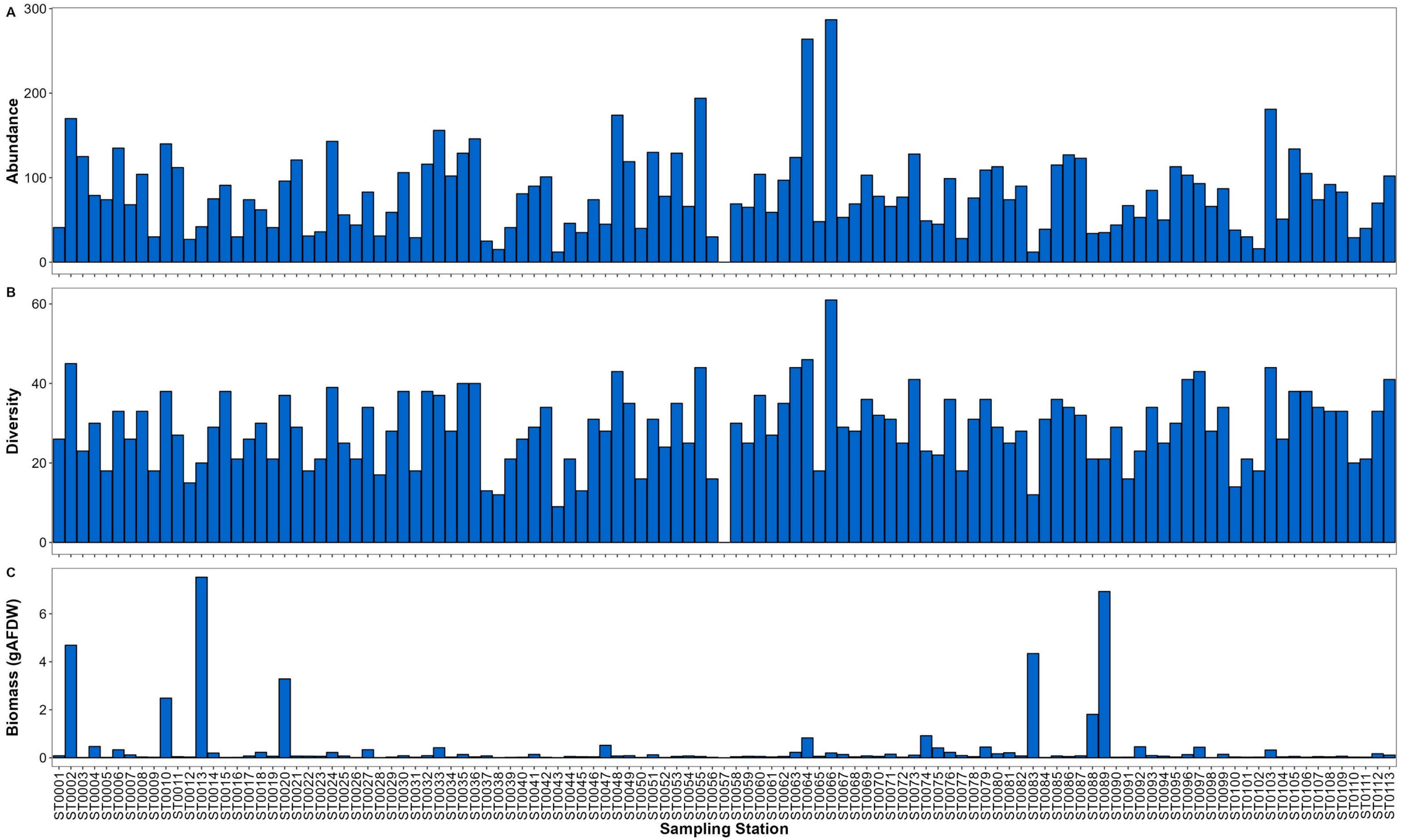

Figure 13 Abundance and diversity per station in the survey area.

6.6.2. Notable Taxa

The only notable taxa recorded across the survey area was the Ocean quahog *A. islandica*, as it is classified as PMF species in Scotland, and also listed in the OSPAR List of Threatened and/ or Declining Species and Habitat (2008). Among the 73 specimens of the Ocean quahog recorded across the survey area, 70 were juveniles, while only three were identified as adults.

To note that no INNS were found in any of the grab samples.

6.6.3. Macrobenthic Groups

Multivariate analysis was undertaken on the square-root transformed macrobenthic grab abundance data to identify spatial distribution patterns in the macrobenthic assemblages across the survey area and identify characterising taxa present.

Cluster analysis of the macrobenthic data was performed on a Bray-Curtis similarity matrix to analyse the spatial similarities in macrobenthic communities recorded across all sampled stations. The dendrogram resulting from the cluster analysis (Appendix XIV) and associated Type 1 SIMPROF similarity (similarity profile routine) permutation test of all nodes within the dendrogram, identified 22 statistically significantly similar groups ($p > 0.05$) and 6 outlier stations that did not belong to any group. A dendrogram resulting from the cluster analysis and associated Type 1 SIMPROF permutation test are provided in Appendix XV. To enable a broad interpretation of the community present across the survey area, a similarity slice at 37 % was used to amalgamate the 28 SIMPROF groups which yielded to 6 broader macrobenthic groups and 6 outlier stations remaining on their own. To note that one of the outlier stations was ST0057 which was barren (i.e., no macrobenthos was recorded at this location).

To visualise the relationships between the sampled macrobenthic assemblages, a non-metric multi-dimensional scaling (nMDS) plot was generated on the abundance data (Figure 14). The nMDS represents the relationships between the communities sampled, based on the distance between sample (station) points. The stress value of the nMDS ordination plot (0.22) indicates that the two-dimensional plot provides a reasonable representation of the similarity between stations, however caution needs to be used when interpreting patterns between and within groups. This relatively high stress value is most likely due to the presence of several groups (clusters) made only of a few stations owning the high diversity in the macrobenthic community observed across the survey area. In general, 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 between different macrobenthic groups.

SIMPER (similarity percentage analysis) was used to identify the key taxa contributing to the within group similarity of the macrobenthic group recognised; the full SIMPER results are provided in Appendix X. The spatial distribution of these macrobenthic groups is presented in Figure 15.

Macrobenthic Group A – Two stations belonged to this group: ST0083, and ST0084. These stations were characterised by the presence of the polychaetes *Goniada oculata*, *S. armiger*, *Lumbrineris cingulata* and *Owenia* sp., as well as juveniles of the heart urchin *Spatangoida,* contributing to about 74% of the group average similarity of 37.93%.

Macrobenthic Group B – Two stations belonged to this group: ST0009, and ST0077. These stations were characterised by the presence of the pea urchin *Echinocyamus pusillus,* the polychaetes *S. armiger, G. maculata, Edwardsiidae*, and *Lanice conchilega* all together contributing to about 77% of the group average similarity of 40.57%.

Macrobenthic Group C – Two stations belonged to this group: ST0056, and ST0090. These stations were characterised by the presence of juveniles of *Ophiuridae,* the polychaetes *G. oculata, Owenia* sp. and *S. armiger,* the bivalve *Lucinoma borealis,* the amphipod *Lepidepecreum longicorne,* and Nemertea contributing to about 70 % of the group average similarity of 48.91%,

Macrobenthic Group D – Seven stations belonged to this group: ST0112, ST0113, ST0103, ST0105, ST0063, ST0064, and ST0066. These stations were characterised by juveniles of *Spatangoida, G. oculata, S. armiger, Owenia, Phascolion strombus strombus, Phoronis, Persiella clymenoides, Chaetozone setosa, Ampharete falcata, Paramphinome jeffreysii, Varicorbula gibba, Phaxas pellucidus, Thyasira flexuosa,* and *Nemertea,* contributing to about 70 % of the group average similarity of 46.40%.

Macrobenthic Group E – Four stations belonged to this group: ST0110, ST0107, ST0101, and ST0111. These stations were characterised by juveniles of *Spatangoida, A. islandica* and *Ophiuridae, S. armiger, E. pusillus, L. borealis, P. pellucidus,* and *Phoronis*, contributing to about 70% of the group average similarity of 42.32%.

Macrobenthic Group F – The remaining 96 stations belonged to this group and were characterised by juveniles of *Spatangoida, Amphiuridae* and *Ophiuridae, E. pusillus, S. armiger, Owenia* sp., *G. oculata, Bathyporeia elegans, Phoronis, S. limicola,* and *S. bombyx*, contributing to about 70% of the group average similarity of 45.65%.

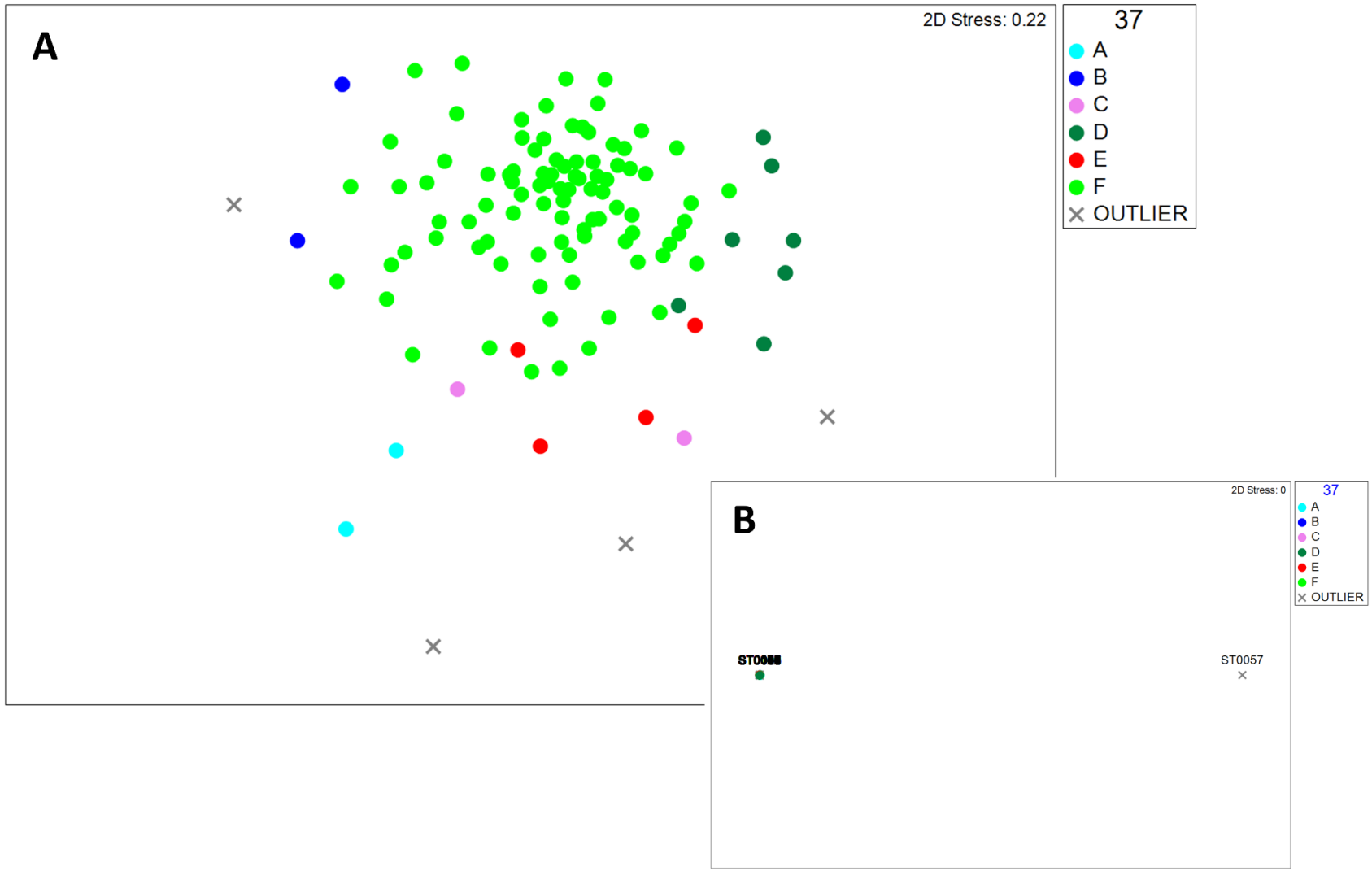

Figure 14 Two-dimensional nMDS ordination of macrobenthic communities at the stations based on square root transformed and Bray-Curtis similarity abundance data. A) Sub-set MDS of all stations except barren station (ST0057). B) With barren station (ST0057).

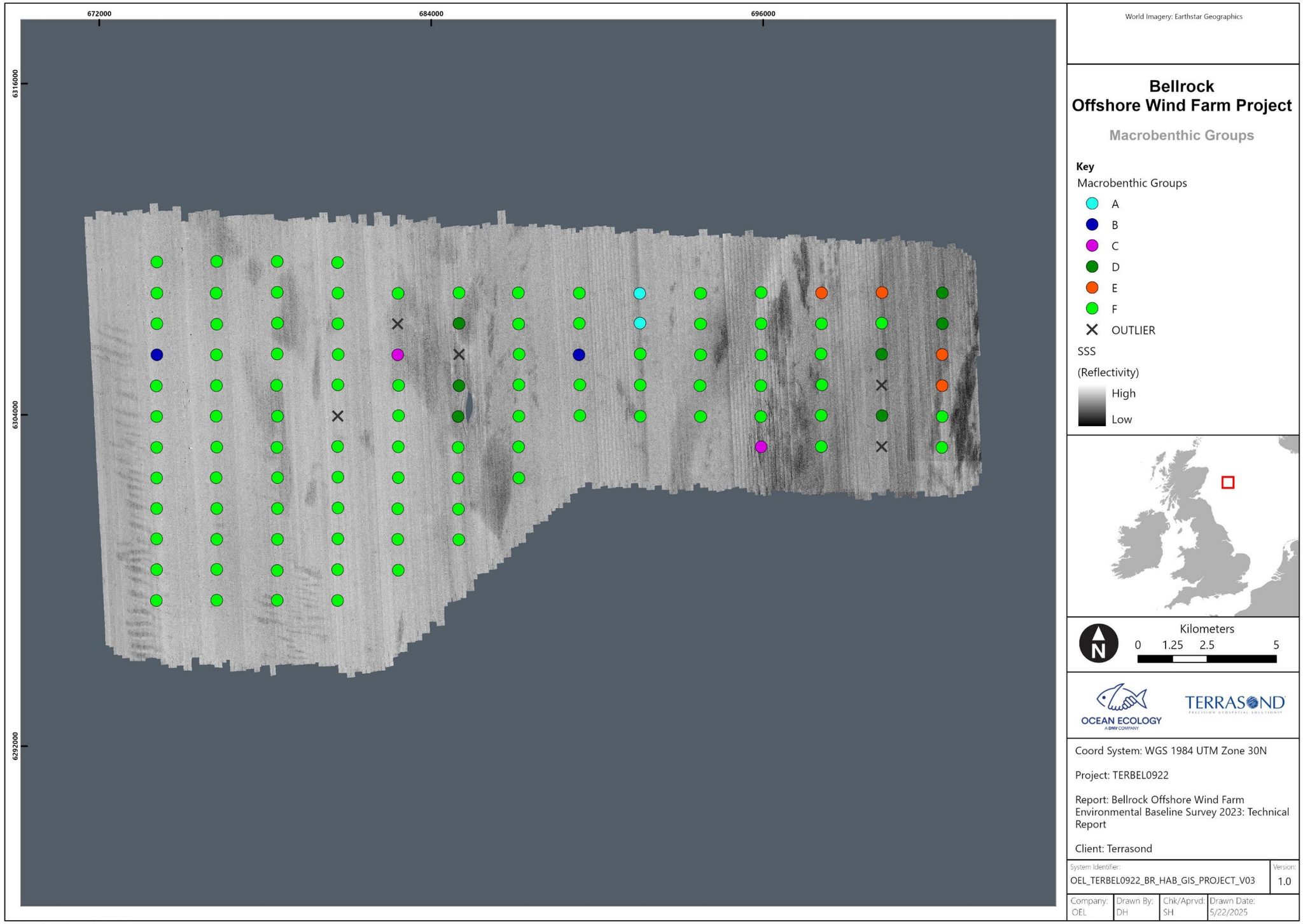

Figure 15 Spatial distribution of macrobenthic groups across the survey area.

6.6.4. Biotope Assignment

For each of the Macrobenthic Groups determined using cluster analysis and a 37 % similarity slice, biotopes and habitats were assigned in consideration of JNCC guidance based upon their faunal and physical characteristics (Parry 2019).

All outlier stations were assigned to their corresponding EUNIS level 4 classification based on sediment and seabed imagery analyses as the macrobenthic multivariate analysis did not show any pattern in the community composition that could be used to assign a biotope (Figure 16).

Similarly, most of the macrobenthic groups which were made up of only a handful of stations were assigned to level 4 EUNIS classifications as their macrobenthic assemblages were not dominated by any key taxa typically associated to a biotope. Therefore, macrobenthic groups A, B C and E most closely aligned with EUNIS level 4 habitat "A5.27 Deep circalittoral sand" (Figure 16).

Two biotopes aligned with the community observed within Macrobenthic Group D: "A5.371 *Ampharete falcata* turf with *Parvicardium ovale* on cohesive muddy sediment near margins of deep stratified seas" and "A5.376 *Paramphinome jeffreysii*, *Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud" (Figure 16). Macrobenthic Group D was made up of 7 stations with relatively high mud content (> 10 %) but only three of them classified as BSH "A5.3 Mud and Sandy Mud" based on PSD data aligning with the above biotopes. Of the remaining four stations belonging to Macrobenthic Group D, one classified as "A5.4 Mixed sediments" and the remaining three stations belonged to BSH "A5.2 Sand and Muddy Sand" suggesting a biotope mismatch between the sediment at these four stations and the community they supported. Characterising taxa of biotopes A5.371 and A5.376 included *A. falcata, Parvicardium pinnulatum, Levinsenia* sp., *P. jeffreysii* and *Thyasira flexuosa* which were driving similarity within Macrobenthic Group D. Taxa typical of deep circalittoral sand such as *G. maculata, Diplocirrus glaucus* and *Spiophanes kroyeri* were also recorded at these locations.

The biotope that most closely aligned with the community observed in Macrobenthic Group F was "A5.272 *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand" (Figure 16). This biotope is typical of areas of slightly muddy sand in offshore waters which is consistent with the PSA results where 87 out of the 91 stations belonging to this group were classified as BSH A5.2. At four stations a biotope mismatch was observed where a community typical of muddy sand was observed over mixed sediments (ST0031, ST0032 AND ST0098) and over mud at ST0038. Characterising taxa of this biotope include *Owenia* sp., juveniles of *Amphiuridae*, *G. maculata, D. glaucus* and *S. bombyx*.

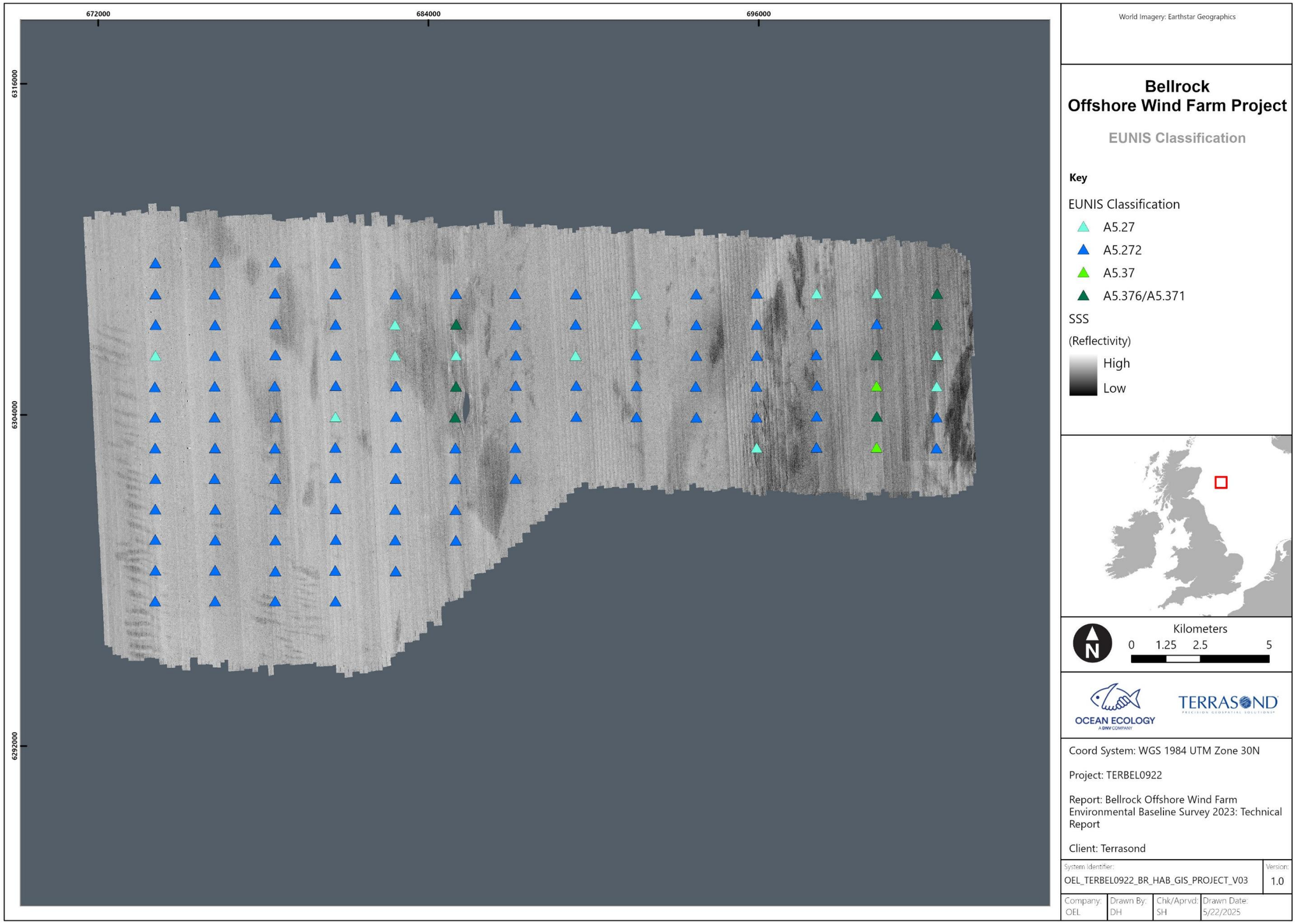

Figure 16 Spatial distribution of biotopes across the survey area based on the interpretation of macrobenthic data.

6.7. Habitat and Biotope Mapping

Seabed imagery and site characterisation sampling were undertaken to identify the principal habitats that occurred across the survey area. Acoustic data was additionally interrogated to identify the boundaries of the habitats/biotopes inferred from seabed imagery and grab samples analyses.

The main complexes identified across the survey area were the EUNIS level 5 habitat "A5.272 *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand" observed at 91 of the 113 grab sampling stations and the mosaic habitat made up of EUNIS level 5 habitats "A5.371 *Ampharete falcata* turf with *Parvicardium ovale* on cohesive muddy sediment near margins of deep stratified seas" and "A5.376 *Paramphinome jeffreysii*, *Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud" observed at 7 stations where mud content was comparatively high. Of note, three of the 7 stations assigned to biotope A5.371/A5.376 did not occur over a mud substrate but over sand and mixed sediments indicating a biotope mismatch at these locations. Additionally, four more areas of the biotope mosaic A5.371/A5.376 were identified across the survey area based on the interpretation of acoustic data alone as no grab samples were collected along these areas (Figure 17). Confidence in the delineation of these four polygons where no ground-truthing data was available was overall low.

In general, the majority of the survey area was characterised by sandy sediments classified as biotope A5.272 and representing the offshore subtidal sands and gravels PMF habitat with small areas of mud occurring in deeper waters and characterised as the mosaic habitat of A5.371 and A5.376. Biotope mosaic A5.371/A5.376 in the eastern reaches of the survey area overlapped with the area of burrowed mud observed in the seabed imagery analysis and identified as the burrowed mud PMF habitat (Figure 17). However, none of the macrobenthos identified at these locations corresponded to a biotope component of the burrowed mud PMF habitat suggesting that this area most likely corresponds to a combination of the PMF habitats burrowed mud and offshore deep sea muds (Figure 17).

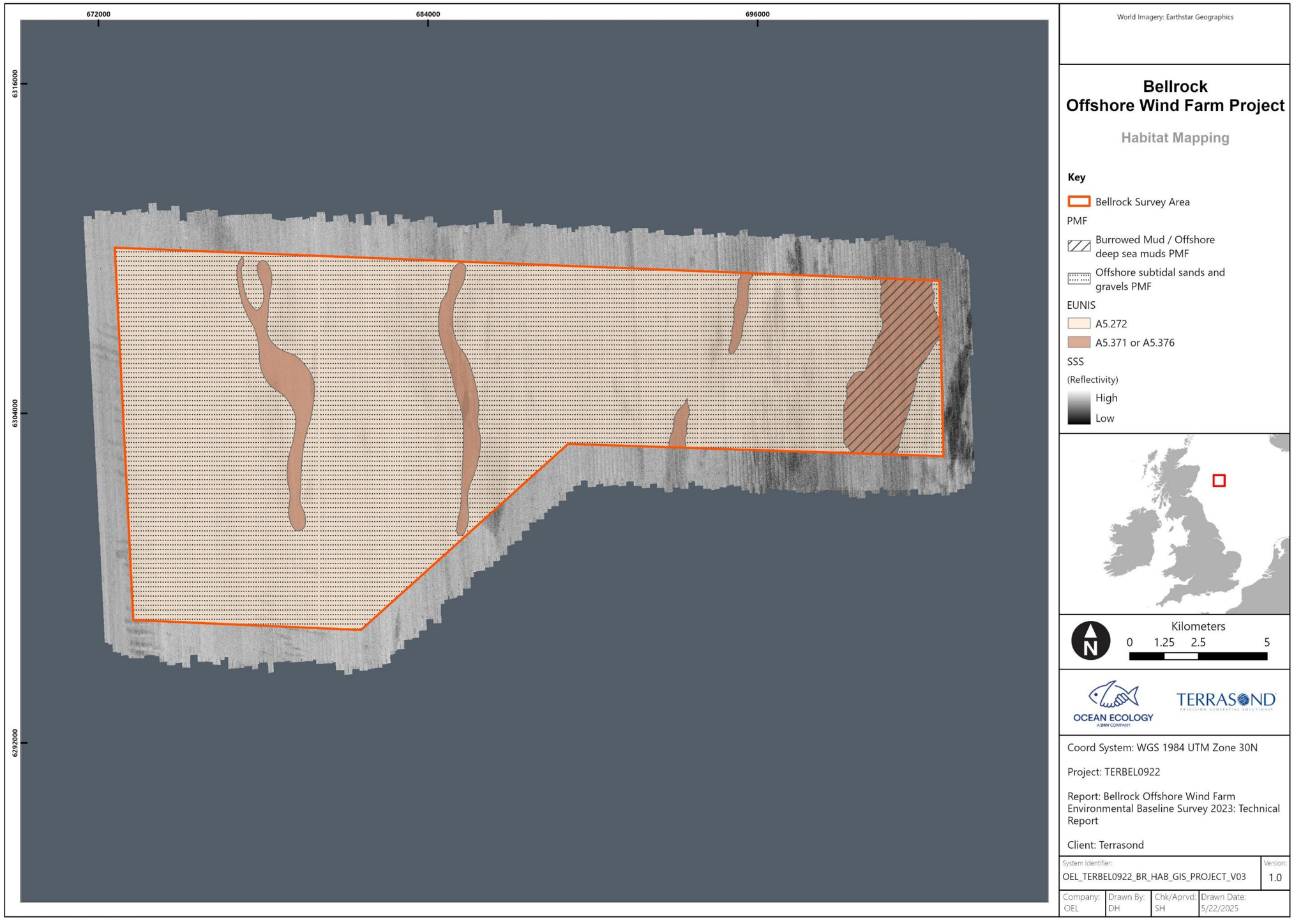

Figure 17 EUNIS habitat/biotope mapping across the survey area considering geophysical, PSD, seabed imagery and macrobenthic data.

6.8. eDNA

eDNA was analysed at 10 stations with samples collected at the top, middle and bottom of the water column at each station as detailed in Section 4.6. At three stations, ST0018, ST0062 and ST0088, the top water samples yield no amplifiable DNA and therefore no species were reported for those three samples.

6.8.1. Fish Community

An examination of the eDNA results led to the identification of a diverse fish community derived from 27 OTUs representative of fish taxa. The most prevalent fish species among these OTUs were the Atlantic Herring, Atlantic Mackerel and Whiting (Table 11). Full eDNA results are provided in Appendix XVI. Of the fish identified, 9 were deemed to be of conservation importance due to their designation as PMF species in Scotland, while 15 species were also listed as species of commercial importance in the UK (Table 11). It should be noted that for 7 of the OTUs there was low confidence in their identification as it was based on fewer than three matches to sequences in the reference database, and/or limited geographic occurrence records for the taxon (Table 11).

A large variability was observed in fish species found in each sample (top, middle and bottom) from the same station (Figure 18). However, no clear pattern was observed between samples as at some stations it was the top sample which reported the highest fish species diversity whereas at other stations it was either the middle or bottom one (Figure 18).

Moreover, the eDNA analysis revealed the likely occurrence of certain species outside their typical geographical ranges. The Boarfish *Capros aper*, typically confined to the southern regions of the UK, was identified in at least one sample per station indicating its occurrence at higher latitudes than expected (Figure 18). However, there was lower support for this identification as it was based on fewer than three matches to reference sequences in the database.

Table 11 Fish taxa identified across the survey area based on eDNA analysis. Asterisk (*) identifies taxa with low confidence in the identification of their OTUs.

Fish	Common Name	Status	Number of samples in which taxon occurred
*Agonus cataphractus**	Hooknose		1
Ammodytidae			6
Argentinidae*			3
Belone belone	Garfish		3
*Capros aper**	Boarfish		1
Clupea harengus	Atlantic Herring	PMF/Commercial	20
*Crystallogobius linearis**	Crystal Goby		1
Enchelyopus cimbrius	Fourbeard Rockling		2
DHeloHel			1
Gadus morhua	Atlantic Cod	PMF/Commercial	4
Glyptocephalus cynoglossus	Witch Flounder	Commercial	3
Hippoglossoides platessoides	American Plaice	Commercial	13
Limanda limanda	Common Dab	Commercial	15
*Liparis montagui**	Montagu's Seasnail		2
Melanogrammus aeglefinus	Haddock	Commercial	17
Merlangius merlangus	Whiting	PMF/Commercial	18
Microstomus kitt	Lemon Sole	Commercial	5
*Molva molva**	Common Ling	PMF/Commercial	2
Pleuronectes platessa	European Plaice	Commercial	12
Pollachius virens	Saithe	PMF/Commercial	1
Pomatoschistus minutus	Sand Goby	PMF	1
Salmo salar	Atlantic Salmon	PMF/Commercial	1
Sardina pilchardus	European Pilchard	Commercial	1
Scomber scombrus	Atlantic Mackerel	PMF/Commercial	20
Sprattus sprattus	European Sprat	Commercial	9
Triglidae			14
*Trisopterus esmarkii**	Norway Pout	PMF	4

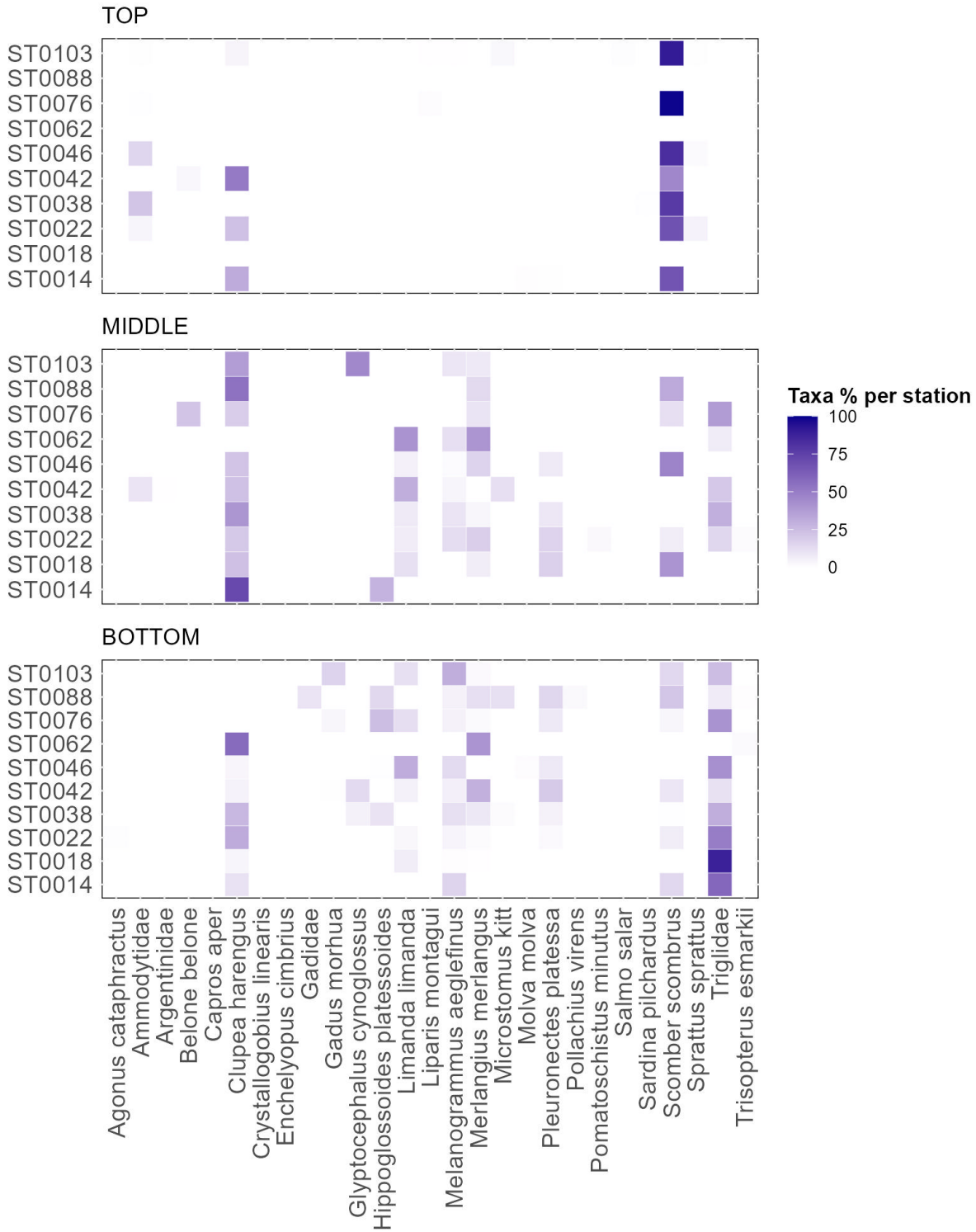

Figure 18 Fish percentage abundance heat map: Analysis of top, middle, and bottom depths at each station. Colour intensity indicates the percentage of sequences per sample based on all DNA sequences within an individual sample (the sum of one station (row) is 100 %).

6.8.2. Other Species of Interest

eDNA was also analysed on a vertebrate array which yielded results for fish, birds, marine mammals as well as terrestrial animals.

Of the 25 fish taxa identified in this analysis, only 6 species were not recorded in the above fish assessment, namely the Fivebeard Rockling *Ciliata mustela*, the Smooth Sandeel *Gymnammodytes semisquamatus*, the common Seasnail *Liparis liparis*, the European Hake *Merluccius merluccius*, the Turbot *Scophthalmus maximus* and the Atlantic Horse Mackerel *Trachurus trachurus*. Of these, the European Hake and the Turbot are of commercial value in the UK, while the Atlantic Horse Mackerel is both of commercial value and a PMF species in Scottish waters. To note that 8 of these OTUs were of low confidence in their identification as it was based on fewer than three matches to sequences in the reference database, and/or limited geographic occurrence records for the taxon (Appendix XVI).

Additionally, of the fish species recorded in both arrays (fish and vertebrates), the Atlantic Salmon yielded a stronger DNA signal and was identified in three stations (four samples) as part of the vertebrate array compared to the fish array where it had a weaker signal and was only identified in one sample (Figure 19).

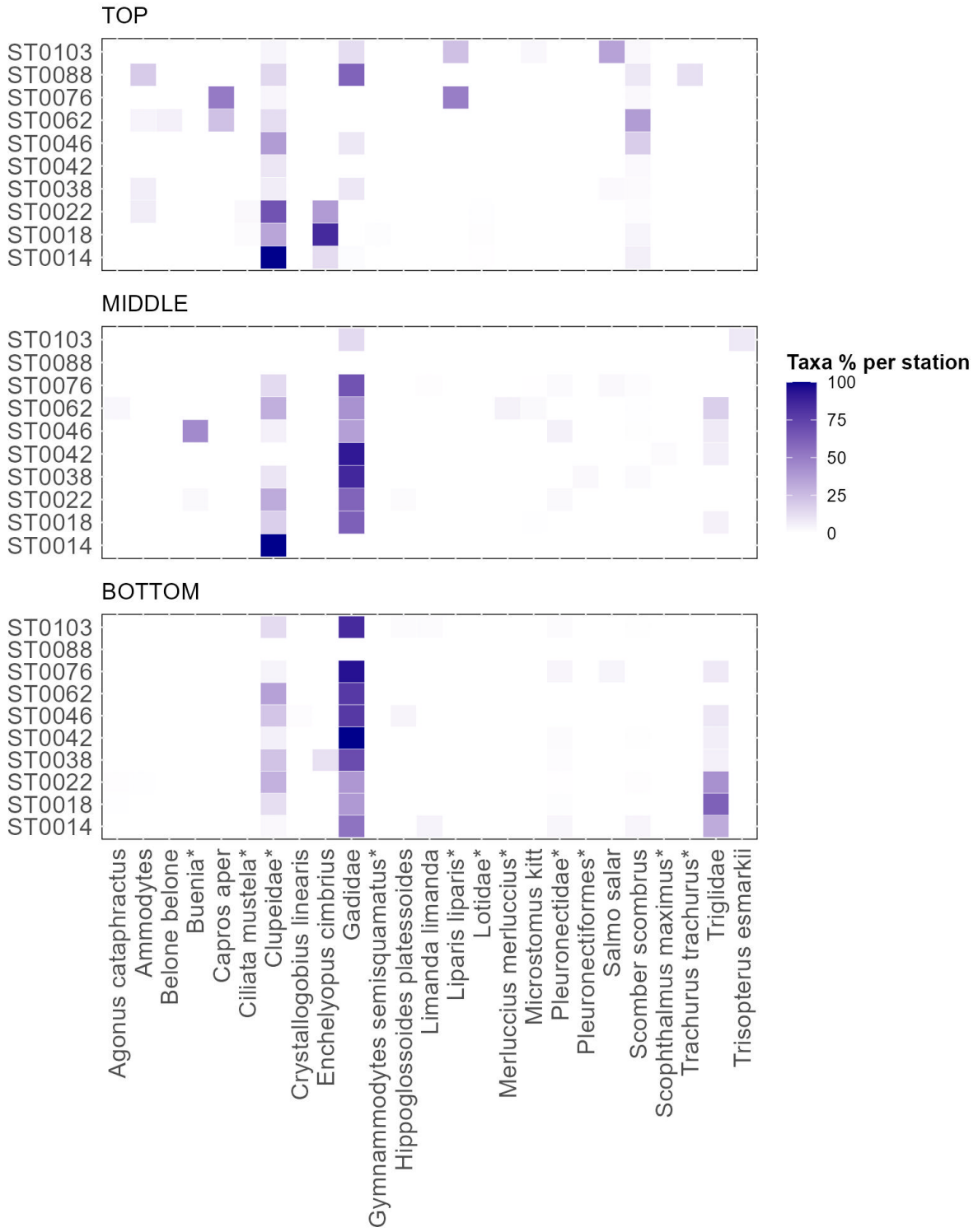

Figure 19 Fish percentage abundance heat map: eDNA vertebrate analysis of top, middle, and bottom depths at each station. Taxa represented with an asterisk are exclusive to the vertebrate assay analysis only. Colour intensity indicates the percentage of sequences per sample based on all DNA sequences within an individual sample (the sum of one station (row) is 100 %).

Marine Mammals

Only three marine mammal taxa were identified across the survey area: the Common Minke Whale *Balaenoptera acutorostrata*, the Harbour Porpoise *Phocoena Phocoena* and dolphins of the genus *Lagenorhynchus* (Table 12 and Figure 20A). All of these are listed as PMF species and protected in Scottish waters.

Table 12 Marine mammal taxa identified across the survey area based on eDNA analysis.

Taxa	Common Name	N of samples in which taxa occurred
Balaenoptera acutorostrata	Common Minke Whale	2
Phocoena phocoena	Harbour Porpoise	9
Lagenorhynchus		2

Birds

Twelve bird taxa were identified across the survey area (Table 13 and Figure 20B) with the Common Tern *Sterna hirundo* and the Common Guillemot *Uria aalge* amber listed in the Birds of Conservation Concern in the UK.

Table 13 Bird taxa identified across the survey area based on eDNA analysis.

Taxa	Common Name	N of samples in which taxa occurred
Parus major	Great Tit	1
Somateria mollissima	Common Eider	1
Sterna hirundo	Common Tern	1
Uria aalge	Common Guillemot	2
Anatidae		1
Passeridae		1
Turdus		1
Tadorna		3
Columbidae		3
Corvidae		4
Sturnidae		6
Laridae		9

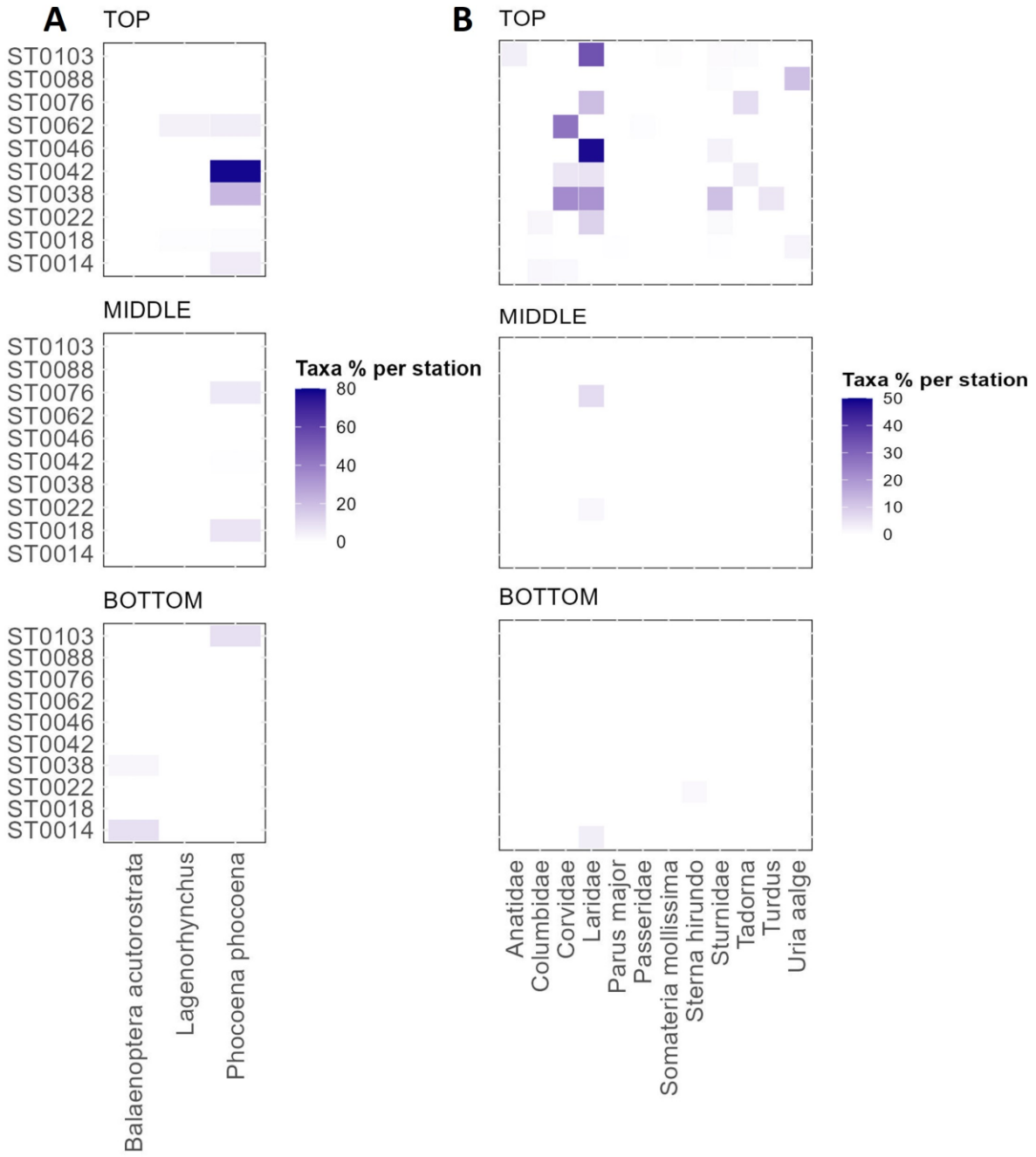

Figure 20 Percentage abundance heat map for marine mammals (**A**) and birds (**B**). eDNA vertebrate analysis of top, middle, and bottom depths at each station. Colour intensity indicates the percentage of sequences per sample based on all DNA sequences within an individual sample.

7. Discussions

This report presents the results and interpretation of the seabed imagery, macrobenthic and sediment analyses with the aim to set out the environmental baseline conditions across the proposed Bellrock WFDA. The findings will inform project EIA and future consenting applications as well as providing a robust dataset for future monitoring if required.

7.1. Seabed Imagery and Geophysical Data

Seabed imagery was successfully collected at all 113 stations, resulting in the collection of 647 still images and 113 videos. One EUNIS Level 4 (biotope complex) was identified in the seabed imagery collected across the survey area: A5.37 Deep circalittoral mud. Based on the seabed imagery analysis a homogenous substrate was identified across the survey area, however it should be noted that seabed imagery analysis has its limitation in differentiating between muddy sand and sandy mud and therefore PSD data was used as the primary information source to delineate areas of sand and mud.

Similarly acoustic data (SSS and MBES) indicated a homogeneous seabed with no distinct features as sandy mud and muddy sand can be particularly difficult to differentiate as they exhibit similar acoustic reflectivity signatures resulting in homogenous SSS data. No geogenic or biogenic reef habitats were observed across the entire survey area.

7.2. Sediments

Despite some variation in sediment types between stations, most stations were dominated by sand and classified as BSH A5.2. Mud contribution to sediment increased with increasing water depth and was substantial at three stations (ST0038, ST0102, and ST0103), where it represented more than 25% of the total composition; these stations were assigned to BSH A5.3. In contrast, gravel content was low at most stations contributing on average to less than 1 % to total sediments.

Considering the water depth at which all grab samples were collected from, these sublittoral sediment types were deemed to represent the 'offshore deep sea muds' and 'offshore subtidal sands and gravels' PMF habitats. It is noteworthy that whilst these habitats are deemed to be of conservation importance in Scottish waters they are also among the most common habitats found in offshore deep waters around the coast of the UK.

7.3. Sediment Chemistry

The examined contaminants included heavy and trace metals, PAHs, PCBs, organotins and THCs. None of the analysed metals, PAHs and THC exceeded any of the reference level while the concentrations of PCBs, and Organotins were found BLD at all stations.

7.4. Macrobenthos

A diverse macrobenthic assemblage was identified across the survey area from 113 samples collected, with a total of 9,194 individuals and 283 taxa recorded. The most abundant taxon with the greatest average density per sample was the heart urchin *Spatangoida* (juveniles) and the most frequently occurring taxon was the polychaete *S. armiger*. Annelida taxa dominated abundance and diversity while biomass was dominated by Echinodermata.

Macrobenthic communities can be highly heterogenous as they are heavily influenced by ambient environmental conditions such as sediment composition (Cooper et al. 2011), hydrodynamic forces and physical disturbance (Hall 1994), depth (Ellingsen 2002), and salinity (Thorson 1966). This was reflected in the macrobenthic communities observed across the survey area where sediment composition was a key factor in determining the macrobenthic community structure at these locations. Macrobenthic Group F, including most stations, exhibited an association with sand and muddy sand supporting a community characterised by *Owenia* sp. and juveniles of *Amphiuridae;* whereas Macrobenthic Group D exhibited an association with mud supporting a community characterised by *A. falcata*, *P. jeffreysii* and *Thyasira flexuosa*.

One notable macrobenthic species was identified across the survey area: the Ocean quahog *A. islandica*. This species is included in the OSPAR List of Threatened and/or Declining Species and Habitats (2008) and is also a PMF species in Scottish waters. Most of the individuals recorded were juveniles, with only three adults noted across the survey area at stations ST0013, ST0020 and ST0088. No trend was evident between the presence of this PMF species and sediment type.

7.5. Habitat Mapping

An integrated interpretation of PSD and macrobenthic data, seabed imagery, and acoustic data suggested that the main biotopes present across the Bellrock WFDA were "A5.272 *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand" covering the majority of the survey area and a mosaic of biotopes A5.371 *Ampharete falcata* turf with *Parvicardium ovale* on cohesive muddy sediment near margins of deep stratified seas" and "A5.376 *Paramphinome jeffreysii*, *Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud" occurring to the east of the survey area and in small elongated north-south patches in between the wider sand area (Figure 17).

The characteristics of acoustic datasets (SSS and MBES) can be used to define habitat boundaries (Limpenny et al. 2010), however, in this case, the acoustic data was largely homogenous with no distinct features evident. Sandy mud and muddy sand can be particularly difficult to differentiate in acoustic datasets as they exhibit similar reflectivity signatures and therefore it was challenging to delineate the boundaries of these overlapping habitats across the survey area resulting in a relatively low confidence habitat map even when combined with

seabed imagery and PSD ground-truthing information. Likewise, the challenges associated with differentiating between muddy sand and sandy mud based on interpretation of seabed imagery meant that PSD data was used as the primary information source to inform the delineation of areas of sand and mud. Low confidence scores were assigned to the polygons identifying these features and their boundaries.

Nevertheless, findings from this survey appeared to align with the predicted BSH mapping available for the survey area. Level 4 EUNIS codes A5.27 and A5.37 were assigned given the overall depth of the survey area being more than 70 m and the results of PSD analysis. Interpretation of the multivariate analysis results of the macrobenthic data allowed for assignment of most sandy stations to biotope A5.272 and the muddy stations to the east of the survey area to biotope mosaic A5.371/A5.376. Mixed sediments (EUNIS BSH A5.4) were confirmed as present at three stations based on the PSD data, however, it was not possible to delineate these habitats as polygons due to the homogenous nature of the acoustic data and lack of clear differences in the macrobenthic communities at these stations to support the presence of distinct patches of mixed sediments.

A comprehensive burrow assessment was made on all still images collected across the survey area, yielding data on burrow density per station with the aim of determining whether the burrowed mud PMF was present within the survey area. This habitat is widely distributed in sheltered sea lochs, other open coast muddy habitats along the western coast of Scotland, and even on the continental slope. Occasional records exist on the east coast, with noteworthy occurrences in offshore waters of the northern North Sea. The key identifying characteristics of this PMF are typically found in areas with fine mud, sandy mud, and muddy sand, at water depths ranging from 10 meters to over 500 meters (Tyler-Walters et al. 2016). It is important to note that the survey area was situated offshore in the open waters of the North Sea and that stations assigned to the EUNIS habitat A5.37 were among those with the highest densities of burrows. This indicates the presence of the burrowed mud PMF in correspondence of EUNIS habitat A5.37. However, seabed imagery data revealed no spatial relationship between burrow mud density and the presence of seapens which were the most commonly occurring epifauna observed in the seabed imagery (Figure 5). This indicates that seapen and burrowing megafauna were not a biotope component of the burrowed mud PMF observed. The subsequent macrobenthic analysis did not reveal the presence of any species that could qualify as a biotope component of the burrowed mud PMF habitat. Most likely this area of mud at the east of the survey area reflects a combination of the offshore deep sea muds PMF habitat and the burrowed mud PMF habitat. No evidence of geogenic or biogenic reef habitats was observed across the Bellrock WFDA. Additionally, biotope A5.272 encountered across most of the survey area was representative of the offshore subtidal sands and gravels PMF habitat.

7.6. eDNA

The use of eDNA has become increasingly popular as a non-invasive and effective method for surveying and monitoring of species in their natural habitats as organisms shed their DNA into their environments as shed cells, waste matter, blood, gametes and decaying material (JNCC 2022). eDNA metabarcoding methods allow the rapid and cost-efficient collection of information on species diversity and composition of fish assemblages in aquatic habitats, which is of particular importance given the current increase in anthropogenic disturbance and associated declines in aquatic biodiversity in these ecosystems. To note that the eDNA analysis presented here was targeted to vertebrates and bony fish meaning that elasmobranchs (rays and skates) might not be as readily detected. In general elasmobranchs are often difficult to detect using eDNA as they do not shed large amounts of DNA compared to other taxa.

The persistence of DNA in the water column depends on a multitude of factors, including environmental conditions, water movement, and the specific type of DNA present. Generally, DNA can remain detectable for varying durations, which can range from a few hours to several weeks or even months. The degradation rates of DNA are contingent upon elements such as ultraviolet (UV) radiation, water temperature, and the presence of nucleases and other enzymatic activities in the water. Additionally, exposure to sunlight and high temperatures can accelerate the degradation process. Conversely, in colder and darker environments, the degradation of DNA may decelerate, allowing it to persist for longer periods (Littlefair et al. 2021, Monuki et al. 2021).

The results of the eDNA analysis indicated the presence of a diverse fish community including 10 PMF species and 18 species of commercial importance. Additionally, three of the detected fish species are listed on the IUCN Red List; these were the Atlantic cod, haddock, and the Atlantic Horse Mackerel. Conducting eDNA sampling at multiple depths yielded valuable insights into the distribution and dynamics of genetic material in the water column. For instance, the Atlantic Salmon was detected across all three depths, yet it exhibited a stronger eDNA signal in the top layer of the water column. Conversely, haddock was detected at all depths but reported the weakest eDNA signal at the surface. Sampling at various depths facilitates the assessment of how DNA profiles might differ with depth, potentially indicating the presence or movement of different organisms at various water depths. Additionally, it aids in the identification of the sources and sinks of genetic material, offering insights into the behaviour and ecological interactions of organisms within the marine environment.

Furthermore, the finding of the Atlantic Salmon underscores the need to better understand the interaction of migratory fish species of ecological and cultural significance with offshore wind farms. The occurrence of species like the Boarfish outside their typical geographical ranges could be indicative of range shifts possibly influenced by changing oceanic conditions, including temperature and currents. However, these detections should be treated with some caution given they relied on fewer than three matches within the reference database and may not be entirely dependable without repeat sampling.

Marine mammals and birds were also identified as part of the eDNA analysis. The analysis confirmed the presence of Minke Whale, Harbour porpoise, and dolphins from the genus *Lagenorhynchus*, consistent with observations by marine mammal observers (MMOs) as part of the marine mammal mitigation undertaken during geophysical survey of area (OEL, 2023). Notably, both the eDNA analysis and the marine mammal mitigation report highlighted Harbour porpoise as the most abundant species in the survey area. While the marine mammal mitigation report specifically identified the white-beaked dolphin, the eDNA results only identified it to genus level. The marked prevalence of the porpoise in the area is a strong indicator of its substantial presence within the local marine environment. In terms of birds, the species identified through the eDNA analysis are common to the entire UK and particularly abundant in the northeastern region of Scotland. Among the taxa identified to a species level, only the Great Tit is typically associated with urban environments, whereas the Common Eider and the Common Tern are commonly observed in coastal settings and the Common Guillemot primarily resides at sea, occasionally coming ashore solely for the purpose of nesting during the breeding season in May (British Trust for Ornithology).

Data presented in this report demonstrates that eDNA metabarcoding provided a non-destructive means of collecting insightful fish community information. There are however limitations to the use of this technique which should be considered when interpreting the findings, namely that the resulting data can only provide a qualitative understanding of the community diversity with true abundance not quantified and only represented as a 'strong/weak' DNA signal.

It was also noteworthy that DNA of terrestrial animals was detected in the water samples as it raises questions over the reliability of the results. It is difficult to identify the specific vectors for DNA of terrestrial species being present across the Bellrock WFDA although a possible explanation includes the presence of DNA in waste matter of predators that might have fed on prey or decaying material from terrestrial sources and/or vessels navigating across the survey area. This includes predation by birds as they are known to serve as significant agents in transporting terrestrial material to marine ecosystems through their droppings. These droppings can contain the DNA of the organisms consumed by the birds, thereby facilitating the transfer of terrestrial genetic material into the marine environment (Leempoel et al., 2020; Polanco et al., 2021). This idea is further supported by the observation that terrestrial mammal species were primarily detected in the top of the water column rather than at greater depths.

7.7. Limitation of Study

The key objectives of the benthic characterisation survey were to provide an initial description of the seabed habitats within the survey area and identify and assess any species and habitats of conservation importance such as PMF habitats and/or species. Whilst this was achieved, it should be noted that the lack of newly acquired geophysical data at the sampling design stage has resulted in the habitat and biotope mapping outputs being of a lower level of resolution and confidence than would otherwise have been achieved if geophysical data would have been available to inform the sampling design.

Upon review of the geophysical data, which was made available only after the survey was completed, it was noted that very few stations were located in areas of predicted muddy sediment as indicated by the lower acoustic reflectivity in the SSS data. It therefore became apparent that the design of the sampling array partially resulted in a systematic underrepresentation of areas of predicted mud due to their linear (north to south) occurrence at regular intervals laterally across the Bellrock WFDA (east to west). The distance between these linear features of muddy sediments was similar to the distance between sampling stations (grid design) meaning they were often missed due to the sampling design.

This finding aptly demonstrates the preference for stratified random sampling designs based on review of existing geophysical datasets as opposed to systematic grids for the purposes of habitat mapping (Noble-James et al., 2018). Due to delays in the prior geophysical survey of the Bellrock WFDA, geophysical data was not available at the point of determining the location of the sampling stations for the benthic characterisation survey meaning a systematic grid, rather than stratified random design had to be employed. Efforts were made to reduce the chances of this approach resulting in bias towards or against regularly spaced features by increasing sampling density from 75 to 113 across the Bellrock WFDA.

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