Liverpool Bay CCS Ltd

HYNET CARBON DIOXIDE TRANSPORTATION AND STORAGE PROJECT - OFFSHORE

Environmental Statement
Volume 3, appendix I1: Marine Biodiversity Subtidal Survey Report

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Marine Biodiversity
Subtidal Survey Report

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OCEAN ECOLOGY

Marine Surveys, Analysis & Consultancy

Hynet Carbon Capture Storage & Decommissioning Benthic Characterisation Survey 2022- Technical Report

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Updates

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Abbreviations

AL	Action Level
BAC	Background Assessment Concentration
BIIGLE	Bio-Image Indexing and Graphical Labelling Environment
BSH	Broad-scale Habitat
CCS	Carbon Capture Storage
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CLOC	Clear Liquid Optical Chamber
CPI	Carbon Preference Index
CSQG	Canadian Sediment Quality Guideline
DDC	Drop-down Camera
DEFRA	Department for Environment Food and Rural Affairs
DTI	Department of Trade and Industry
DVV	Dual Van Veen
EA	Environmental Appraisal
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency (USA)
ERL	Effect Range Low
EU	European Union
EUNIS	European University Information Systems
FOCI	Features of Conservation Importance
GPS	Global Positioning System
HD	High-definition
HMW	Heavy Molecular Weight
HOCI	Habitat of Conservation Importance
ICES	International Council for the Exploration of the Sea
IDA	Industrial Denatured Alcohol
ISQG	International Sediment Quality Guideline
JNCC	Joint Nature Conservation Committee
LED	Light-emitting diode
LMW	Light Molecular Weight
MCA	Marine Character Areas
MCZ	Marine Conservation Zone
MHSOD	Marine Habitats and Species Open Data
MHWS	Mean High-Water Spring
MMO	Marine Management Organisation
MP	Megapixels
NERC	Natural Environment Research Council
NMBAQC	NE Atlantic Marine Biological Analytical Quality Control
NRW	Natural Resources Wales
OEL	Ocean Ecology Ltd.
OSI	Oil Storage Installation

PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyls
PEL	Permissible Exposure Limit
PRP	Processing Requirement Protocol
PSA	Particle Size Analysis
PSD	Particle Size Distribution
SAP	Sampling and Analysis Plan
SE	Standard Error
SIMPER	Similarity Percentages
SOCI	Species of Conservation Importance
SSS	Special Scientific Interest
SSSI	Site of Special Scientific Interest
TEL	Threshold Effect Level
THC	Total Hydrocarbon Content
UK	United Kingdom
UPS	Uninterruptable Power Supply
USBL	Ultra-short Baseline
UTM	Universal Transverse Mercator

Non-Technical Summary

Introduction

Ocean Ecology Limited (OEL) was commissioned by RPS Energy Ltd. on behalf of ENI UK Ltd. to complete a subtidal benthic survey to inform the Environmental Impact Assessment (EIA) for the HyNet North West carbon dioxide Transport and Storage Offshore project (the Project), as well as to support the Environmental Appraisal (EA) for the partial decommissioning of the existing ENI UK Liverpool Bay oil and gas offshore infrastructure, and the full decommissioning of the Oil Storage Installation (OSI).

Survey

All survey operations were conducted onboard OEL's survey vessel, the *Argyll Explorer*. The survey involved the collection of seabed imagery and sediment samples using a drop-down camera system and a combination of dual Van Veen and Day grabs. Eighty-five stations were targeted and successfully sampled by drop-down camera. Seventy-six of the targeted 77 grab stations, based on the revised sampling strategy, were successfully sampled for sediment particle size and macrobenthic analyses. Sixty-six of these 77 stations were further successfully subsampled for sediment chemistry analysis.

Sediment

The sediment on the seabed in the Carbon Capture Storage (CCS) and partial decommissioning survey areas varied in composition due to differences in the amount of mud, gravel, and sand. This heterogeneity was likely due to the location of the sites relative to the river Dee estuary and the coastline. The full decommissioning sites were located farthest from the shore compared to the other sampling sites, resulting in less variation in sediment composition. The particle size distribution and type also varied depending on the extent of the spatial range within which the sites were located. Sand was the main component across all sites, resulting in a mostly sandy and muddy sand classification according to the EUNIS BSH classification. Notably, gravel was hardly present in the full decommissioning sites. To note that finer sediments were found at decommissioning stations located in proximity of platforms which could be associated with drill cuttings.

Sediment Chemistry

None of the metals measured exceeded Cefas Action Level (AL) 1 at any of the CCS and full decommissioning stations, while Arsenic (As) and Cadmium (Cd) were above Cefas AL1 at partial decommissioning stations GS23 and GS34, respectively. Additionally Mercury (Hg) was above the OSPAR background (BAC) level at CCS station GS10, at four partial decommissioning stations and at two full decommissioning stations. Zinc (Zn) was the most abundant metal across the survey area, however its concentration never exceeded any of the reference levels. When compared to available data for the North Sea, all the above metals occurred in concentrations comparable to existing background data or in line with the range of concentrations known for areas located in proximity of active platforms.

None of the measured Polycyclic Aromatic Hydrocarbons (PAHs) exceeded Cefas AL1 at any of the CCS and full decommissioning stations, while Chrysene and Benzo[a]pyrene were above Cefas AL1 at partial decommissioning station GS36. A positive correlation was observed between Chrysene, Benzo[a]pyrene and mud content with higher PAHs concentrations in muddier sediments apart from station GS36 which had the highest Chrysene and Benzo[a]pyrene concentrations but an average mud content. No relationship was observed between the concentration of PAHs and proximity to platforms that could have indicated dispersal of drill cuttings.

THC was the highest (30,600 µg kg^{-1}) at partial decommissioning station GS36, where Chrysene and Benzo[a]pyrene were found to exceed Cefas AL1. In the North Sea, THC concentrations at locations between 1 and 2 km from an active platform range between 32,710 µg kg^{-}1 and 33,810 µg kg^{-1} in line with the findings at station GS36 which was located in proximity of a platform.

The Pristane/Phytane (Pr/Ph) ratio and the Carbon Preference Index (CPI) both suggested a biogenic dominance in the source of hydrocarbons across all stations, with stations located closer to land and/or in the path of longshore currents associated with the Dee estuary influenced by terrestrial inputs (Pr/Ph > 3). These findings were overall comparable with the CPI for the central sector of the North Sea which is 2.04.

All Polychlorinated Biphenyls (PCBs) were measured below detection limits at all CCS stations and did not exceed CEFAS AL1 at any of the decommissioning stations.

All organotins measured were below the detection limit of 0.001 mg kg^{-1} at all stations.

Macrobenthos

A diverse macrobenthic assemblage was identified across the survey area, including both CCS and decommissioning areas. A total of 2,001 individuals and 215 taxa recorded across CCS stations, with the brittle star *Amphiura filiformis* being the most abundantly recorded taxon accounting for 15.3 % of all individuals identified. Key epifaunal taxa identified in CCS samples were the tube worm *Spirobranchus triqueter* which accounted for 20 % of all individuals, and Actinaria which was identified in 30 % of all samples.

A total of 13,332 individuals and 322 taxa were recorded within decommissioning samples. Most decommissioning stations were characterised by the presence of Nemertea and *Kurtiella bidentata,* which occurred in 98 % of samples. The epifaunal community was characterised by relatively high numbers of the common brittle star *Ophiothrix fragilis* and Actinaria, with the latter being also the most frequently occurring taxon.

EUNIS Habitats/Biotopes

PSD and macrobenthic data clearly indicated the presence of a heterogeneous substrate and a diverse macrobenthic community across the survey area. Despite sand being the dominant size fraction at all stations, the relative contributions of mud and gravel greatly varied among stations resulting in the presence of an intricate mosaic of substrates across the survey area. Sediment heterogeneity and the diverse macrobenthic community observed meant that no clear biotopes could be defined. As such, EUNIS classifications were limited to a EUNIS level 4 at most stations.

1. Introduction

1.1. Project Overview

Ocean Ecology Limited (OEL) was commissioned by RPS Energy Limited on behalf of ENI UK Limited to complete a subtidal benthic survey to inform the Environmental Impact Assessment (EIA) for the HyNet North West carbon dioxide Transport and Storage Offshore project (the Project), as well as to support the Environmental Appraisal (EA) for the partial decommissioning of the existing ENI UK Liverpool Bay oil and gas offshore infrastructure, and the full decommissioning of the Oil Storage Installation (OSI).

1.2. Background Information

The survey area spanned both English and Welsh territorial waters within Liverpool Bay (Figure 1). The survey area was located approximately 2.8 km from the English coast at its nearest point and extended toward the Welsh coastline at Point of Ayr. The sampling stations were located in water depths varying from 0 m to 35 m.

There were several designated sites within proximity of the survey area. Of particular interest to the benthic subtidal survey were the Liverpool Bay / Bae Lerpwl Special Protected area (SPA), the Shell Flat and Lune Deep Special Area of Conservation (SAC), the Fylde Marine Conservation Zone (MCZ), the Ribble and Alt Estuaries Ramsar site and the Sefton Coast Site of Special Scientific Interest (SSSI).

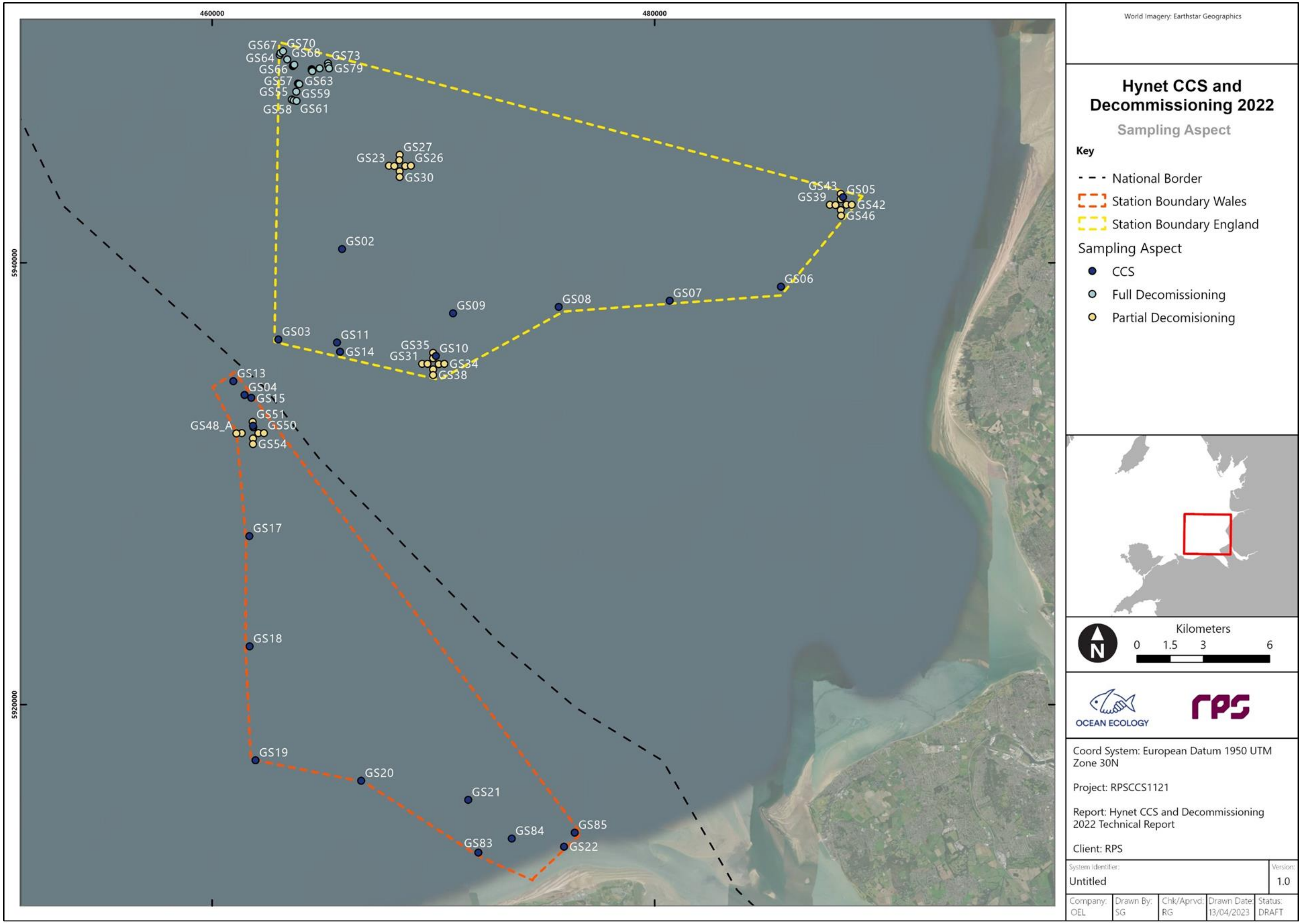

Figure 1 Overview of the survey areas and respective sampling stations. Note the territorial English and Welsh boundaries.

1.3. Aims and Objectives

The aims and objectives of the benthic subtidal survey were split between supporting the Project and decommissioning activities.

As part of the Project the following areas were surveyed:

- The Carbon Storage Complex area offshore (within CS004 CO_2 Appraisal and Storage License Area)
- All associated infrastructures to transport and re-inject CO_2 into the Liverpool Bay depleted offshore fields, including the laying of new electrical and fibre optic cables up to the Mean High-Water Spring (MHWS).

As part of the decommissioning activities, the following areas were surveyed:

- Existing Eni UK Liverpool Bay oil and gas infrastructure: Douglas Process, Hamilton Main, Hamilton North, and Lennox platforms, to be repurposed for CO_2 service,
- The OSI.

2. Current Understanding

2.1. Existing Habitat Mapping and Data

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 survey area primarily consisted of circalittoral fine sand (A5.25), circalittoral muddy sand (A5.26), deep circalittoral sand (A5.27), deep circalittoral coarse sediment (A5.15) and circalittoral coarse sediment (A5.14), as mapped in Figure 2.

The Northwest region is subject to aggregate dredging, and long-term monitoring of sediment and macrobenthos has been carried out as part of the Regional Seabed Monitoring Programme (RSMP). A baseline assessment of macrobenthic infauna based on these data identified a macrobenthic community characterised by Spionidae, Semelidae, Nephtyidae, Capitellidae, Cirratulidae, Amphiuridae, Oweniidae and Nemertea supported by sandy sediments with variable amounts of mud and gravel (Cooper & Barry 2017).

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' ensured 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) has been established to grant protection and conservation to rare and threatened habitats and species.

Sections 41 and 42 of the Natural Environment and Rural Communities (NERC) Act 2006 defined a list of habitats (HOCI) and species (SOCI) of principal importance for the conservation of biodiversity in England and Wales. Under the Environment (Wales) Act (2016), Section 7 defined a list of habitats of 'Principal Importance' for the purpose of maintaining and enhancing biodiversity in Wales. This list supersedes the duty in Section 42 of the NERC Act 2006. In addition to this, marine habitats can be protected under the OSPAR Convention, which has established a list of 'threatened and/or declining species and habitats' in the North-East Atlantic.

The Marine and Coastal Access Act (2009) provides the legal mechanism to assist in the conservation and enable the recovery of protected wildlife and habitats within Marine Conservation Zones (MCZ).

Section 28(1) of the Wildlife and Countryside Act 1981 granted designation to sites of special scientific interest (SSSI) due to the flora or fauna present or the area's geological or physiography. The Ramsar Convention is an intergovernmental treaty for the conservation and sustainable use of wetlands and their resources. The Convention was adopted in 1971 and came to force in 1975, providing a list of wetlands of international and national importance and ensuring their effective management.

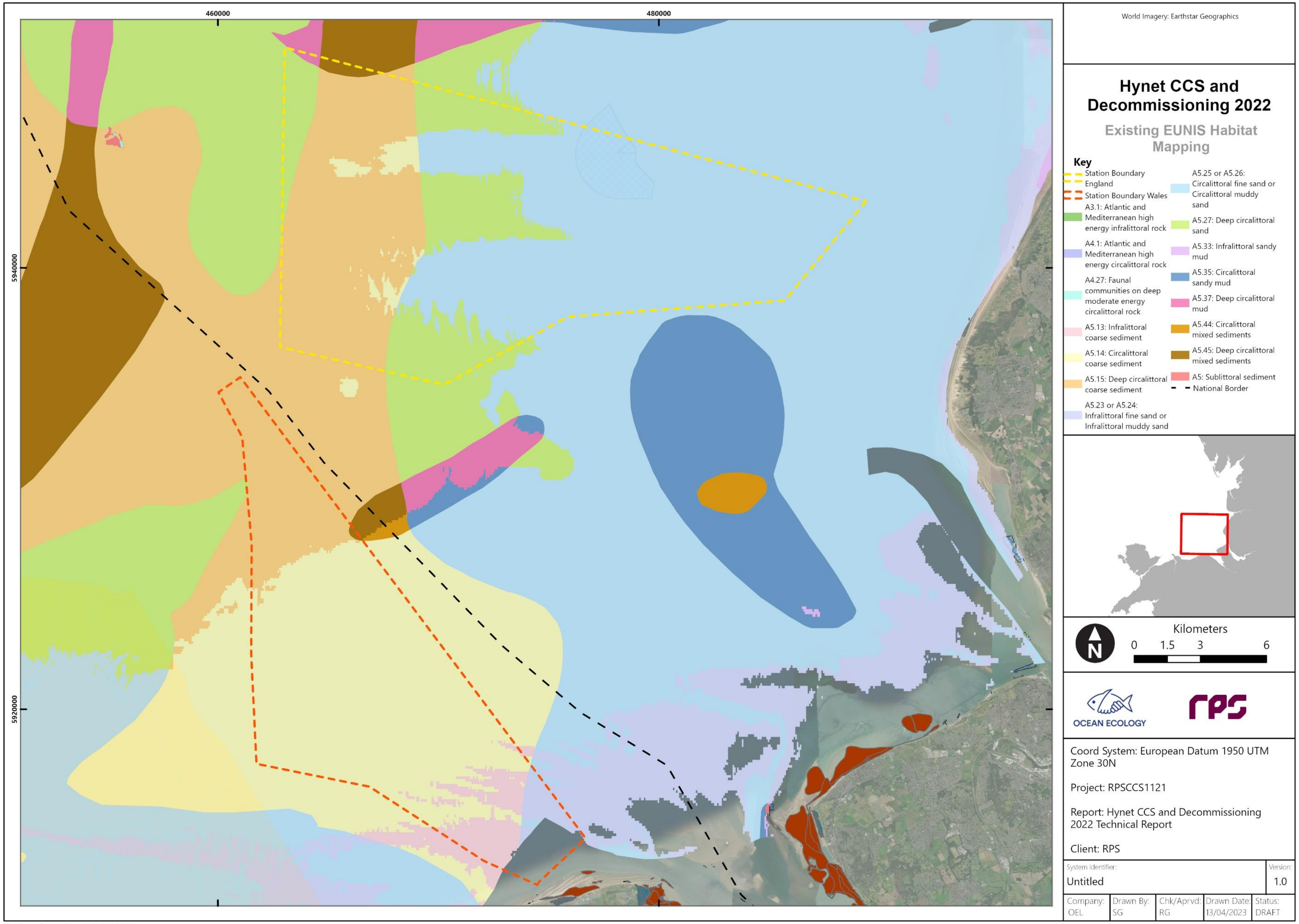

Figure 2 Existing habitats across the Hynet survey area.

2.3. Designations

Five nature conservation designations fall within the survey area: The Liverpool Bay / Bae Lerpwl SPA, the Fylde MCZ, the Colwyn Bay and Rhyl Flats Marine Character Area (MCA), the Dee Estuary (Wales) MCA and the North Wales Open Waters MCA (Figure 3). Additionally, the Dee Estuary SAC and SPA are situated in close proximity to the survey area (Figure 3).

2.3.1. Liverpool Bay / Bae Lerpwl SPA

Liverpool Bay / Bae Lerpwl SPA borders the coastlines of north-west England and north Wales and intersects the majority of the survey area (Figure 3). This SPA is classified for the protection of red-throated diver (*Gavia stellata*), common scoter (*Melanitta nigra*), and little gull *(Hydrocoloeus minutus*) in the non-breeding season; common tern (*Sterna hirundo*) and little tern (*Sterna albifrons*) in the breeding season and is an internationally important waterbird assemblage. The SPA extends beyond the 12 nautical mile boundary, lying partly in Welsh territorial waters and partly in UK offshore waters meaning that Natural Resources Wales (NRW) and the Joint Nature Conservation Committee (JNCC) are responsible for providing statutory advice.

2.3.1. Dee Estuary SAC and SPA

The Dee Estuary SAC and SPA are situated on the boundary between England and Wales and lie 175 m south of the survey area (Figure 3). This site has been designated as an SAC as it supports a variety of estuarine habitats, including mudflats and sandflats. This site has also been designated as a SPA due to its significant importance for waterbirds, including bar-tailed godwit (*Limosa lapponica*), curlew (*Numenius arquata*) and dunlin (*Calidris alpina*).

2.3.2. Fylde MCZ

Fylde MCZ is located in Liverpool Bay, lying between 3 and 20 km off the Fylde coast and Ribble estuary and intersects the north of the survey area (Figure 3). This MCZ is classified for extensive areas of subtidal sediment habitats which support rich bivalve mollusc populations. The site also provides important nursery and spawning grounds for several commercially important fish species, including sole (*Solea solea*), plaice (*Pleuronectes platessa*) and whiting (*Merlangius merlangus*).

2.3.3. Colwyn Bay and Rhyl Flats MCA

Colwyn Bay and Rhyl Flats MCA is located across the shallow coastal and inshore waters of Colwyn Bay and the extensive sand banks of Rhyl Flats, Chester Flats and Constable Bank. This MCA intersects the southern extent of the survey area (Figure 3) and comprises sand flat, sandbank, bay and rocky shore habitats, which are important for biodiversity.

2.3.4. Dee Estuary (Wales) MCA

Dee Estuary MCA is situated across the west of the Dee Estuary, extending offshore to cover the sand banks and main approach channels which define the entrance from Liverpool Bay (Figure 3). This area intersects the southern extent of the survey area and provides important shifting sandbank habitat and estuary habitat, internationally and nationally designated for biodiversity.

2.3.5. North Wales Open Waters MCA

The North Wales Open Waters MCA covers the outer inshore waters of North Wales and intersects the south of the survey area (Figure 3). This area provides important feeding grounds for sea birds and also supports bottlenose dolphins (*Tursiops truncatus*) and grey seals (*Halichoerus grypus*).

2.3.6. Features of Conservation Importance (FOCI)

Historical records of SOCI were identified within proximity to the proposed survey area using Natural England Marine Habitats and Species Open Data (MHSOD). Records within close proximity to the survey area comprised the spiny dogfish (*Squalus acanthias*), the European eel (*Anguilla anguilla*), and ocean quahog (*Arctica islandica)* (Figure 4).

Subtidal Mixed Muddy Sediment habitat of 'Principal Importance' was identified across the southern survey area using data from NRW (Figure 4). This habitat may support a wide range of infauna and epibiota, including polychaetes, bivalves, echinoderms, anemones, hydroids and Bryozoa and is afforded protection under the Environment (Wales) Act (2016), Section 7.

2.3.7. Annex I Habitats

Several important and sensitive habitats are known to be present within the vicinity of and/or intersected by the survey area (Figure 4), which comprise Annex I habitats that are a primary reason for the selection of designated sites. These include:

- Reefs
- Mudflats and sandflats not covered by seawater at low tide
- Salicornia and other annuals colonising mud and sand
- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)

Reefs

Geogenic Reef

Geogenic reefs can be very variable in terms of both their structure and the communities that they support. They provide a home to many species, such as corals, sponges, and sea squirts, as well as give shelter to fish and crustaceans, such as lobsters and crabs. They can be classified as either bedrock or stony reefs.

Based on existing habitat mapping derived from JNCC, rocky habitats, including bedrock or stony reefs, are thought to occur within in northern sector of the survey area (Figure 4). Geogenic reefs are also a primary designating feature of the Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay SAC, situated to the southwest of the survey area (Figure 3).

Stony Reef

Stony reef habitats occur when stable hard substrata, namely cobbles and boulders > 64 mm in diameter, arising from the surrounding habitat, creating a habitat colonised by a variety of species. Numerous SAC sites have been designated in UK waters to protect stony reef habitats and associated communities. Such communities can be highly diverse, supporting assemblages of various corals, sponges, ascidians, fish, and crustaceans. These associated communities vary dramatically according to environmental variables and may incorporate species that occupy a range of trophic levels. The complexity of the habitat created by stony reefs often supports a higher abundance of mobile fauna such as echinoderms and various crabs, hermit crabs, and squat lobsters, as well as fish species for which these species represent key prey items.

Bedrock Reef

Similar to the stony reef, Annex I bedrock reef habitat occurs where soft (e.g., clay) or hard bedrock arises from the surrounding seabed, providing a stable habitat for attachment for a diverse range of epibiota. Bedrock reefs and associated biological communities can be highly variable due to the diverse nature of these habitats in terms of topography, structural complexity, and exposure to tidal streams. In the photic zone, communities associated with bedrock reefs are often dominated by attached algae and often support various invertebrate species such as corals, sponges, and ascidians.

These epibiotic communities further increase structural complexity and represent key prey items that, in turn, attract more mobile and commercially valuable species, such as fish and crustaceans.

Sabellaria Reef

Sabellaria reefs are biogenic habitats formed by sedentary filter-feeding polychaete worms belonging to the family Sabellariidae. Two species are found in Wales, the honeycomb worm (*Sabellaria alveolata*) and the Ross worm (*Sabellaria spinulosa*). Both are gregarious species and can form biogenic reef colonies that can cover hundreds of thousands of square meters of the seabed (Jenkins et al. 2018) and similarly large areas of intertidal lower shore (Dubois et al. 2002).

Biogenic reefs formed by *Sabellaria* spp. are thought to benefit wider ecosystem functioning. Their structures are topographically complex, with features such as standing water, crevices and consolidated fine sediments providing microhabitats for other organisms and high levels of biodiversity (Limpenny et al. 2010, Pearce et al. 2011). The associated communities can vary according to local conditions of salinity, water movement, depth, and turbidity (Natural England & Countryside Council for Wales 2009).

The extent and distribution of *S. alveolata* reefs are thought to be increasing in Wales (Mercer 2016), whilst it is thought that the extent of *S. spinulosa* reefs is potentially underestimated (NRW 2019). Despite this, no known *Sabellaria* spp. reefs have previously been recorded across the survey area.

Due to their historic losses, sensitivity to anthropogenic disturbance, and biological importance, *Sabellaria* spp. reefs are afforded protection under several conservation policies and legislations. For example, *S. spinulosa* reefs are listed on the OSPAR List of Threatened and/or Declining Species and Habitats, whilst *S. alveolata* reefs are listed as a Priority Habitat under Section 7 of the Environment (Wales) Act 2016 (previously NERC S42 lists) within the category of "Littoral Rock". Reefs formed by both species are also considered within the Marine Protected Area network feature list for Wales (Carr et al. 2016) and are considered as Water Framework Directive (WFD) higher sensitivity habitats as 'Polychaete reefs'.

Mudflats and sandflats not covered by seawater at low tide

Mudflats and sandflats not covered by seawater at low tide (mudflats and sandflats) consist of intertidal flats characterised by mobile coarse sand beaches and mudflats in the proximity of estuaries and marine inlets. This habitat is a primary designated feature of the Dee Estuary SAC, situated 175 m south of the survey area (Figure 3).

Mudflats and sandflats are characterised by faunal and floral communities that reflect the type of sediment present. Specifically, in locations where wave action is strong, clean sands are predominant, with ecological communities dominated by resilient taxa, such as amphipods, polychaetes worms, and few bivalve molluscs. In contrast, relatively sheltered sites are characterised by a mixture of sand and mud, with a wide range of species colonising the sediment. Among them, the lugworm *Arenicola marina* is one of the most notable polychaetes, although sizable *Mytilus edulis* beds can also be found at the lower shore. Importantly, eelgrass (*Zostera* spp.) bed can also be found. Finally, where the coast is particularly sheltered, mud is the major constituent of the sediment, and the habitat is typically dominated by polychaete worms, bivalve molluscs, and the gastropod *Hydrobia ulvae*. In turn, these prey-species are an important source of food for some species of birds, like the common shelduck *Tadorna tadorna*, the knot *Calidris canuta*, and the dunlin *C. alpina*.

***Salicornia* and other annuals colonising mud and sand**

These habitats are typically intertidal mud and sandflats occurring in areas relatively sheltered from waves, allowing for the growth of pioneer vegetation. Typically, these floral communities are not particularly diverse. However, they are characterised by stable stands comprising a small number of species (e.g., *Suaeda maritima*, *Sagina maritima*, *Salicornia* spp.). Here, in the proximity of the sites considered for the CCS, partial, and total decommissioning, is the Dee estuary, which is representative of *Salicornia* spp. saltmarshes. Importantly, the habitat-type features of the area are outstanding in a European context.

Atlantic salt meadows (Glauco-Puccinellietalia maritimae)

Atlantic salt meadows are characterised by halophytic (i.e., tolerant of high-salinity) vegetation colonising a mixture of sediment composed of mud and sand, similar to *Salicornia* spp. Saltmarshes. However, complete, regular inundation can still occur due to tides. The Dee Estuary boasts floral communities typical of this habitat type, especially *Puccinellia maritima*, *Aster tripolium*, and *Triglochin maritima*.

2.3.8. Other Annex I Habitats

In addition to the habitats described above, Annex I habitats that are present as a qualifying feature are also known to be in the vicinity of and/or within the area. These include:

- Estuaries
- Annual vegetation of drift lines
- Vegetated sea cliffs of the Atlantic and Baltic Coasts
- Embryonic shifting dunes
- Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)
- Fixed coastal dunes with herbaceous vegetation (grey dunes)
- Humid dune slack

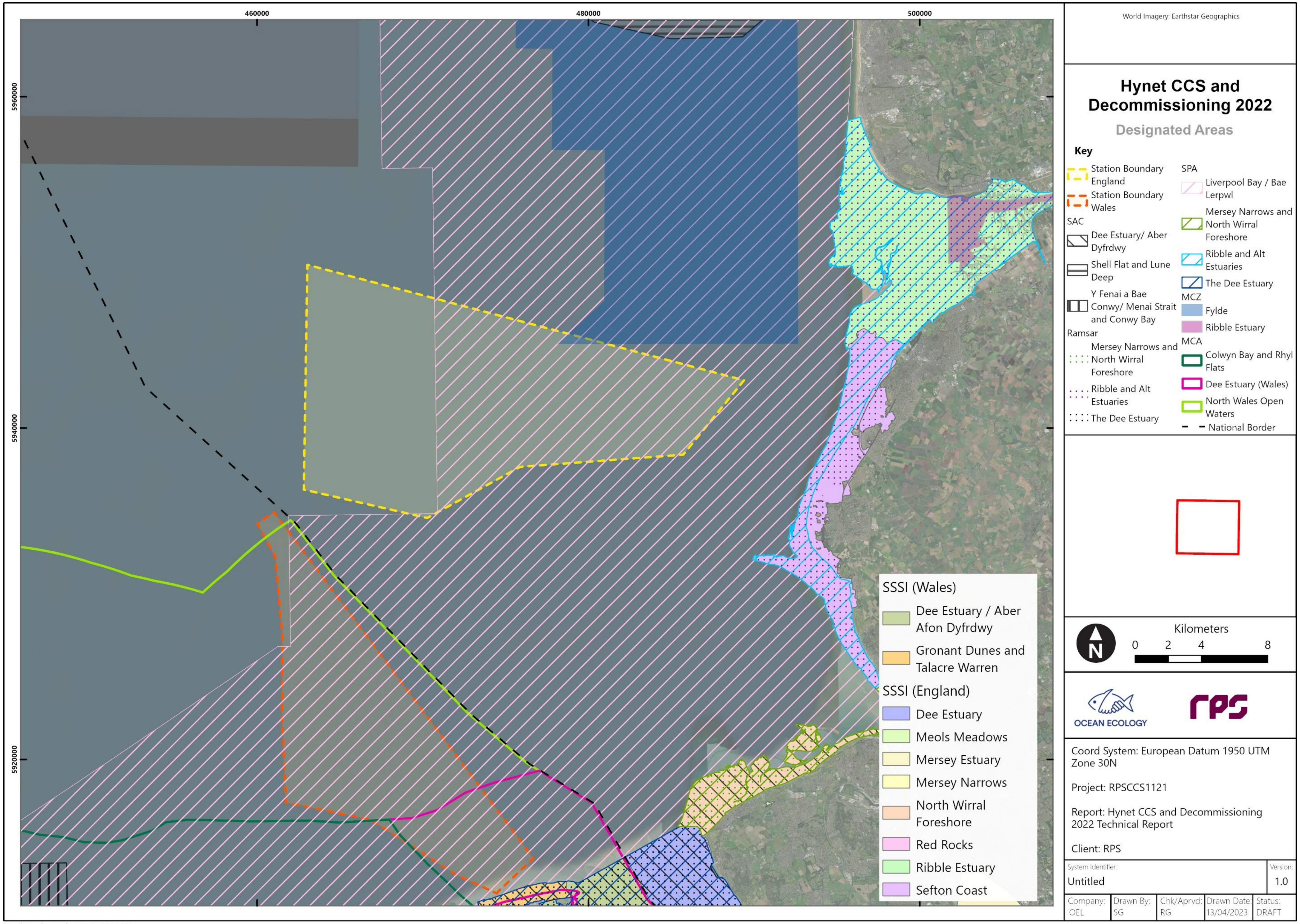

Figure 3 Designated sites across and in the vicinity of the survey area.

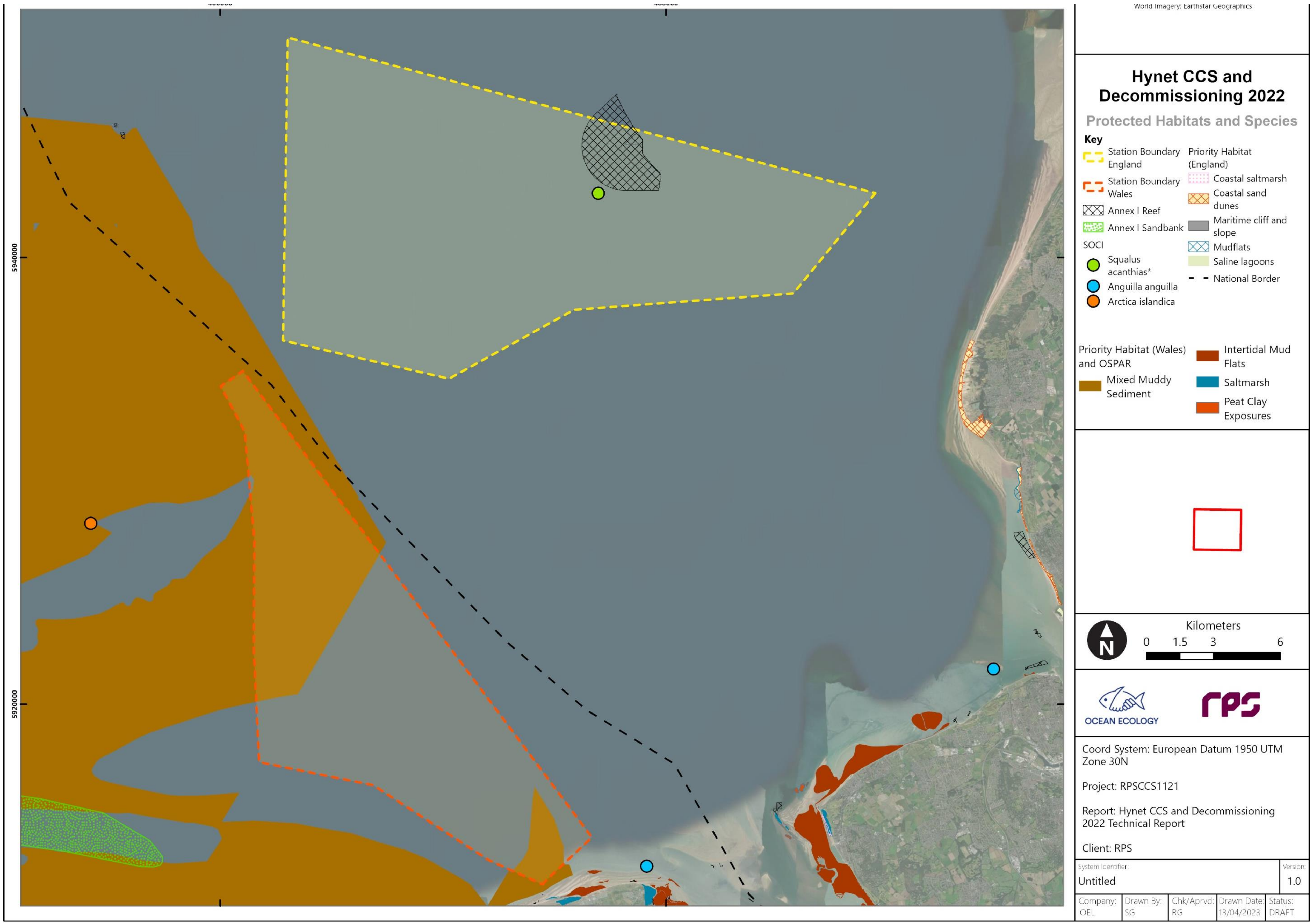

Figure 4 Overview of protected habitats and species within and in the vicinity of the survey area.

3. Survey Design

3.1. Rationale

Seabed imagery was collected at all sampling locations using a drop-down camera (DDC) system to determine the feasibility of collecting macrobenthic and sediment samples. Following an onboard review of the DDC footage, if an Annex I habitat was confirmed at a location, sampling was to be limited to DDC only rather than a combination of benthic grab sampling and DDC. Following this pre-screening at each sampling station, grab sampling for macrobenthic, particle size distribution (PSD) and sediment chemical analysis were conducted. A total of 85 stations were targeted during the survey, with a different sampling approach employed for the Project and decommissioning activities.

3.2. Sampling Strategy

Table 1 outlines the final stations agreed upon in the Sampling and Analysis Plan (SAP) for sampling across the survey area.

Table 1 Agreed sampling strategy.

Site	DDC Stations	Macrobenthic/PSD	Chemical
Proposed Development	26	26	15
Partial decommissioning of existing Eni UK Liverpool Bay	32	32	32
OSI full decommissioning	27	27	27
Total	**85**	**85**	**74**

A revised scope for grab sampling was provided by RPS and agreed upon with ENI during the survey programme. The scope was updated following a review of DDC imagery, with two development stations removed due to proximity to successfully sampled stations of corresponding habitat and six full decommissioning stations removed due to the heterogenous nature of the habitat in the vicinity of the OSI. These were removed from the middle sample locations on six of the anchor chains, with the key stations for the assessment being the inner stations closest to the OSI for potential contaminants and the outer stations at the anchor locations where disturbance would be greatest during decommissioning (Table 2).

Table 2 Revised sampling strategy.

Site	DDC Stations	Macrobenthic/PSD	Chemical
Proposed Development	26	24	14
Partial decommissioning of existing Eni UK Liverpool Bay	32	32	32
OSI full decommissioning	27	21	21
Total	**85**	**77**	**67**

4. Field Methods

4.1. Survey Vessel

The survey was conducted aboard OEL's 11.7 m Marine and Coastal Agency (MCA) Category 2 coded dedicated survey vessel *Argyll Explorer* (Plate 1 and Table 3).

Plate 1 OEL's dedicated survey vessel '*Argyll Explorer*' alongside Rhyl Harbour.

Table 3 Vessel details.

Vessel Name	*Argyll Explorer*
Mobilisation Port	Rhyl, UK
Length	11.7 m
Beam	5.5 m
Draft	1.1 m

4.2. Geodetic Parameters

4.2.1. Horizontal Datum

All coordinates were based on ED50 with projected grid coordinates based on Universal Transverse Mercator (UTM) zone 30 N with a Central Meridian of 03° W. A summary of the geodetic and projection parameters is outlined in Table 4 and Table 5.

Table 4 Datum parameters.

Parameter	Details
Name	ED50 / UTM Zone 30N
Ellipsoid	International 1924
Semi-Major Axis (a)	6 378 388.00 m
Semi-Minor Axis (b)	6 356 911.95 m
Inverse Flattening	297
Geodetic parameters EPSG Code	7022

Table 5 Projection Parameters.

Parameter	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	16030
Units	Meters

4.2.2. Unit Format and Conversions

The used throughout this project were expressed using the conventions described in Table 6.

Table 6 Project unit format and convention details.

Unit Formats and Conventions	
Geographical Coordinates	Latitude N DD˚MM.mmmmmm' to six decimal places.
	Longitude E/W DD˚MM.mmmmmm' to six 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 one decimal place.
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 unless otherwise stated.

4.3. Survey Equipment

4.3.1. Surface Navigation

The vessel was equipped with a Hemisphere V200s Global Positioning System (GPS) Compass system that provided an offset position of the sampling equipment when deployed from the stern A-frame. This provided a GPS feed to a dedicated survey navigation PC operating EIVA NaviPac, and TimeZero Navigator v4 marine navigation with routing module and Class A AIS. Subsea positioning was achieved using Ultra-short baseline (USBL) positioning through EIVA NaviPac V4.5 software.

4.3.2. Subsea Positioning

Hardware

An Easytrak Nexus 2 Lite USBL transducer was used for subsea positioning of 1329A Omni-directional +/-90° Micro Beacons mounted on the DDC frame and grab samplers. The USBL transducer was mounted on an over-the-side pole and was calibrated on-site. A Valeport miniSVP sound velocity profiler was used to conduct daily sound velocity profiles.

Software

The USBL system was controlled through its dedicated software Easytrak Nexus 2 Lite. Daily sound velocity readings with depth were imported into the USBL software to correct the soundings and improve the accuracy of the subsea positioning.

4.3.3. Calibrations and checks

Positioning checks, along with a calibration of the USBL system, were undertaken at the start of the survey.

4.3.4. Drop Down Camera (DDC)

Seabed imagery was collected using OEL's DDC system to collect high-definition (HD) video and high-resolution (up to 24 megapixels (MP) still images at each targeted station (Plate 2). The camera system consisted of a SubC Rayfin 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 was obtained. Two RovTech LED strip lights with two 5 kW green dot lasers (set to 10 cm distance for scale), a 300 m umbilical and a 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 caused a power surge. 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 at each station (e.g., high turbidity). Following an *in situ* review of seabed imagery, adjustments to the lighting angle were made to improve illumination across the centre of the field of view.

Plate 2 DDC system (top), DVV grab (bottom left), and equipment dampener (bottom right) mobilised aboard the Argyll Explorer.

4.3.5. Grab Samplers

Sediment samples were collected using a combination of a 0.1 m^2 Day grab and a 0.2 m^2 Dual Van Veen (DVV) grab (Plate 2). A 0.1 m^2 mini-Hamon grab was also available as backup for areas of coarse sediment where samples could not be collected using the Day or DVV samplers. The DVV sampler was used at the first five stations that were sampled. The Day grab was employed for all remaining stations.

4.4. DDC Sampling

All seabed imagery was collected in consideration of the Joint Nature Conservation Committee (JNCC) epibiota remote monitoring operational guidelines (Hitchin et al. 2015). At each DDC station, a minimum of two minutes of video footage and five seabed still images were obtained. The vessel was moved within a 20 m radius of the target location to adequately characterise the target area. All video footage was reviewed in situ by OEL's environmental scientists.

The DDC was deployed from the vessel using the A-frame mounted winch equipped with a Dyneema line (Plate 2). The DDC umbilical was run through a secondary block mounted from the equipment dampener and lowered to the seabed over the target location, and slowly 'flown' just above the seabed to obtain continuous video footage. Still images representative of each target location were captured by landing the frame on the seabed. The camera was kept as close to the seabed as possible to gain a clear image where possible while also being high enough in the water column that accidental collisions with the seabed did not occur. The footage was viewed in real-time by the topside marine biologist via an umbilical.

4.5. Grab Sampling

The grab samplers were deployed to the seabed from the vessel using the A-frame mounted winch equipped with a Dyneema line. To ensure consistency in sampling, grab samples were screened by the lead marine ecologist and considered unacceptable if:

- The sample was less than 5 L – i.e., the sample represented less than half the 10 L capacity of the 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)

Where a suitable sample was not collected after three attempts within 20 m of the target sampling locations, the sampling location was moved up to 50 m from the original target location. If the location was within proximity to subsea infrastructure, the vessel was moved in the opposite direction to the hazard. Where samples of less than 5 L were continually achieved, these samples were assessed on-site to establish if the sample volume was acceptable to allow subsequent analysis. No pooling of samples was undertaken.

4.5.1. Macrobenthic / PSD Sample Processing

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

- Initial visual assessment of sample size and acceptability made.
- Photograph of the sample with station details taken in grab and once released.

- 10 % of the sample was removed for PSD analysis and transferred to a labelled tray.
- The remaining sample was emptied onto a 0.5 mm sieve net laid over a 4.0 mm sieve table and washed through using gentle rinsing with a seawater hose (note all samples, including development scope, sieved at 0.5 mm in the field to remove the risk of decommissioning samples being sieved at 1.0 mm, development scope samples were then sieved at 1.0 mm during sample processing on return to OEL laboratory).
- The remaining sample for faunal sorting and identification was back washed into a suitable-sized sample container and diluted 10 % formalin solution was added to fix the sample prior to laboratory analysis.
- Sample containers were clearly labelled internally and externally with the date, sample ID and project name.
- The PSA samples were frozen immediately on board the vessel.
- 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.

4.5.2. Contaminant Sample Processing

Detailed notes were taken of visible sediment conditions and seabed features, obvious fauna and habitat-related features whilst in the field. Sample processing was undertaken onboard the survey vessel using the following methodology:

- Initial visual assessment of sample size and acceptability made.
- Photograph of the sample with station details taken of the grab.
- Two sub-samples for metals contaminant analysis (‘A rep’ and back up ‘B rep’) were taken from undisturbed sediment within the grab using a plastic trowel cleaned in acetone.
- Samples stored in 500 ml plastic sample containers clearly labelled externally with date, sample ID and project name.
- Three sub-samples for hydrocarbon contaminant analysis (2 x ‘A rep’ and back up ‘B rep’) were taken from undisturbed sediment within the grab, using a metal trowel cleaned in acetone.
- Samples were stored in 150 ml glass sample containers sealed with metal foil and clearly labelled externally with the date, sample ID and project name.
- All contaminant samples were frozen immediately on board.

5. Laboratory and Analytical Methods

5.1. PSD Analysis

PSD analysis of sediment samples was undertaken by in-house laboratory technicians at OEL's MMO Validated 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 six 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 removed from the sample. A representative sub-sample of the whole sample was then removed for laser diffraction analysis before the remaining sample was screened over a 0.5 mm sieve for partial and total decommissioning stations and over a 1 mm sieve for the CCS stations. This procedure was carried out to sort coarse and fine fractions. Care was taken so as not to overload the sieve and allow a continual flow of sediment through until the water ran clear.

5.1.1. Dry Sieving

The > 0.5 mm and > 1 mm fractions were then returned to a drying oven and dried at 80° C for at least 24 hours before dry sieving. Once dry, the sediment samples 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 7.

Table 7 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 samples were 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. A further 10 minutes of shaking was undertaken if there was evidence that particles had not been properly sorted.

5.1.2. Laser Diffraction

The sub-samples for laser diffraction were first screened over a 0.5 mm sieve (partial and total decommissioning) and a 1 mm sieve (CCS), and the fine fraction residue was transferred to a suitable container and allowed to settle for 24 hours before excess water was 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. For silty sediments, ultrasound was used to agitate particles and prevent aggregation of fines.

5.1.3. Data Merging

The dry sieve and laser data were then merged for each sample, with the results expressed as a percentage of the whole sample at 0.5 φ intervals from - 5.5 (45 mm) to > 14.5 (< 0.04 µm). Once data were 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 were defined by their size class based on the Wentworth classification system (Wentworth 1922) (Table 8). 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 8 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

Samples collected were assessed for chemical contaminants (see Appendix I for methods).

5.2.1. Hydrocarbons

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 (Page et al. 1999, Junttila et al. 2015), such as forest fires and incomplete combustion of fossil fuels.

Indices and ratios were calculated to assess the source origin of hydrocarbons in the sediment sampled across the Hynet CCS and decommissioning stations (Ines et al. 2013, Al-hejuje et al. 2015). Based on aliphatic hydrocarbons and n-alkanes, the following index and ratios were calculated:

Carbon Preference Index (CPI): the ratio between the concentration of odd-numbered and even-numbered carbon chains in n-alkanes. CPI values close to one indicate hydrocarbons of petrogenic origin, CPI values below one indicate pyrogenic origin (Fagbote 2013), and CPI values higher than one indicate a biogenic origin of alkanes (Al-hejuje et al. 2015).

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 & 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.

5.2.2. Heavy Trace Metals

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), 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). 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.

5.2.3. Macrobenthic Analysis

All elutriation, extraction, identification, and enumeration of the grab samples were undertaken at OEL's NMBAQC scheme participating laboratory in line with the NMBAQC Processing Requirement Protocol (PRP) (Worsfold et al. 2010). All processing information and macrobenthic records were recorded using OEL's cloud-based data management application 'ABACUS' which employs MEDIN[1]-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 0.5 mm (partial and total decommissioning) and 1 mm mesh (CCS) sieves in a well-ventilated area. The samples were then re-sieved over 0.5 mm (partial and total decommissioning), and 1 mm mesh (CCS) sieves to remove all remaining fine sediment and fixative. The low-density fauna was then separated by elutriation with fresh water, poured over 0.5 mm (partial and total decommissioning) and 1 mm mesh (CCS) sieves, transferred into a Nalgene, and preserved in 70 % Industrial Denatured Alcohol (IDA). The remaining sediment from each sample was subsequently separated into 0.5 mm, 1 mm, 2 mm, and 4 mm fractions for the partial and total decommissioning and 1 mm, 2 mm, and 4 mm fractions for the CCS. These were then sorted under a stereomicroscope to extract any remaining fauna (e.g., high-density bivalves not 'floated' off during elutriation).

[1] Marine Environmental Data and Information Network.

All macrobenthos present was identified to species level, where possible, and enumerated by trained benthic taxonomists using the most up-to-date taxonomic literature and checks against existing reference collections.

Nomenclature utilised the live link within ABACUS to the WoRMS (World Register of Marine Species) REST web service to ensure the most up-to-date taxonomic classifications were recorded. Colonial fauna (e.g., hydroids, bryozoans) were recorded as present (P). For the purposes of subsequent data analysis, taxa recorded as P were given the numerical value of 1.

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

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

5.3. Macrobenthic Data Analysis

5.3.1. Data Truncation and Standardisation

The macrobenthic species 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 the taxonomic resolution were identified.

5.3.2. Pre-Analysis and Data Treatment

All data were collated in excel spreadsheets and made suitable for statistical analysis. All data processing and statistical analysis were undertaken using R v. 1.2 1335 (R Core Team 2020) and PRIMER v7 (Clarke & Gorley 2015a) software packages. Note that no replicate samples were available for macrobenthic analysis. Thus, no mean values could be calculated per sampling station.

In accordance with the OSPAR Commission guidelines (OSPAR 2004), records of colonial, meiofaunal, parasitic, egg, and pelagic taxa (e.g., epitokes, 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 10 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 Amphiuridae appeared in the top 10 most dominant taxa across the survey area, a 2STAGE analysis was conducted to compare the two data sets (with and without juveniles), which revealed a 96 % of similarity between the two and, therefore juveniles were retained in the dataset for all further analyses and discussion.

In accordance with NMBAQC PRP (Worsfold & Hall 2010), Nematoda taxa 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 shaded 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 & Gorley 2015) was utilised to undertake the multivariate statistical analysis on the macrobenthic biotic 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 II.

5.3.4. Determining EUNIS Classifications

Macrobenthic assemblages were characterised based on their community composition, with hierarchical clustering used to identify groupings of sampling stations that could be grouped together as a habitat type or community. Setting these groupings as factors within PRIMER, SIMPER analysis was then applied to identify which taxa contributed the most to the similarity within that community. EUNIS classifications were then assigned based on the latest JNCC guidance.

5.4. 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 line with JNCC epibiota remote monitoring interpretation guidelines (Turner et al. 2016). A full reef habitat assessment was conducted on all images to determine whether habitats met the definitions of Annex I reef habitats as detailed in Table 9 and Table 10. The annotation label tree used during the analysis had major headings for each 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 III.

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. The second stage, 'Tier 2', was used to assign percentage cover of reef types by drawing polygons.

Table 9 Characteristics of a 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 epibiotic species		

Table 10 Characteristics of *Sabellaria spinulosa* reef (Gubbay 2007a).

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

5.5. Determining Habitat Classifications

Habitats were identified and classified in accordance with the EUNIS habitat classification system (under the 2012 EUNIS classification system), in consideration 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). Seabed features were assigned as high-level classification as possible based on the macrobenthic community observed across the survey area. All habitat/biotope determination was undertaken through consideration of the following:

- Existing habitat mapping (derived from EMODnet)
- Seabed imagery
- PSA and macrobenthic analysis

6. Results

6.1. Particle Size Distribution Data

The sediment composition at each grab sampling station across all the survey areas is plotted in Figure 6, Figure 5, and Figure 7 and mapped in Figure 8 and Figure 11 . Grab sampling logs and sample photos for the stations are provided in Appendices IV, V, VI, and VII, and full PSD data has been provided in Appendices VIII (CCS) and IX (Decommissioning).

6.2. Sediment Type

Sediments were heterogeneous across the survey area with sand dominating across all stations and highly variable contributions of gravel and mud.

6.2.1. CCS

Of the 23 stations sampled, 11 were classified as EUNIS BSH A5.2 (Sand and Muddy Sand) including the textural groups Slightly Gravelly Sand ((g)S) and Sand (S). Nine stations represented EUNIS BSH A5.4 (Mixed Sediment) including the textural groups Gravelly Muddy Sand (gmS) and Muddy Sandy Gravel (msG), two stations belonged to BSH A5.1 (Coarse Sediments) being made of Gravelly Sand (gS) and Sandy Gravel (sG), and one Slightly Gravelly Muddy Sand ((g)mS) station was classified as BSH A5.3 (Mud and Sandy Mud).

Fifty-two percent of the CCS sediment samples were classified as very poorly sorted. The remaining CCS stations were classified as moderately well sorted (26.1 %), well sorted (13.0 %), poorly sorted (4.4 %), and moderately sorted (4.4 %). This variation results from a mixed composition of different size fractions of all three principal sediment types (gravel, sand, and mud).

6.2.2. Partial Decommissioning

Of the 32 partial decommissioning stations, 16 represented EUNIS BSH A5.2 including (g)S, S and (g)mS, nine stations were classified as BSH A5.4 all being made of gmS, five stations belonged to BSH A5.1 all being gS while two stations represented BSH A5.3 both being (g)mS.

6.2.3. Full Decommissioning

Of the 21 full decommissioning stations sampled, 14 represented BSH A5.2 and were made of mS, S, (g)mS and (g)S. The remaining stations classified as BSH A5.3 and included textural groups mS and (g)mS.

39.62% of all decommissioning sediment samples were classified as very poorly sorted, 22.64% as poorly sorted, 18.87% moderately sorted, and the remainder of the samples were split evenly as moderately well sorted (9.43%) and well sorted (9.43%).

6.3. Sediment Composition

Sediment was characterised by a predominance of sand across the survey area as a whole. While full decommissioning stations had very little gravel content, all other stations showed variable contributions of gravel and mud. The percentage contribution of gravels (> 2 mm), sands (0.63 mm to 2 mm), and fines (< 63 µm) at each station are presented in Figure 7. The mean proportion (± Standard Error, SE) of sands across all stations was 83 % (± 2), the mean (± SE) gravel and mud content across the survey area was 7 % (± 1) and 10% (± 1) respectively. A clear spatial pattern was evident in the distribution of mean grain size across the survey area with coarser sediments characterising stations located within the western reaches of the Welsh survey area (Figure 10).

6.3.1. CCS

Mean grain size across the CCS survey area ranged from 89 µm at station GS09 to 1070 µm at station GS18 (Figure 8).

Sand dominated across all CCS stations contributing a maximum of 100 % at stations GS22 and GS58. Highly variable contributions of gravel and mud characterised CCS stations with stations to the west of the survey area and within the Welsh boundary displaying the highest contributions of gravel reaching a maximum of 40 % at station GS18 (Figure 10), and station GS09 having the highest mud content at 35 % (Figure 9).

6.3.2. Partial Decommissioning

Mean grain size ranged between 91 µm at station GS29 and 792 µm at station GS54. A general pattern was observed in the spatial distribution of mean grain size with typically finer sediment in proximity of the platforms (Figure 8).

Sand dominated across all partial decommissioning stations with stations GS39, GS40, GS44, GS45, and GS46 made of 100 % sand. Mud was the second size fraction contributing to sediment composition reaching a peak of 35 % at station GS29 where no gravel was present and being generally high (>20 %) at stations GS31, GS33 and GS34 (Figure 9). Gravel contribution reached a maximum of 22 % at station GS52 (Figure 10).

6.3.3. Full Decommissioning

Mean grain size ranged between 90 µm at station GS69 and 374 µm at station GS58. As already seen for partial decommissioning stations, a general pattern was observed in the spatial distribution of mean grain size with typically finer sediment in proximity of the platform (Figure 8).

Sand dominated at all stations reaching a maximum of 100 % at station GS58. Mud notably contributed at most stations being above 20 % at seven stations and reading a maximum of 29 % at stations GS77 and GS81 (Figure 9). Gravel was overall very low at these stations with the highest contribution of 1 % found at station GS81 (Figure 10).

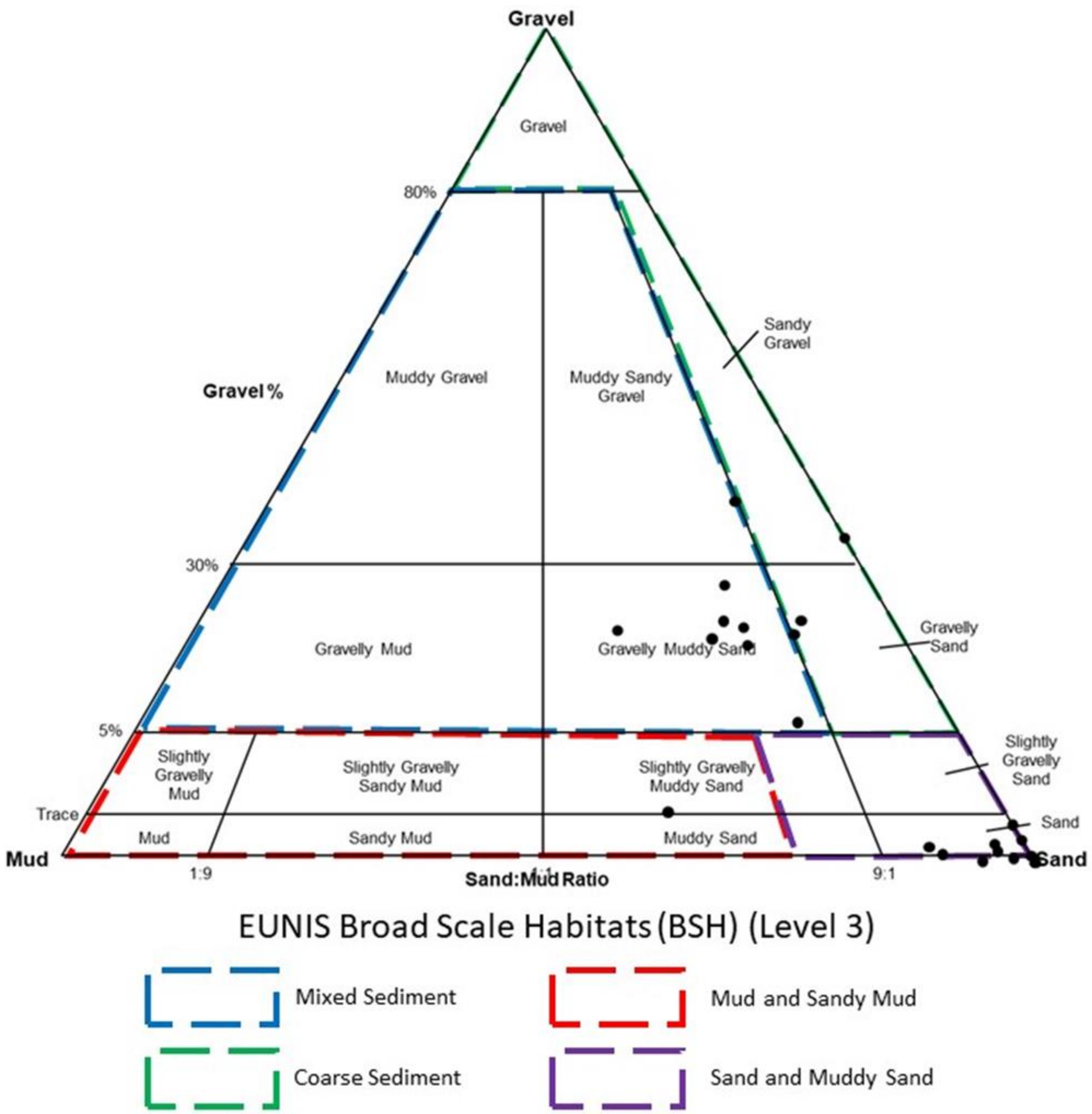

Figure 5 Folk (1954) triangle classifications of sediment gravel percentage and the sand-to-mud ratio of samples collected across the CCS survey area, overlain by the modified Folk triangle for determination of mobile sediment BSHs under the EUNIS habitat classification system (adapted from (Long 2006)).

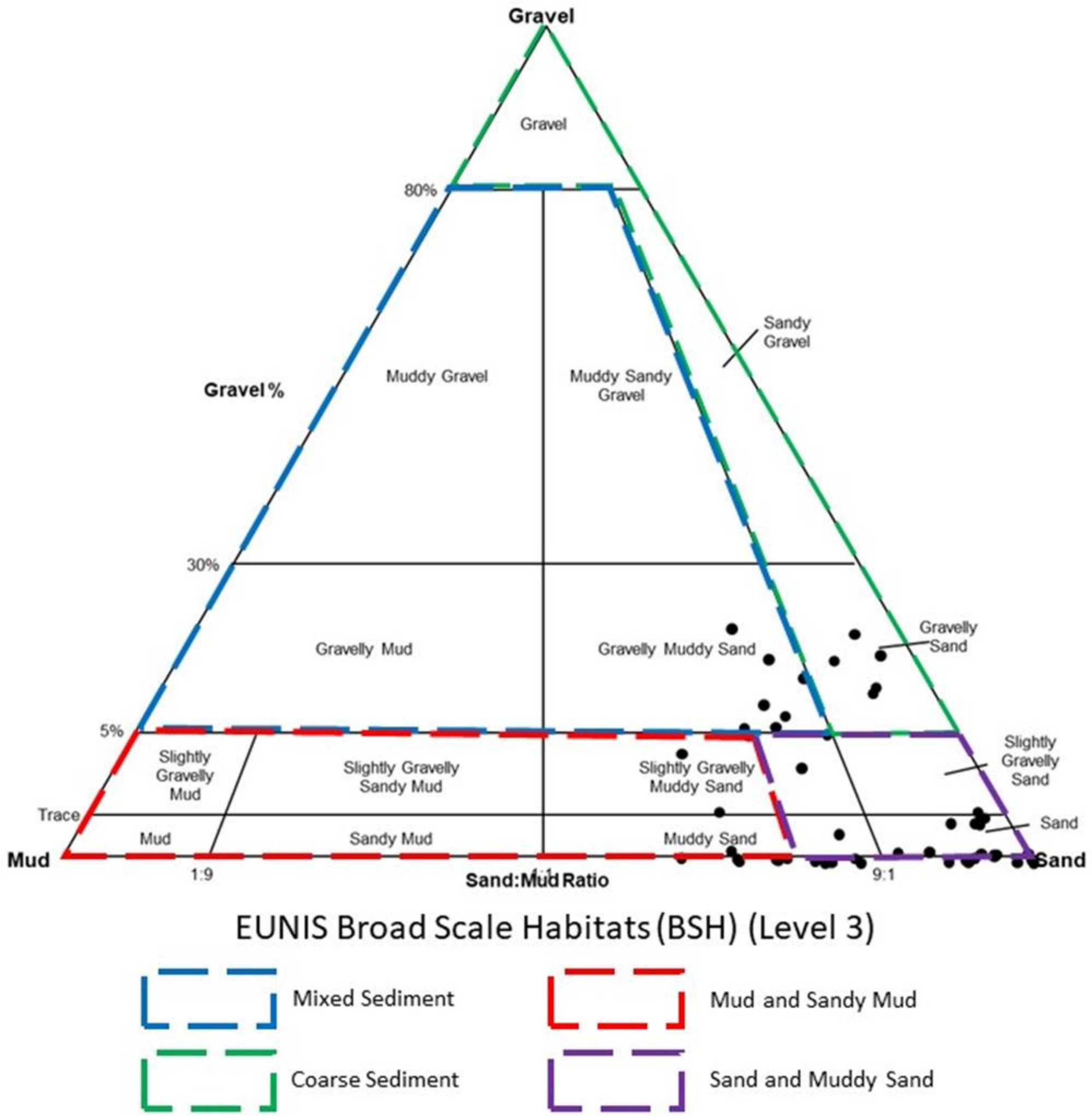

Figure 6 Folk (1954) triangle classifications of sediment gravel percentage and the sand-to-mud ratio of samples collected across the decommissioning survey area, overlain by the modified Folk triangle for determination of mobile sediment BSHs under the EUNIS habitat classification system (adapted from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

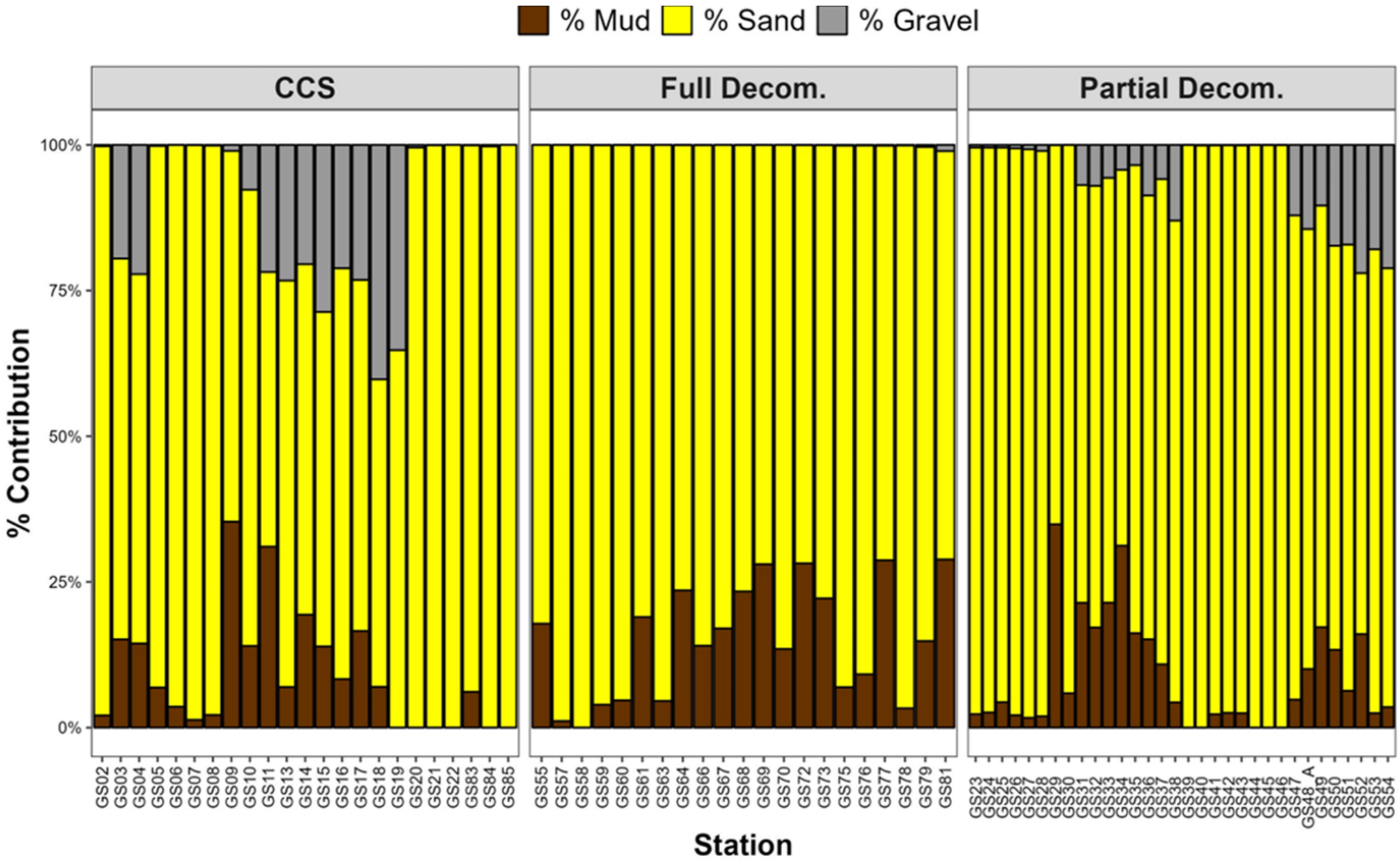

Figure 7 Relative contribution to the volume of sediment at each sampling station across the survey area. Plot facets indicate the scope of the project.

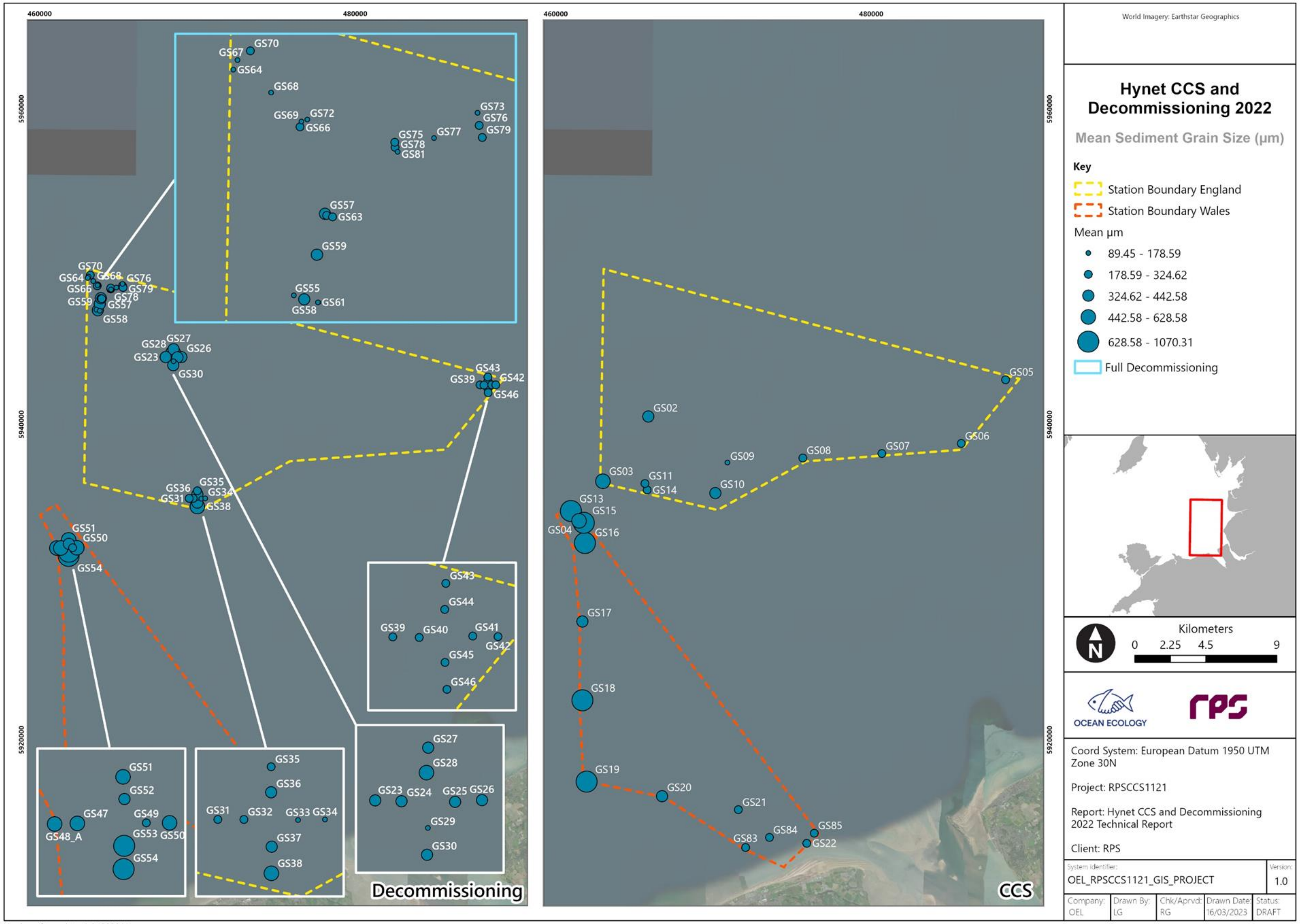

Figure 8 Mean grain size (µm) at each sampling station across the survey area.

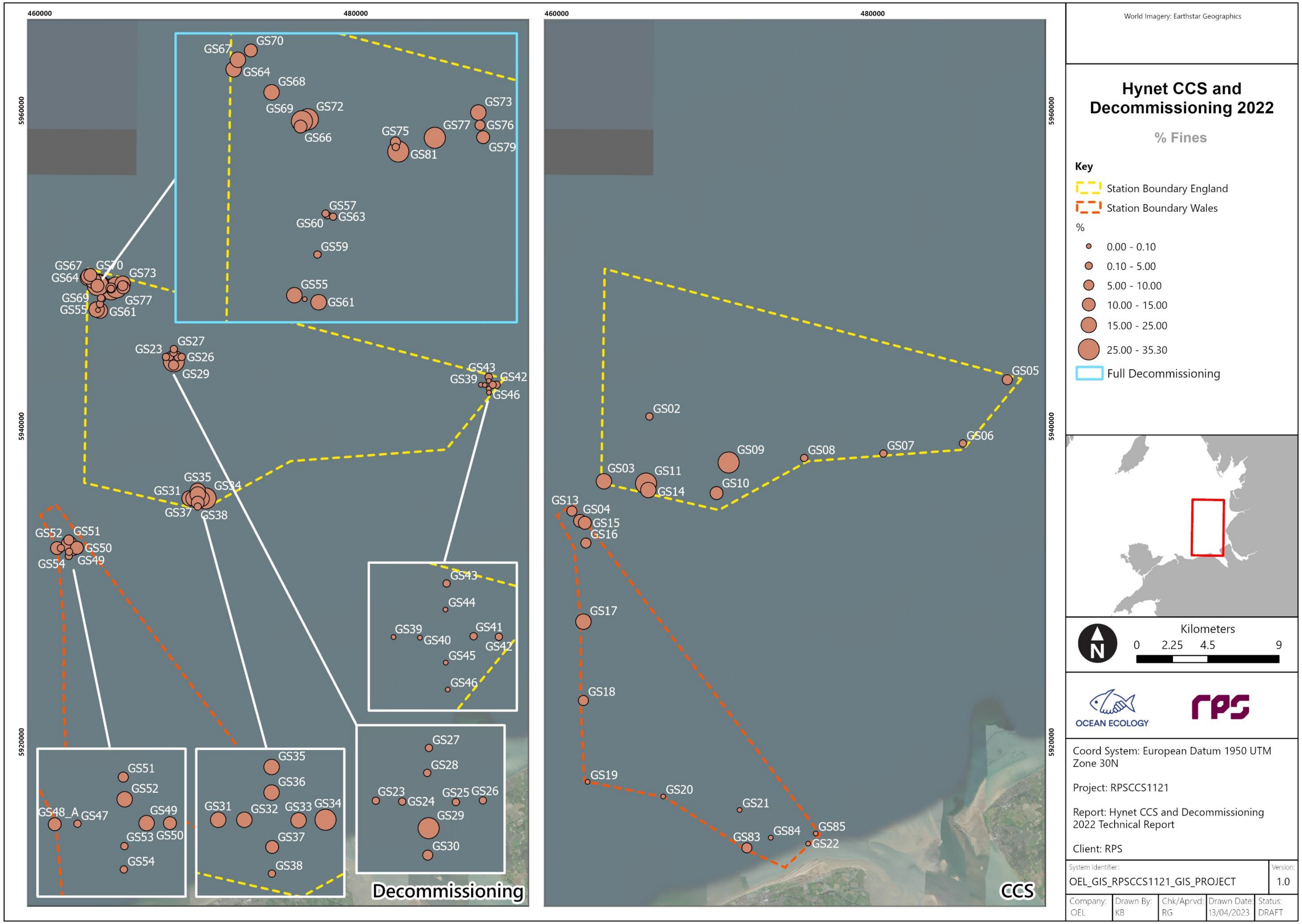

Figure 9 Percentage of fines (< 63 µm) at each sampling station across the survey area.

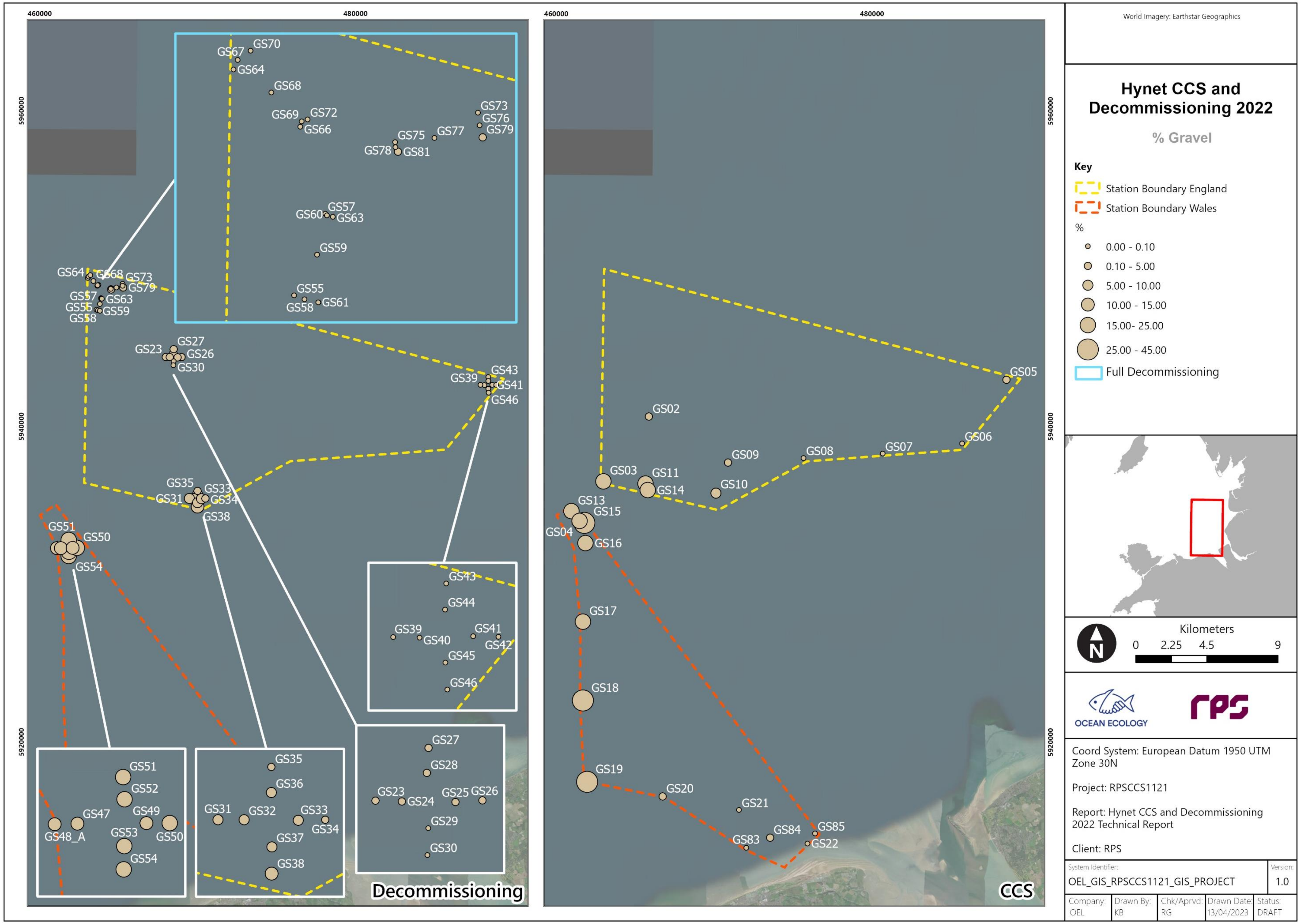

Figure 10 Percentage of gravel (> 2mm) at each sampling station across the survey area.

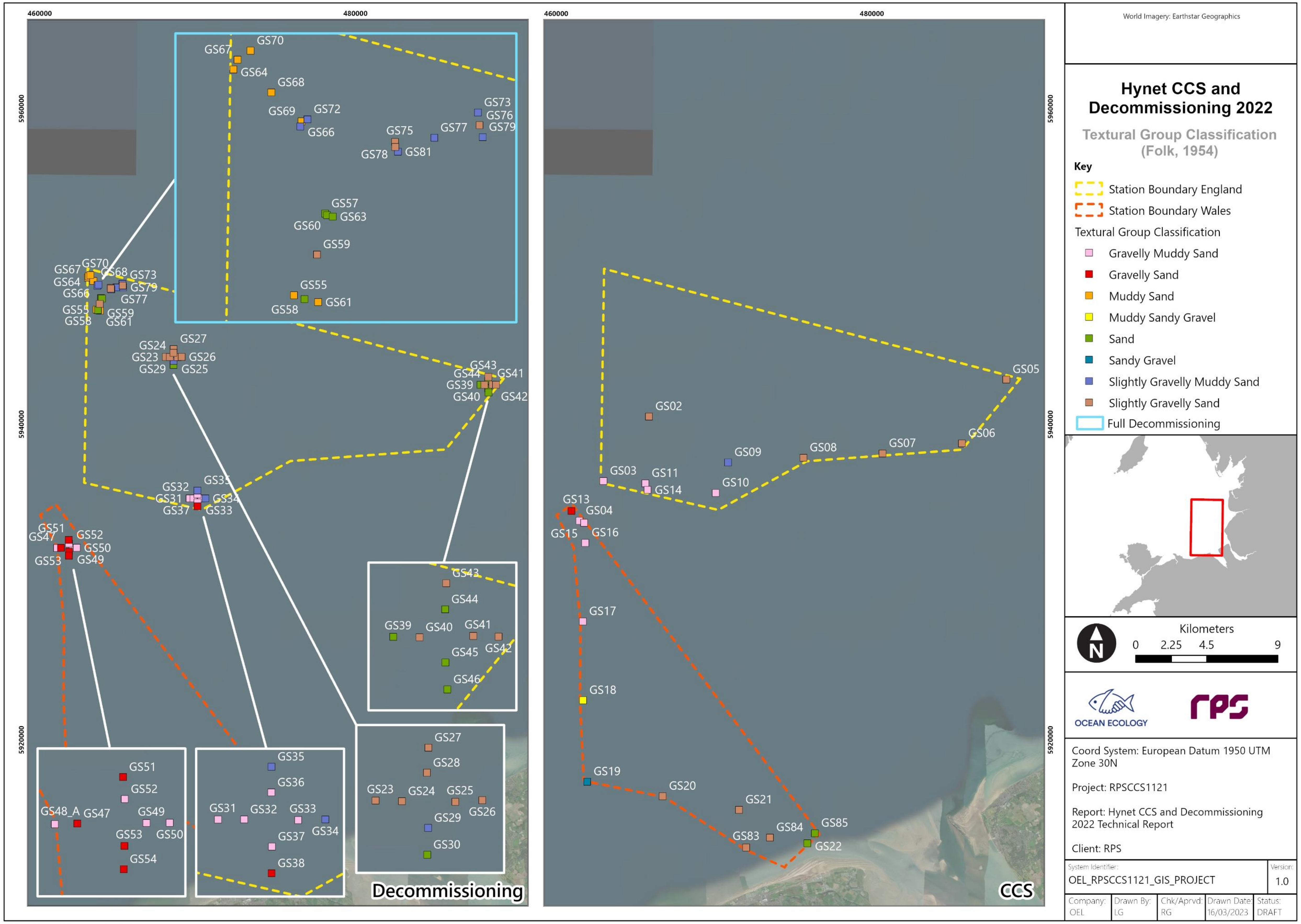

Figure 11 Textural group classification at each sampling station across the survey area.

6.4. Sediment Chemistry

Sediment samples for chemical contaminant analysis were collected at all decommissioning stations and at some selected CCS stations. Grab samples taken for chemical analyses were analysed for heavy and trace metals, Polycyclic Aromatic Hydrocarbon (PAH) and Total Hydrocarbon Content (THC), Organotins and Polychlorinated Biphenyls (PCBs). Raw sediment chemistry data are provided in Appendix X.

6.4.1. Heavy and Trace Metals

A total of eight 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).

CCS

Raw data for the eight main heavy and trace metals (dry-weight concentration, mg kg^{-1}) are shown in Table 12 together with available reference levels. None of the main heavy and trace metals exceeded CEFAS AL1. Station GS10 exceeded the OSPAR BAC reference levels for Hg; however, it was a very minor exceedance of 0.01 mg kg^{-1}, and the BAC for Hg is considerably lower than any of the other reference levels. Nine stations were above TEL and seven stations were above ERL for As.

The most abundant metal was zinc which ranged from 19.8 mg kg^{-1} at station GS85 to 49.8 mg kg^{-1} at station GS10 with an average concentration across all stations of 30.9 mg kg^{-1} ± 2.6 mg $kg^{-1.}$ Zinc was always recorded below reference levels at all stations.

Table 11 Number of stations across the Carbon Capture and Storage survey area exhibiting elevated heavy and trace metals levels in comparison reference levels.

Analyte	CEFAS		OSPAR		CSQG	
	AL1	AL2	BAC	ERL	TEL	PEL
As	0	0	0	7	9	0
Cd	0	0	0	0	0	0
Cr	0	0	0	0	0	0
Cu	0	0	0	0	0	0
Hg	0	0	1	0	0	0
Ni	0	0	0	0	-	-
Pb	0	0	0	0	0	0
Zn	0	0	0	0	0	0

Table 12 Summary of heavy and trace metal concentrations (mg kg-1) in sediments.

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
GS02	8.1	0	5.9	4.4	0.02	6	7.9	22.6
GS04	8.8	0	13.7	6.7	0.03	13	10.4	32.1
GS06	6.8	0.13	8	5.6	0.05	6.6	10.8	43.4
GS08	14.1	0.09	5.8	5.1	0.03	5.6	14.2	35.2
GS10	7.9	0.27	11.5	20.5	0.08	10.5	27.5	49.8
GS13	9.6	0.16	13.4	6.4	0.05	11.7	13.1	34.9
GS15	9.3	0.21	15.7	7.8	0.04	16.6	11.4	36.8
GS17	11.3	0.14	15	6.9	0.06	13.3	10	33.6
GS19	10.4	0	14.3	6.4	0.02	13.3	6	27.4
GS21	10.3	0	5	4.4	0.02	6.6	5.4	21.9
GS83	7.2	0	7.2	6.4	0	6.4	6.6	23.7
GS84	6.6	0.16	4.7	3.9	0	5.7	4.3	19.9
GS85	6.6	0.12	4.9	4.1	0	7.1	4.3	19.8
Min	6.6	0	4.7	3.9	0	5.6	4.3	19.8
Max	14.1	0.27	15.7	20.5	0.08	16.6	27.5	49.8
Mean	9.0	0.1	9.6	6.8	0.0	9.4	10.1	30.9
SE	0.6	0.0	1.2	1.2	0.0	1.0	1.7	2.6
CEFAS AL1	20	0.4	40	40	0.3	20	50	130
CEFAS AL2	100	5	400	400	3	200	500	800
OSPAR BAC	25	0.31	81	27	0.07	36	38	122
ERL	8.2*	1.2	81	34	0.15	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

*The ERLs for As and Ni are below the BACs therefore As and Ni concentrations are usually assessed only against the BAC.

Partial Decommissioning

Raw data for the eight main heavy and trace metals (dry-weight concentration, mg kg^{-1}) measured within the partial decommissioning stations are shown in Table 14. Both As and Cd exceeded CEFAS AL 1 at one station. As was above CEFAS AL 1 at station GS23 whilst Cd was elevated at station GS34. As was also above OSPAR ERL at 29 stations and TEL at 32 stations. Cd also exceeded the OSPAR BAC at stations GS34 and GS38. Hg was above OSPAR BAC at four stations. None of the heavy or trace metals exceeded CEFAS AL2 guidelines.

The most abundant metal was zinc which ranged from 25.6 mg kg^{-1} at station GS26 to 62.5 mg kg^{-1} at station GS51 with an average concentration across all stations of 37.9 mg kg^{-1} ± 1.5 mg $kg^{-1.}$ Zinc was always recorded below reference levels at all stations.

Table 13 Number of stations across the partial decommissioning survey area exhibiting elevated heavy and trace metals levels in comparison to reference levels.

Analyte	CEFAS		OSPAR		CSQG	
	AL1	AL2	BAC	ERL	TEL	PEL
As	1	0	0	29	32	0
Cd	1	0	2	0	0	0
Cr	0	0	0	0	0	0
Cu	0	0	0	0	0	0
Hg	0	0	4	0	0	0
Ni	0	0	0	0	-	-
Pb	0	0	0	0	0	0
Zn	0	0	0	0	0	0

Table 14 Summary of heavy and trace metal concentrations (mg kg^{-1}) in sediments within the partial decommissioning stations. Shading indicates values above reference levels.

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
GS23	20.5	0.15	7.8	5.1	0	8.4	12.1	28.3
GS24	15.6	0.07	7.5	5.9	0	8.1	13.6	34.6
GS25	14.2	0	6.7	5.8	0	9	11.9	27.9
GS26	15.4	0	5.8	5.2	0	7	11.8	25.6
GS27	17.8	0.1	7.3	6.2	0	8.3	16.6	33.4
GS28	17.9	0.05	7	5.7	0	8.6	12.6	28.8
GS29	12.5	0.12	6.9	5.6	0	7	12.6	29.7
GS30	12.7	0.12	8.2	6.7	0	8.1	13.4	33.5
GS31	8.1	0.22	10.2	7.6	0.08	10.9	11.8	38.1
GS32	9.6	0.18	13.2	8.8	0.08	12.7	14.9	43.4
GS33	8.9	0.15	11.8	9.7	0.09	10.1	12.3	36.8
GS34	9.1	0.48	13.9	8.1	0.1	11.8	17.2	48
GS35	7.4	0.22	8.3	6.2	0.01	11	11.7	33.7
GS36	8	0.2	11.9	8.9	0.05	12.5	14.1	43.4
GS37	9.3	0.3	9.3	7.7	0.03	12.7	12.8	39.4
GS38	12.6	0.32	9.8	8.7	0.03	13.9	13.1	39.6
GS39	14.8	0.15	6.1	4.7	0.02	10.2	9.1	40.8
GS40	15.7	0.04	5.6	6.1	0	15.2	10.4	43
GS41	16.3	0.14	7.1	5.5	0	16.9	11.2	59.1
GS42	13.6	0.12	7	5.4	0	15	9.3	45.6
GS43	13	0.1	6.1	5.5	0	6.7	10.5	38.6
GS44	16.5	0.17	6.7	5.1	0	6.7	10.2	37.2
GS45	14.6	0.12	6	3.9	0	8.2	8.3	34
GS46	8.7	0.09	4.3	3.2	0	4.3	6	25.7
GS47	13.2	0.2	11.6	7.6	0.03	11.5	13.6	38.1
GS48	10.5	0.25	11.2	6.2	0	10.2	12	32.6
GS49	12.1	0.21	13.7	7.7	0.01	11.8	16.2	38.8
GS50	10.6	0.23	13.1	7.1	0.01	11.5	13.4	43.4
GS51	10.4	0.25	14.8	10.5	0	14.8	13.8	62.5
GS52	9.3	0.13	13.4	6.7	0	12	13.6	38.6
GS53	11.9	0.06	11.9	6.5	0	12.6	12.3	35.2
GS54	12	0.2	12.8	6.7	0	12.1	14.3	34

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Min	7.4	0	4.3	3.2	0	4.3	6	25.6
Max	20.5	0.48	14.8	10.5	0.1	16.9	17.2	62.5
Mean	12.6	0.2	9.3	6.6	0.0	10.6	12.4	37.9
SE	0.6	0.0	0.5	0.3	0.0	0.5	0.4	1.5
CEFAS AL1	20	0.4	40	40	0.3	20	50	130
CEFAS AL2	100	5	400	400	3	200	500	800
OSPAR BAC	25	0.31	81	27	0.07	36	38	122
ERL	8.2*	1.2	81	34	0.15	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

*The ERLs for As and Ni are below the BACs therefore As and Ni concentrations are usually assessed only against the BAC.

Full Decommissioning

Raw data for the eight main heavy and trace metals (dry-weight concentration, mg kg^{-1}) measured within the partial decommissioning stations are shown in Table 16. None of the metals analysed exceeded CEFAS AL 1 levels. As was above the TEL at stations GS58 and GS61. Hg exceeded OSPAR BAC reference levels at two stations GS66 and GS68 and exceeded the TEL at station GS68.

The most abundant metal at the stations within the full decommissioning scope was Zn which ranged from 24.3 mg kg^{-1} at station GS77 to 60.5 mg kg^{-1} at station GS81 with an average concentration across all stations of 34.0 mg kg^{-1} ± 2.1 mg kg^{-1}. Zinc was always recorded below reference levels at all stations.

Table 15 Number of stations across the Full decommissioning survey area exhibiting elevated heavy and trace metals levels in comparison to reference levels.

Analyte	CEFAS		OSPAR		CSQG	
	AL1	AL2	BAC	ERL	TEL	PEL
As	0	0	0	0	2	0
Cd	0	0	0	0	0	0
Cr	0	0	0	0	0	0
Cu	0	0	0	0	0	0
Hg	0	0	2	0	1	0
Ni	0	0	0	0	-	-
Pb	0	0	0	0	0	0
Zn	0	0	0	0	0	0

Table 16 Summary of heavy and trace metal concentrations (mg kg-1) in sediments.

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
GS55	7.2	0.2	7.3	4.6	0.02	7.6	7.9	27.3
GS57	5.5	0.2	8.4	6.0	0.00	8.6	9.3	32.5
GS58	7.8	0.2	7.8	4.8	0.00	7.2	8.7	27.1
GS59	5.9	0.1	8.0	5.2	0.00	7.2	9.2	26.8
GS60	5.5	0.2	7.8	5.2	0.00	7.6	9.5	31.2
GS61	7.9	0.2	6.9	3.6	0.00	6.6	7.6	24.3
GS63	5.2	0.2	8.1	5.2	0.00	6.8	9.0	29.3
GS64	4.1	0.2	9.5	5.9	0.02	8.0	10.8	34.4
GS66	5.7	0.2	11.4	8.5	0.09	9.3	14.7	40.2
GS67	5.5	0.1	9.2	8.9	0.04	9.8	12.1	36.3
GS68	5.9	0.2	16.7	11.6	0.11	13.6	20.6	58.3
GS69	5.7	0.2	12.1	7.4	0.05	9.5	13.8	37.7
GS70	5.2	0.1	8.5	9.2	0.02	9.4	11.6	34.8
GS72	4.5	0.2	8.9	6.8	0.04	9.0	12.2	35.6
GS73	5	0.1	8.8	14.6	0.03	8.7	13.9	40.5
GS75	5.1	0.2	7.4	7.3	0.01	7.1	9.5	26.3
GS76	5.3	0.1	8.6	8.4	0.02	7.7	11.1	31.8
GS77	4.9	0.1	6.5	7.9	0.00	6.7	9.0	24.3
GS78	4.6	0.2	6.8	9.5	0.01	6.7	10.6	28.2
GS79	5.1	0.1	7.9	7.1	0.02	6.8	10.4	27.2
GS81	4.9	0.2	7.5	7.3	0.01	10.6	9.6	60.5
Min	4.1	0.1	6.5	3.6	0.0	6.6	7.6	24.3
Max	7.9	0.2	16.7	14.6	0.1	13.6	20.6	60.5
Mean	5.5	0.2	8.8	7.4	0.0	8.3	11.0	34.0
SE	0.2	0.0	0.5	0.6	0.0	0.4	0.6	2.1
CEFAS AL1	20	0.4	40	40	0.3	20	50	130
CEFAS AL2	100	5	400	400	3	200	500	800
OSPAR BAC	25	0.31	81	27	0.07	36	38	122
ERL	8.2*	1.2	81	34	0.15	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

*The ERLs for As and Ni are below the BACs therefore As and Ni concentrations are usually assessed only against the BAC.

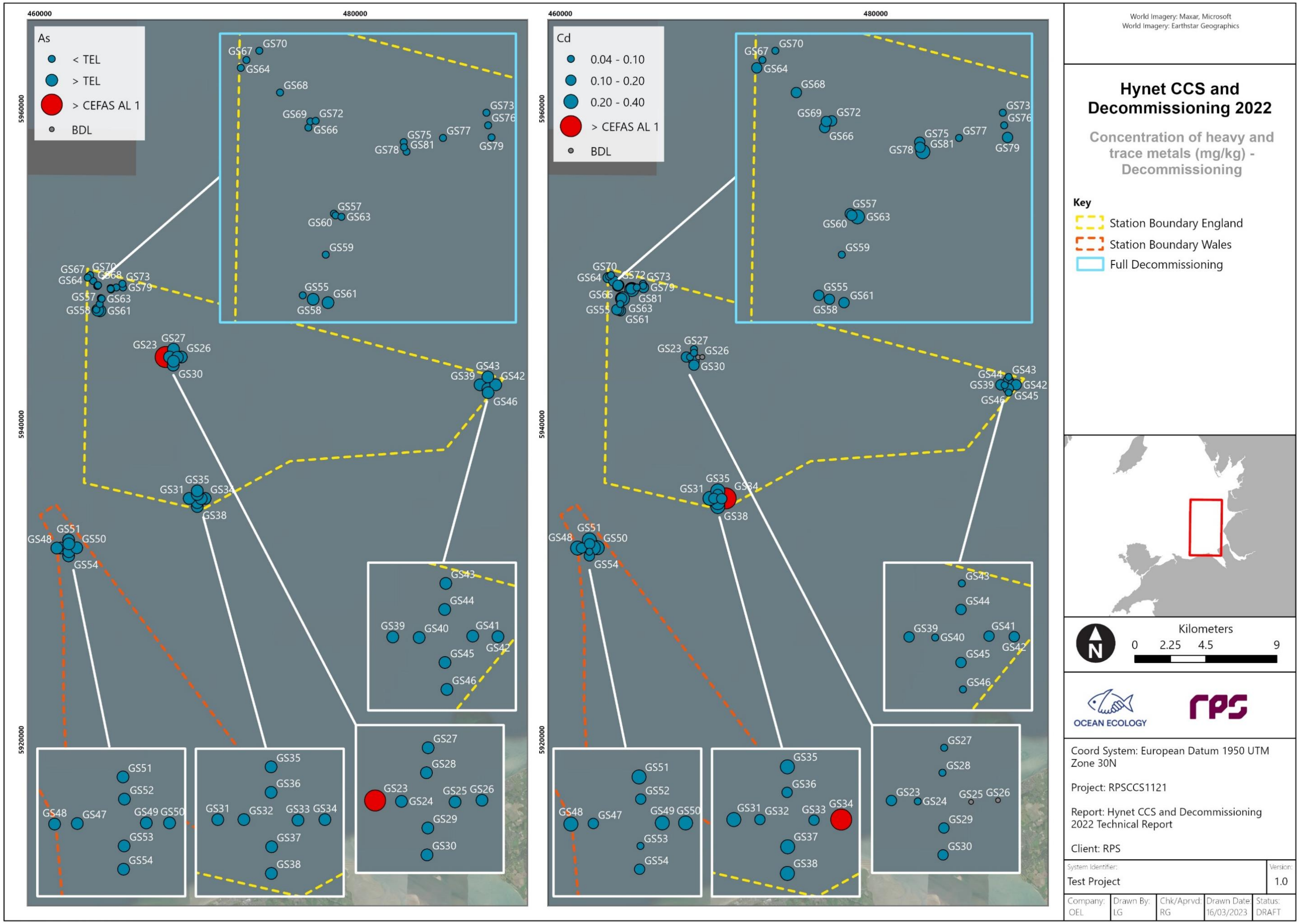

Figure 12 Spatial distribution of As and Cd across the survey area. TEL = Threshold Effect Levels as defined by the Canadian Sediment Quality Guidelines (CQSG). AL = Action Level as defined by CEFAS.

6.4.2. PAHs

The full range of EPA PAHs was tested and raw data reported in Appendix X. PAH concentrations were compared to CEFAS AL1 (no CEFAS AL2 available for PAHs), OSPAR BAC levels and ERLs, and TEL and PEL where possible.

CCS

None of the reference levels were exceeded for any of the measured PAHs across all the CCS survey stations. The most abundant PAHs across the CCS survey stations was Benzo[b]fluoranthene which ranged from below the limit of detection at five stations to 21.1 mg kg^{-1} at station GS10 with an average concentration of 5.4 mg kg-1 ±1.9 mg kg^{-1}.

Partial Decommissioning

The CEFAS AL1 was exceeded at station GS36 for both Chrysene and Benzo[a]pyrene (Figure 13). These two PAHs are found in coal tar and more in general can be the result of incomplete combustion of organic matter (oil and gas products). OSPAR BAC was exceeded at three stations for Naphthalene, two stations for Pyrene and Benzo[a]anthracene and one station for Anthracene, Benzo[k]fluoranthene and Benzo[a]pyrene. Station GS36 reported concentrations above the TEL for Acenaphthene, Fluorene, Benzo[a]anthracene, Benzo[a]pyrene and Dibenzo[a,h]anthracene.

Table 17 Number of stations across the partial decommissioning survey area exhibiting elevated PAH levels in comparison to reference levels.

Analyte	CEFAS	OSPAR		CSQG	
	AL1	BAC	ERL	TEL	PEL
Naphthalene	0	3	0	0	0
Acenaphthylene	0	-	-	0	0
Acenaphthene	0	-	-	1	0
Fluorene	0	-	-	1	0
Phenanthrene	0	0	0	0	0
Anthracene	0	1	0	0	0
Fluoranthene	0	0	0	0	0
Pyrene	0	2	0	0	0
Benzo[a]anthracene	0	2	0	1	0
Chrysene	1	-	-	0	0
Benzo[b]fluoranthene	0	0	0	-	-
Benzo[k]fluoranthene	0	1	0	0	0
Benzo[a]pyrene	1	1	0	1	0
Indeno[123,cd]pyrene	0	0	0	-	-
Dibenzo[a,h]anthracene	0	-	-	1	-
Benzo[ghi]perylene	0	0	0	-	-

Full Decommissioning

None of the measured PAHs exceeded CEFAS AL1 guidelines across the full decommissioning stations. However, OSPAR BAC reference levels were exceeded for multiple PAHs, including Naphthalene at three stations, Anthracene at two stations, Fluoranthene and Benzo[a]pyrene at station GS68, Pyrene and Benzo[a]anthracene at two stations.

The most abundant PAH was Benzo[b]fluoranthene ranging from below the limit of detection to 43.8 mg kg^{-1} at station GS68 with an average concentration across all full decommissioning stations of 12.1 mg kg^{-1} ± 2.5 mg kg^{-1}.

Table 18 Number of stations across the full decommissioning survey area exhibiting elevated PAH levels in comparison to reference levels.

Analyte	CEFAS	OSPAR		CSQG	
	AL1	BAC	ERL	TEL	PEL
Naphthalene	0	3	0	0	0
Acenaphthylene	0	-	-	0	0
Acenaphthene	0	-	-	0	0
Fluorene	0	-	-	0	0
Phenanthrene	0	0	0	0	0
Anthracene	0	2	0	0	0
Fluoranthene	0	1	0	0	0
Pyrene	0	2	0	0	0
Benzo[a]anthracene	0	2	0	0	0
Chrysene	0	-	-	0	0
Benzo[b]fluoranthene	0	0	0	-	-
Benzo[k]fluoranthene	0	0	0	0	0
Benzo[a]pyrene	0	1	0	0	0
Indeno[123,cd]pyrene	0	0	0	-	-
Dibenzo[a,h]anthracene	0	-	-	1	-
Benzo[ghi]perylene	0	0	0	-	-

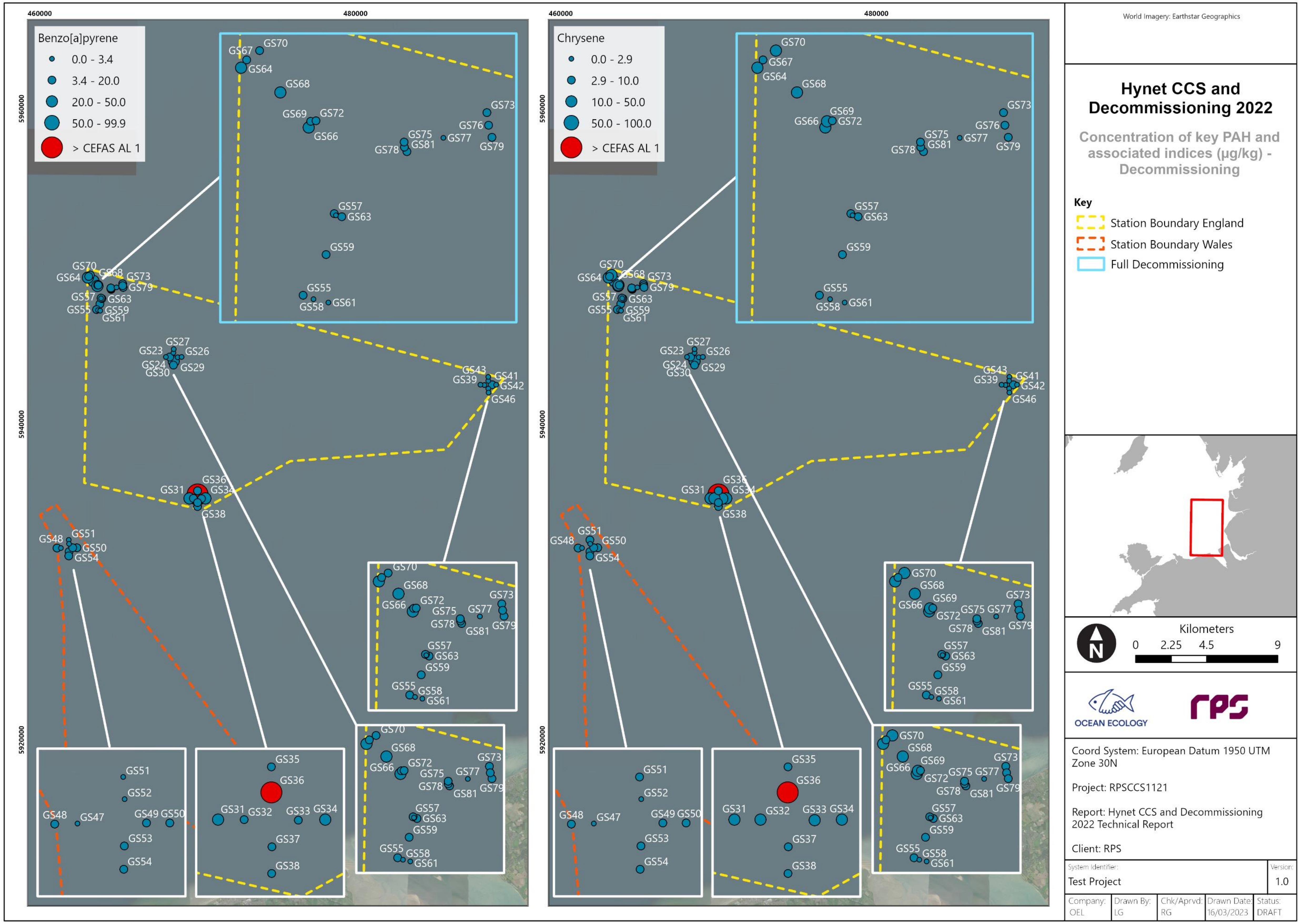

Figure 13 Spatial distribution of PAHs above CEFAS AL1 reference levels across the decommissioning sampling stations. TEL = Threshold Effect Levels as defined by the Canadian Sediment Quality Guidelines (CQSG). AL = Action Level as defined by CEFAS.

6.4.3. Total Hydrocarbons THC

CCS

The THC in sediment samples collected from the CCS stations ranged from 969 µg kg^{-1} at station GS85 to 16,500 µg kg^{-1} at station GS10 with an average value (± SE) for the whole area of 4,926 ± 1,274 µg kg^{-1}.

N-alkanes (saturates) in sediments had carbon chains length ranging between C13 and C37, with the dominant chains being C14 for the even-numbered chains and C13 for the odd-numbered chains. The highest concentration of total n-alkanes was recorded at station GS10, 245 µg kg^{-1}, while the lowest concentration of 11.49 µg kg^{-1} was found at station GS19.

Pristane and Phytane both reached a maximum at station GS10 being 17.7 µg kg^{-1} and 6.66 µg kg^{-1}, respectively. Pristane was below detection limit (BDL) (<1 µg kg^{-1}) at four stations GS19, GS83, GS84 and GS85 while Phytane was BDL at five stations: GS19, GS21, GS83, GS84 and GS85. Therefore, the Pristane/Phytane ratio could not be calculated at these five stations due to undetectable levels of phytane and pristane.

The results obtained when using the Pr/Ph ratio indicated a biogenic predominance in the source of n-alkanes, as the ratio was larger than one at all stations where it could be calculated. Notably the Pr/Ph ratio was higher than three at stations GS04, GS06 and GS08 possibly indicating terrestrial inputs stemming from the Dee River.

The CPI was used to assess n-alkanes origin sources, and the origin of n-alkanes was considered predominantly biogenic (CPI >1) at all stations except GS21, where it could not be calculated. No stations were found to represent pyrogenic or petrogenic sources of n-alkanes.

Partial Decommissioning

The THC in sediment samples collected from partial decommissioning stations ranged from 1,320 µg kg^{-1} at station GS23 to 30,600 µg kg^{-1} at station GS36 with an average value (± SE) for the whole of the cruciform areas of 7,446 ± 1,205 µg kg^{-1}.

N-alkanes (saturates) in sediments had carbon chains length ranging between C12 and C37, with the dominant chains being C14 for the even-numbered chains and C31 for the odd-numbered chains. The highest concentration of total n-alkanes was recorded at station GS36, 604 µg kg^{-1}, while the lowest concentration of 18.45 µg kg^{-1} was found at station GS23.

Pristane was the highest at station GS34, 47 µg kg^{-1}, and the lowest at station GS46, 1.06 µg kg^{-1}. The highest concentration of phytane was also measured at station GS34, 13.4 µg kg^{-1}, while it was BDL at thirteen stations; therefore, the Pristane/Phytane ratio could not be calculated at these thirteen stations.

The results obtained when using the Pr/Ph ratio indicated a biogenic predominance in the source of n-alkanes (Figure 15), as the ratio was larger than one at all stations. Notably the Pr/Ph ratio was above three at stations GS24, GS33, GS41, GS34, GS54, GS37 and GS49 potentially indicating terrestrial inputs stemming from the Dee River.

The CPI was used to assess n-alkanes origin sources, and it was found that the origin of n-alkanes was of biogenic predominance (CPI >1) at all stations. No stations represented pyrogenic or petrogenic sources of n-alkanes.

Full Decommissioning

The THC in sediment samples collected from full decommissioning stations ranged from 2,080 µg kg^{-1} at station GS61 to 26,100 µg kg^{-1} at station GS68 with an average value (± SE) for the whole of the cruciform areas of 9,534 ± 1,452 µg kg^{-1}.

N-alkanes (saturates) in sediments had carbon chains length ranging between C12 and C36, with the dominant chains being C28 for the even-numbered chains and C31 for the odd-numbered chains. The highest concentration of total n-alkanes was recorded at station GS64 534 µg kg^{-1}, while the lowest concentration of 21.4 µg kg^{-1} was found at station GS61.

Pristane was the highest at station GS64 being 31.7 µg kg^{-1}, and BDL at station GS61. The highest concentration of phytane was also measured at station GS64, 13.8 µg kg^{-1}, while it was BDL at five stations; therefore, the Pristane/Phytane ratio could not be calculated at these five stations.

The results obtained when using the Pr/Ph ratio indicated a biogenic predominance in the source of n-alkanes (Figure 15), as the ratio was larger than one at all stations. Notably, Pr/Ph ratios were higher than three at stations GS63, GS78, GS70, GS76, GS72, GS57, GS69, GS75 and GS68 potentially indicating terrestrial inputs stemming from the Dee River.

The CPI was used to assess n-alkanes origin sources, and it was found that the origin of n-alkanes was of biogenic predominance (CPI > 1) at all stations. No stations had a pyrogenic or petrogenic source of n-alkanes.

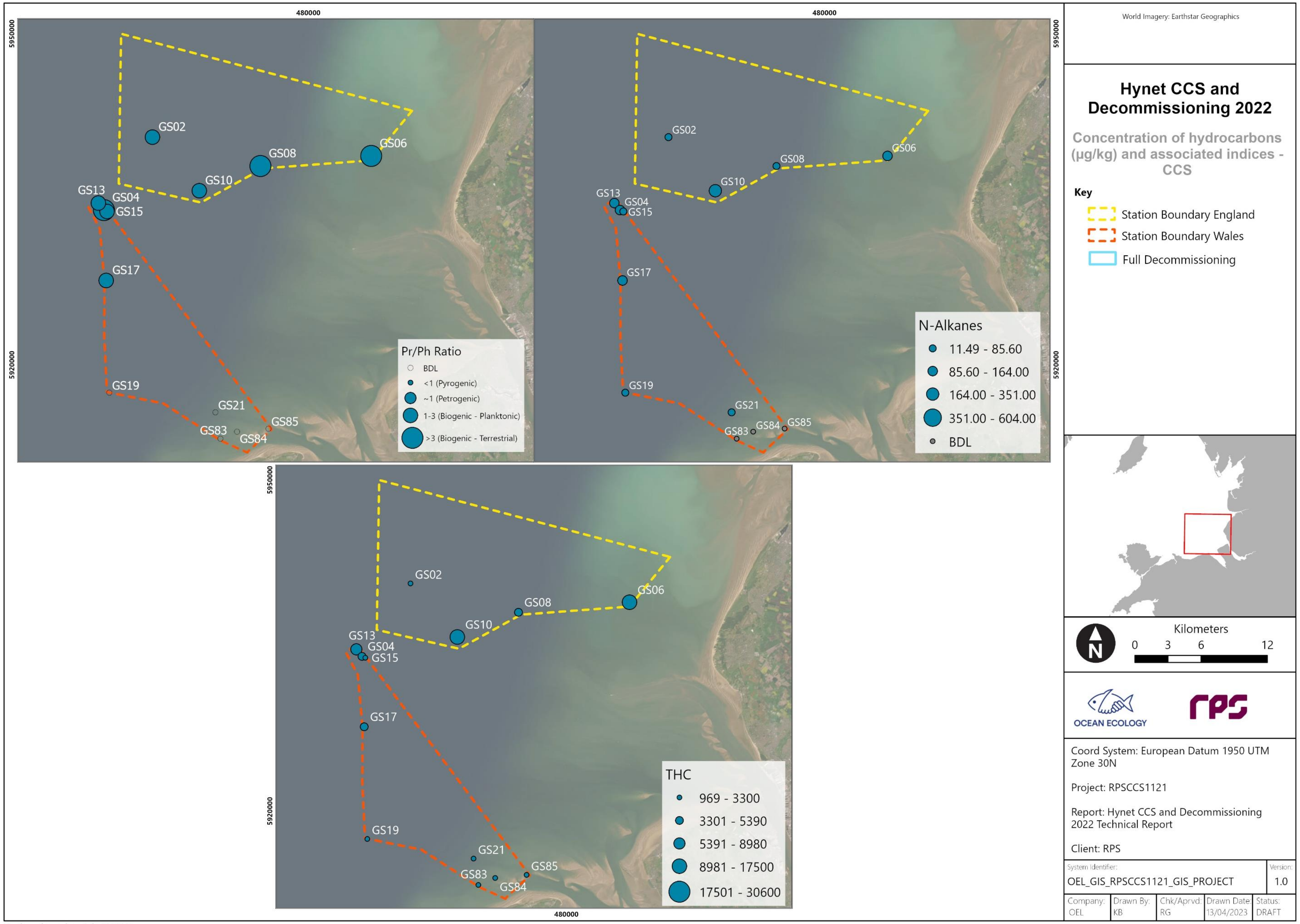

Figure 14 Summary of Pr/Ph ratios, N-Alkanes and THC concentrations across the CCS sampling stations.

Figure 15 Summary of Pr/Ph ratios, N-Alkanes and THC concentrations across partial and full decommissioning sampling stations.

6.4.4. Polychlorinated Biphenyls (PCBs)

The seven ICES PCBs congeners (PCB28, PCB52, PCB101, PCB118, PCB138, PCB153 and PCB180) were analysed from the sediments taken at each station and raw data are presented in Appendix X. The seven ICES PCBs are widely used in environmental monitoring as they cover the range of toxicological properties of the group.

Most PCBs had concentrations BDL of 0.08 µg kg^{-1} across the survey area. No CEFAS Action Levels exist for each individual PCB, but for the sum of the seven ICES PCBs (ΣICES7) the AL1 is 10 µg kg^{-1}.

CCS

All analysed PCBs were measured below the limit of detection for all stations within the CCS scope.

Partial decommissioning

PCB138 had the highest concentrations across the partial decommissioning stations, ranging from BDL at 26 stations to 0.41 µg kg^{-1} at GS29 with an average of 0.10 µg kg^{-1} ± 0.006 µg kg^{-1} from the remaining 5 stations.

ΣICES7 was below CEFAS AL1 at all stations.

Full Decommissioning

PCB138 had the highest concentrations across the full decommissioning stations ranging from BDL at 13 stations to 0.3 µg kg^{-1} at station GS61 with an average of 0.13µg kg-1 ± 0.02 µg kg^{-1} at the remaining 7 stations.

ΣICES7 was below CEFAS AL1 at all 21 stations.

6.4.5. Organotins

Dibutyltin and Tributyltin were the two organotins analysed and were both measured BDL at all stations.

6.5. Seabed Imagery

DDC sampling was successfully conducted at 86 stations resulting in the collection of 442 stills images and approximately three hours of video footage. Full results of the seabed imagery analysis and assessment of conspicuous taxa can be found in Appendices XI and XII.

6.5.1. CCS

Three BSHs, five EUNIS Level 4 (biotope complexes) and one EUNIS Level 5 biotope were identified in the seabed imagery collected across the 137 images taken within the CCS stations (Table 19 and Figure 16).

The most commonly encountered classification was A5.44 "Circalittoral mixed sediments", being identified in 34.3 % (47) of images (Plate 3), and broadly located in the western CCS stations. This was followed by A5.26 'Circalittoral muddy sand' identified in 30 images (Plate 3).

Biotope A5.445 "*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment" was found in six images and may occur as part of the FOCI 'Sheltered Muddy Gravels' (Plate 4). No Annex I reef features were found across the site.

Table 19 EUNIS BSH and biotope complexes identified in seabed imagery across the CSC area.

BSH	EUNIS Code	EUNIS Description
A5.1	A5.14	Circalittoral coarse sediments
A5.2	A5.25	Circalittoral fine sand
	A5.26	Circalittoral muddy sand
A5.4	A5.44	Circalittoral mixed sediments
	A5.445	*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment

6.5.2. Partial Decommissioning

Three BSHs, four EUNIS Level 4 (biotope complexes) and one EUNIS Level 5 biotope were identified in the seabed imagery collected across the 168 images taken within the partial decommissioning stations (Table 20 and Figure 16).

The most commonly encountered classification was A5.44 "Circalittoral mixed sediments", being identified in 33.3 % (56) of images and was predominantly found in the southern area of the site. This was followed by A5.26 "Circalittoral muddy sand" identified in 48 images (Plate 3).

Biotope A5.445 '*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittle star beds on sublittoral mixed sediment' was found in 12 images and may occur as part of the FOCI 'Sheltered Muddy

Gravels'. Brittle star beds were interspersed within the mixed sediment found in the southern area of the site. No Annex I reef features were found.

Table 20 EUNIS BSH and biotope complexes identified in seabed imagery across the partial decommissioning area.

BSH	EUNIS Code	EUNIS Description
A5.1	A5.14	Circalittoral coarse sediments
A5.2	A5.25	Circalittoral fine sand
	A5.26	Circalittoral muddy sand
A5.4	A5.44	Circalittoral mixed sediments
	A5.445	*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment

6.5.3. Full Decommissioning

Three BSHs and three EUNIS Level 4 (biotope complexes) were identified in the seabed imagery collected across the 140 images taken within the full decommissioning stations (Table 21 and Figure 16).

The most commonly encountered classification was A5.44 "Circalittoral sandy mud" identified in 48.5 % (68) of images and was mostly recorded in stations to the south (Plate 3). This was followed by A5.26 'Circalittoral muddy sand' identified in 66 image. Sandy substrates supported ripple bedforms which were not as frequently observed in areas with a higher mud content.

Table 21 EUNIS BSH and biotope complexes identified in seabed imagery across the full decommissioning area.

BSH	EUNIS Code	EUNIS Description
A5.1	A5.14	Circalittoral coarse sediment
A5.2	A5.26	Circalittoral muddy sand
A5.4	A5.44	Circalittoral mixed sediment

6.5.4. Epibenthic Taxa

Within the CCS stations, the green sea urchin *Psammechinus miliaris*, the brittle star *Ophiura albida* and Serpulidae tubes were amongst the most abundant epibenthic taxa present. Faunal burrows were also notable across these stations. Additionally, the bed forming brittle star *O. fragilis* was observed at stations GS03, GS04, GS11, GS14 and GS86.

Partial decommissioning stations displayed a sparser faunal cover than CCS stations with the dominant taxon being *Ophiura* sp.; faunal burrows were also noted. In stations GS33, GS34 and GS52, there was clear presence of *O. fragilis* beds (Plate 4).

Full decommissioning stations also exhibited a sparser faunal cover than CCS stations, with dominance of Paguridae and faunal burrows.

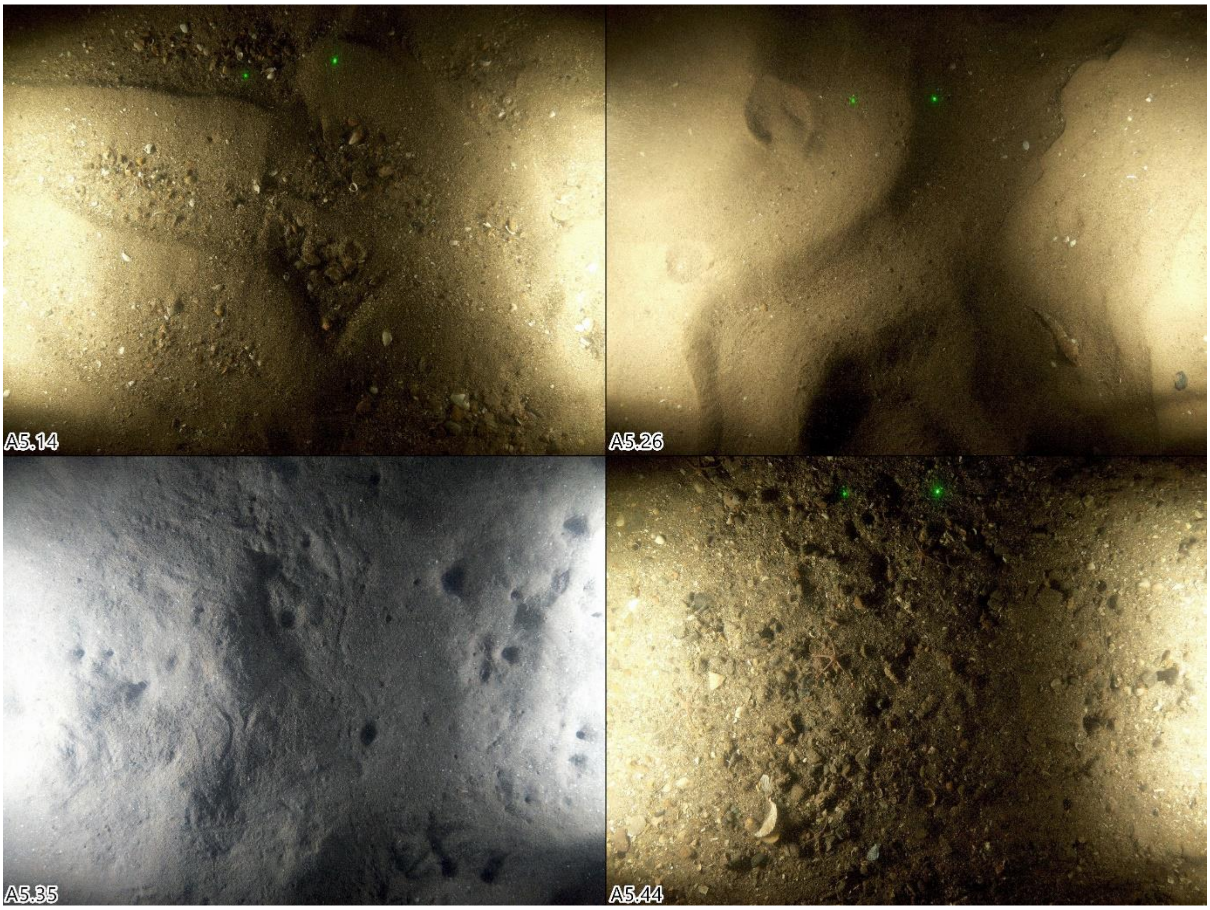

Plate 3 Common EUNIS classifications identified in seabed imagery analysis.

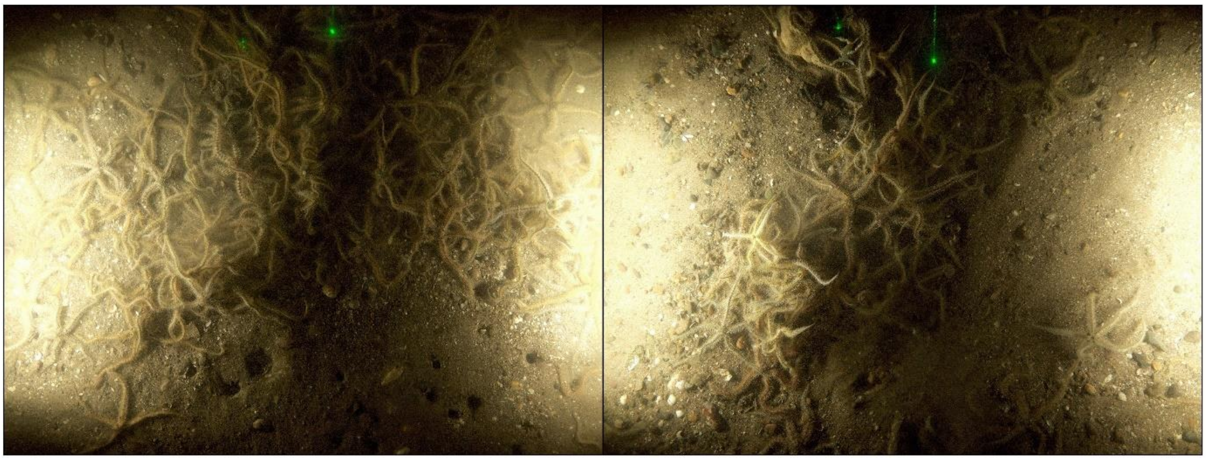

Plate 4 FOCI habitat 'sheltered muddy gravels' at stations GS33 (left) and GS52 (right) with the presence of *Ophiothrix fragilis* beds.

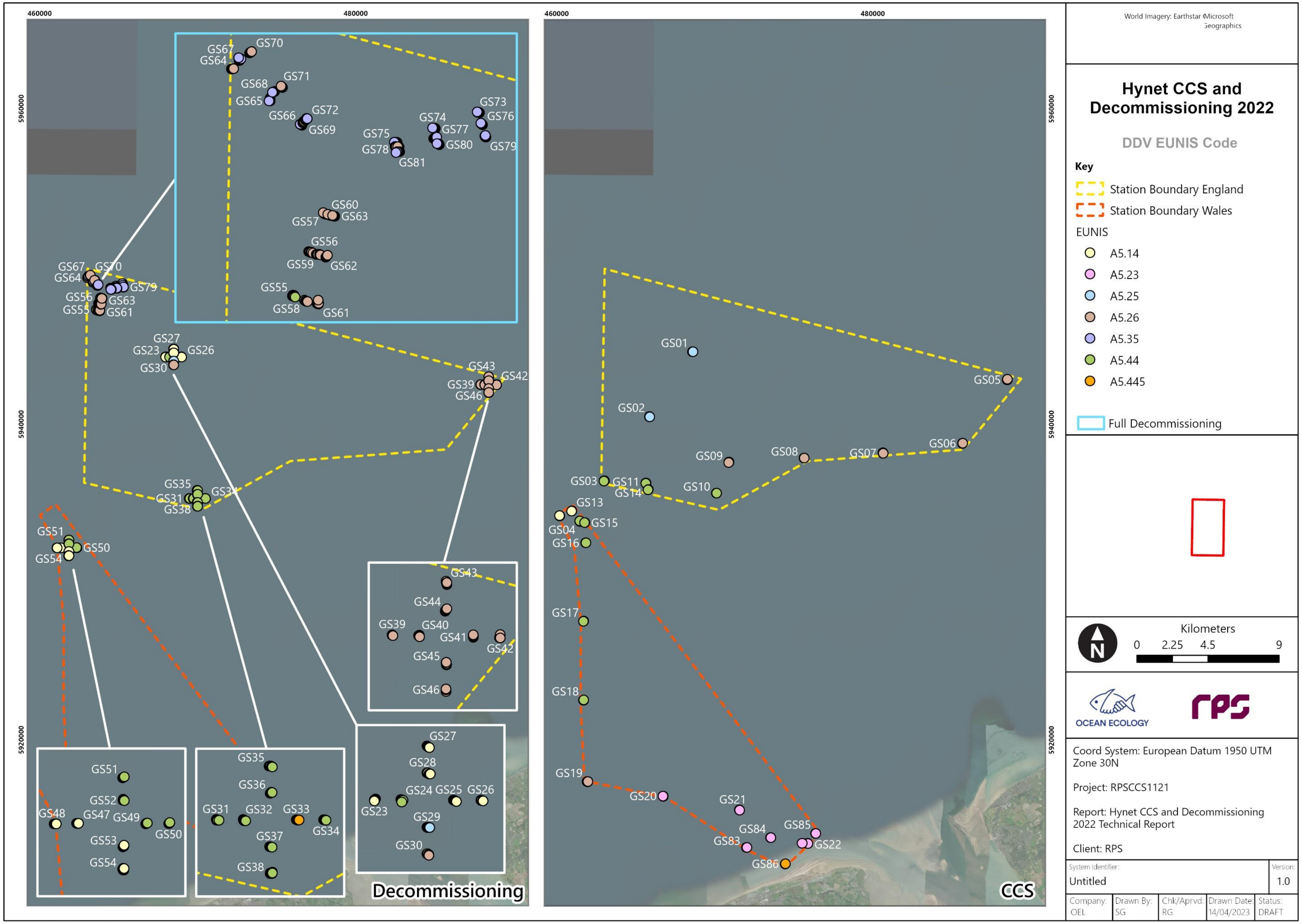

Figure 16 EUNIS classifications based on the seabed imagery analysis.

6.6. Macrobenthic Composition

6.6.1. CCS

A diverse macrobenthic assemblage was identified across the survey area from the 23 macrobenthic samples collected across the CCS area, with a total of 2,001 individuals and 215 taxa recorded. The mean (± SE) number of taxa per station was 23 ± 3, mean (± SE) abundance per station was 871 ± 32 and mean (± SE) biomass per station was 0.4571 ± 0.1451 gAFDW.

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

Figure 17 shows the main infaunal taxa characterising CCS stations. The brittle star *Amphiura filiformis* was the most abundant taxon sampled accounting for 15.3 % of all individuals recorded. It also accounted for the maximum abundance in a sample and greatest average density per sample (Figure 17). Other key taxa were Nemertea and Nematoda which were the most frequently occurring being recorded in 78 % of samples (Figure 17 and Figure 21).

Figure 18 shows the main epifaunal taxa characterising CCS stations. The tubeworm *Spirobranchus triqueter* was the most abundant taxon sampled accounting for 20 % of all individuals recorded; it also accounted for the maximum abundance and greatest average density per sample. Other key taxa were Actinaria which was the most frequently occurring being recorded in 30 % of samples, followed by the brittle star *O. albida* and juveniles of Mytilidae both occurring in 13 % of samples (Figure 18).

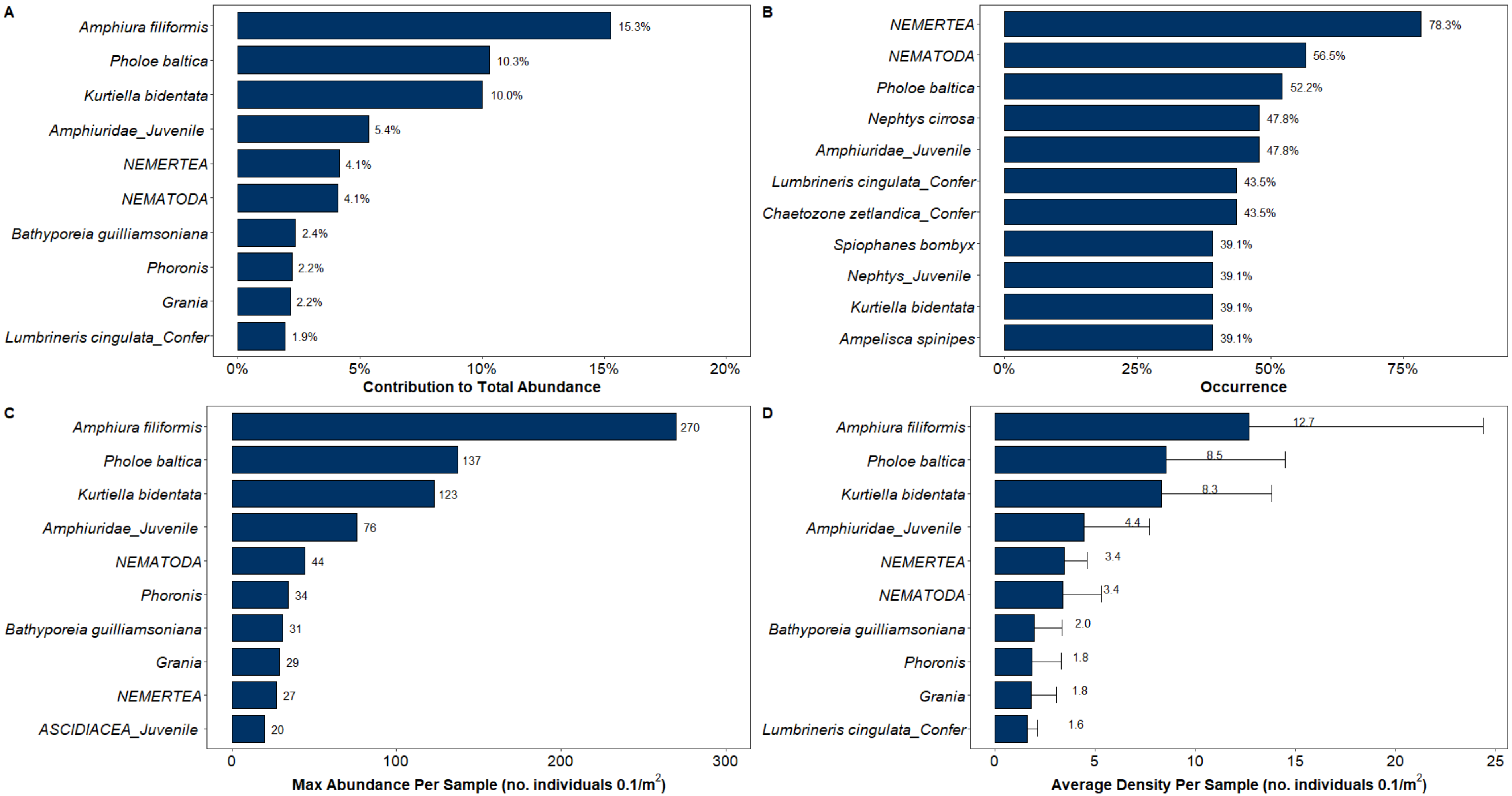

Figure 17 Percentage contributions of the top 10 infaunal taxa to total abundance (a) and occurrence (b) from samples collected across CCS stations. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

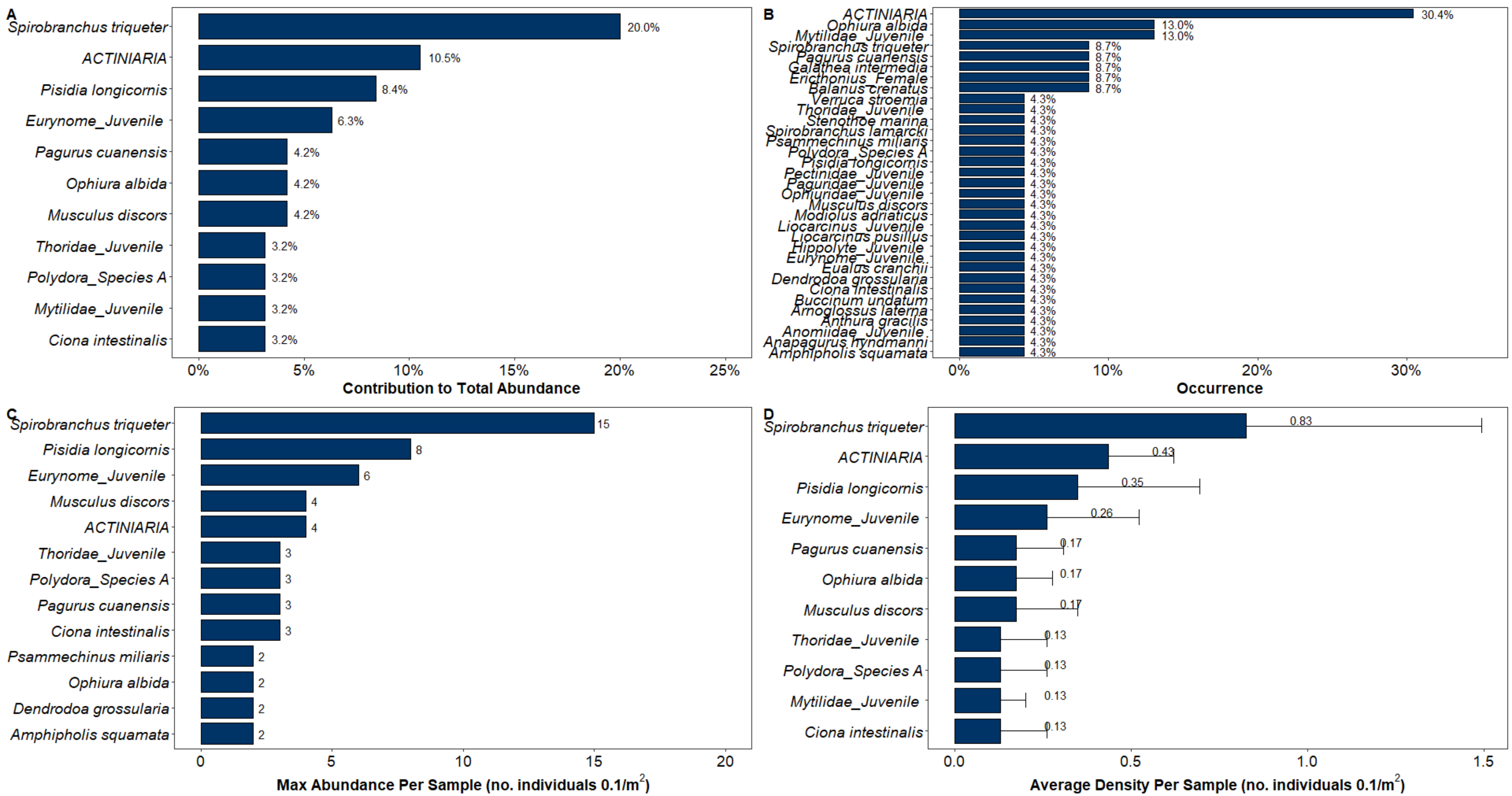

Figure 18 Percentage contributions of the top 10 epifaunal taxa to total abundance (a) and occurrence (b) from samples collected across CCS stations. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

Figure 19 illustrates the relative contributions to total abundance, diversity, and biomass of the major taxonomic groups in the macrobenthic community sampled across all CCS stations. Annelida taxa dominated infaunal abundance as they accounted for 35 % of all individuals recorded, while Crustacea taxa dominated epifaunal abundance as they accounted for 38 % of all individuals recorded. Annelida taxa also contributed the most to infaunal diversity at 50 %, while Miscellaneous taxa dominated epifaunal diversity at 61 % (Figure 19Figure 23).

Biomass was measured by major group without discriminating between infaunal and epifaunal species, however for ease of comparison is presented in Figure 19 under the infauna heading as infaunal taxa made up most of the macrobenthic community across all CCS stations. Biomass was dominated by Mollusca contributing to 48 % of the total biomass.

The highest infaunal abundance and diversity was recorded at station GS09 with 757 individuals recorded and 44 taxa counted. Epifaunal abundance and diversity was greatest at station GS15 with 58 individuals recorded and 20 taxa counted (Figure 20).

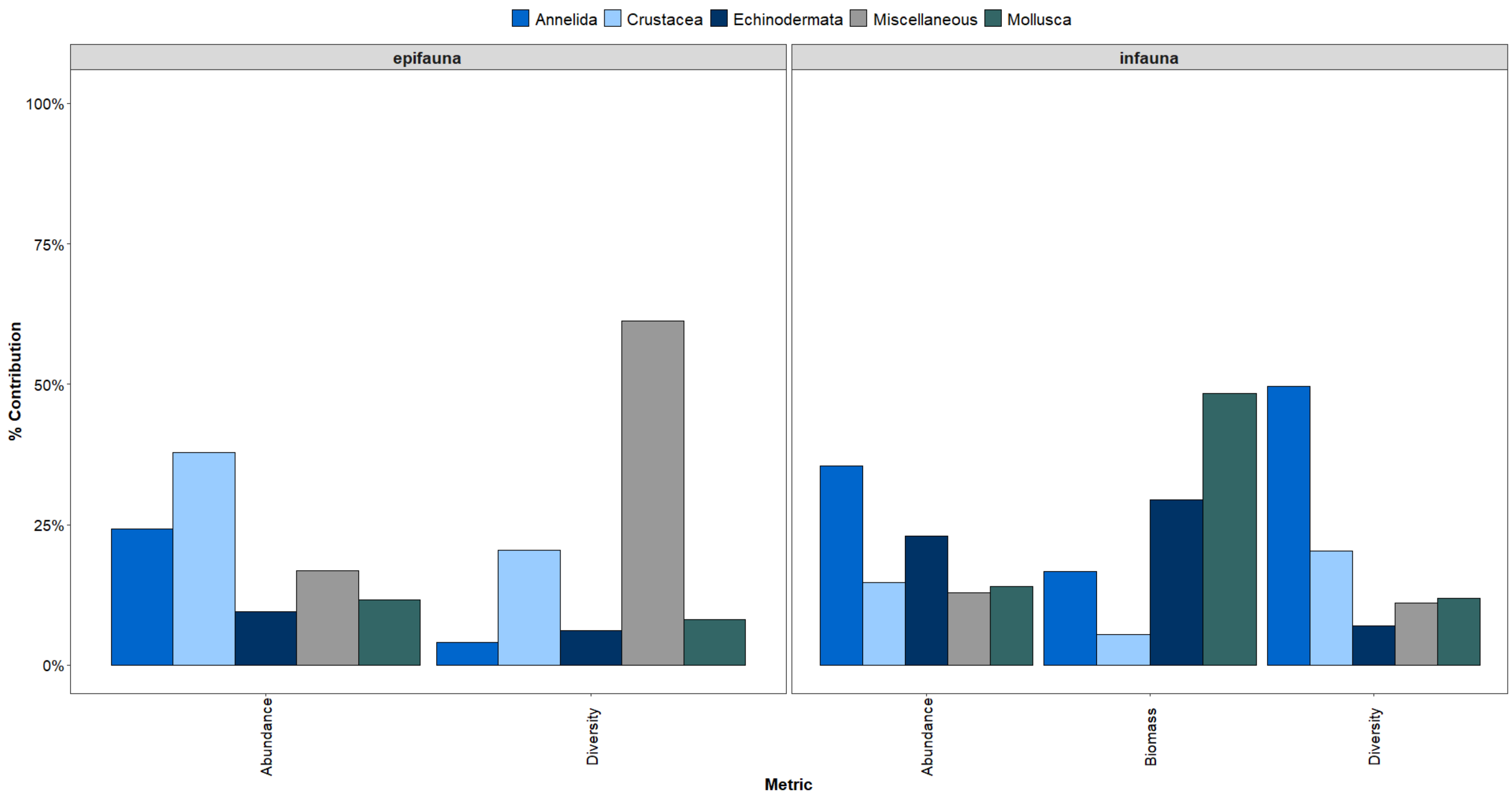

Figure 19 Relative contribution of the major taxonomic groups to the total abundance, diversity and biomass of the infaunal and epifaunal taxa sampled at CCS stations.

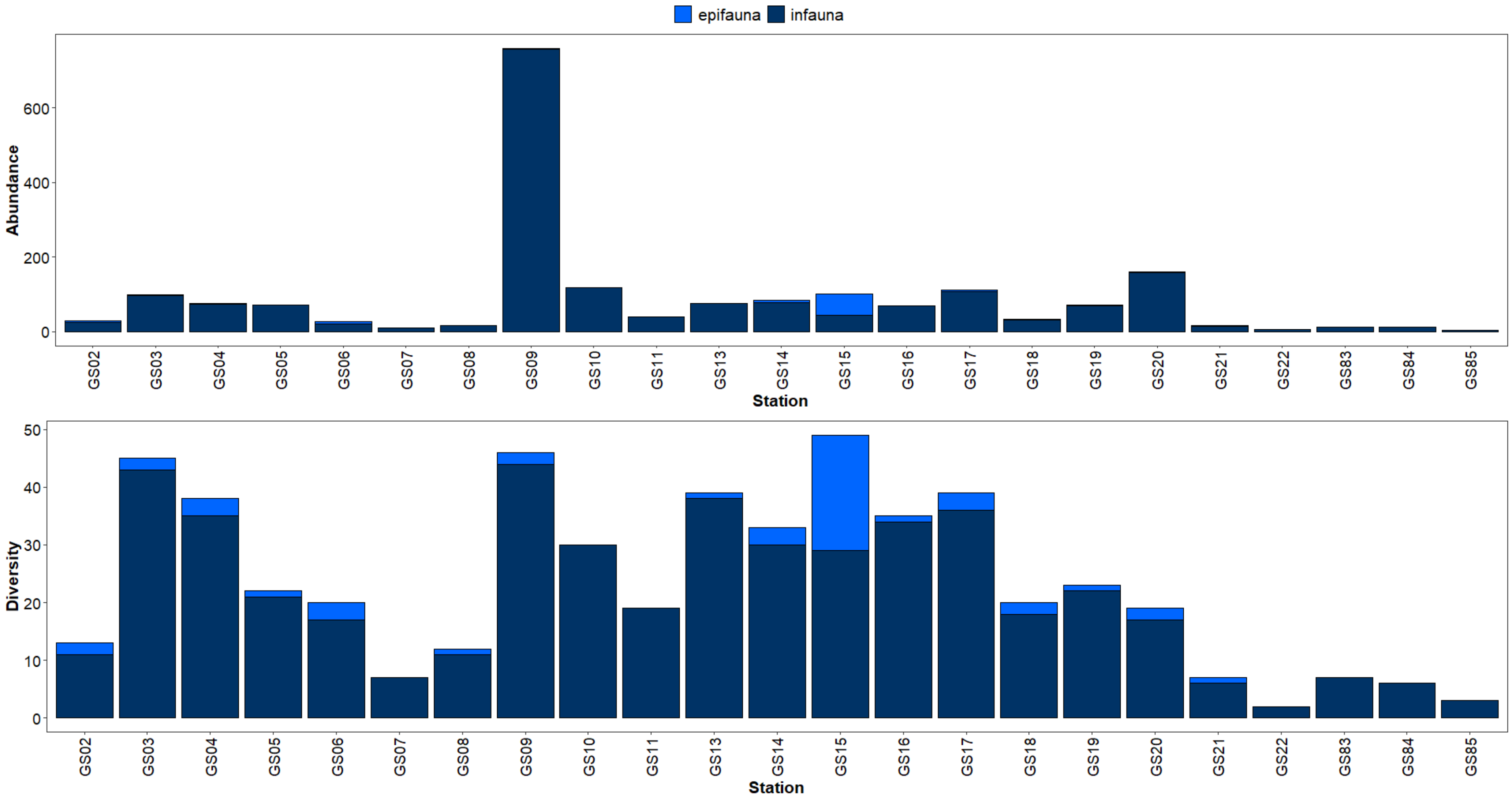

Figure 20 Abundance and diversity per station across CCS stations. Colours denote epifauna (light blue) and infauna (navy blue) contributions to abundance and diversity.

6.6.2. Decommissioning

A diverse macrobenthic assemblage was identified across the survey area from the 53 macrobenthic samples collected to monitor decommissioning activities, with a total of 13,332 individuals and 322 taxa recorded. The mean (± SE) number of taxa per station was 22 ± 3 for the partial decommissioning dataset and 20 ± 3 for the full decommissioning. Mean (± SE) abundance per station was 121 ± 22 for the partial decommissioning dataset and 133 ± 26 for the full decommissioning; mean (± SE) biomass per station was 0.2449 ± 0.0609 gAFDW for the partial decommissioning dataset and 0.0566 ± 0.0084 gAFDW for the full decommissioning.

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

Figure 21 shows the main infaunal taxa characterising both decommissioning datasets. Nematoda was the most abundant taxon sampled accounting for 24 % of all individuals recorded. It also accounted for the maximum abundance in a sample and greatest average density per sample (Figure 21). Other key taxa were Nemertea and the two-toothed Montagu shell *Kurtiella bidentata* which were the most frequently occurring being recorded in 98 % of samples (Figure 21).

Figure 22 shows the main epifaunal taxa characterising both decommissioning datasets. The common brittle star *O. fragilis* and Actinaria were the most abundant taxa sampled accounting for 18 % of all individuals recorded and they also accounted for the greatest average density per sample. *O. fragilis* also accounted for the maximum abundance in a sample, while Actinaria was the most frequently occurring taxon being recorded in 21 % of samples (Figure 22).

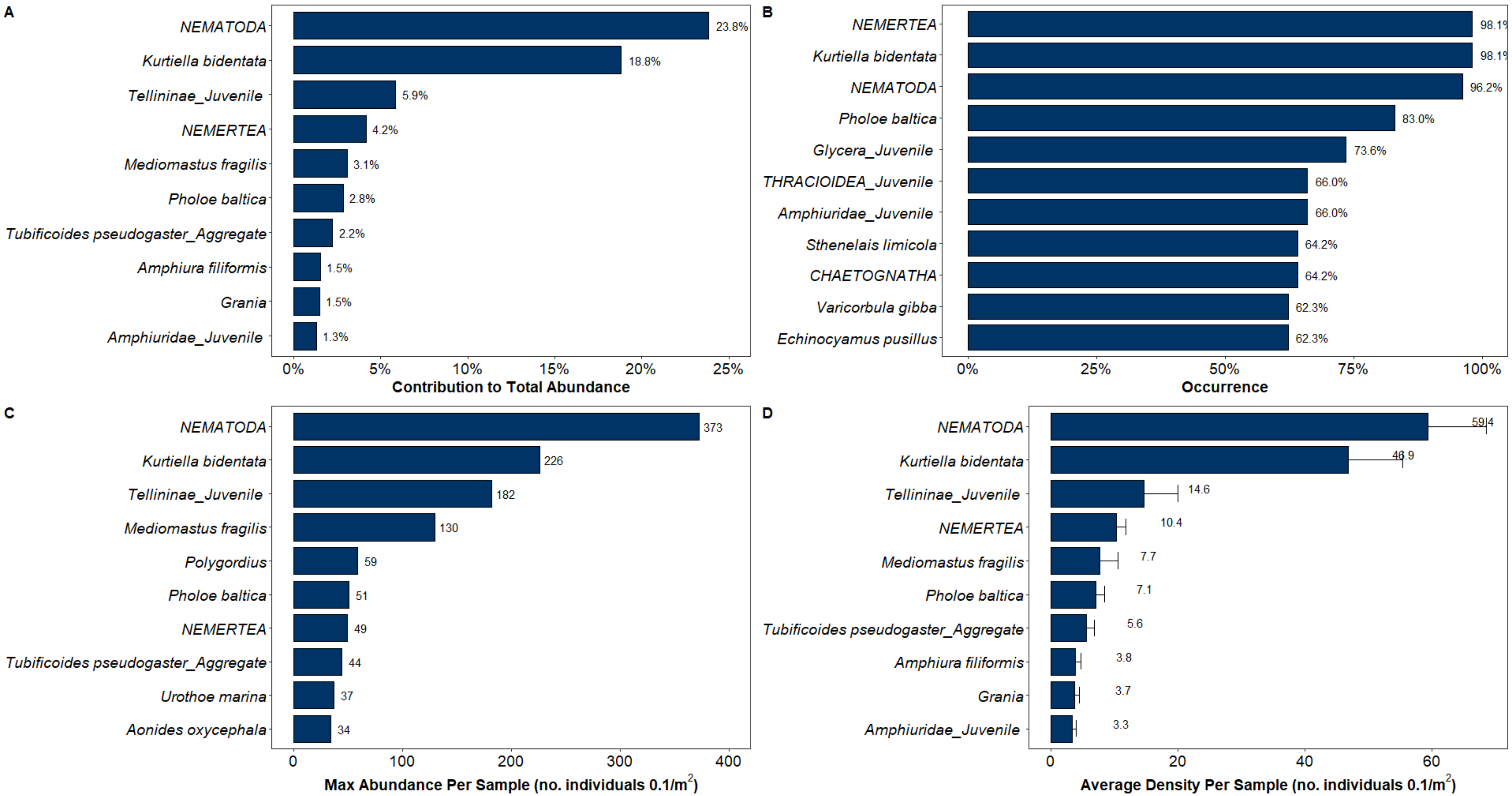

Figure 21 Percentage contributions of the top 10 infaunal taxa to total abundance (a) and occurrence (b) from samples collected across all decommissioning stations. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

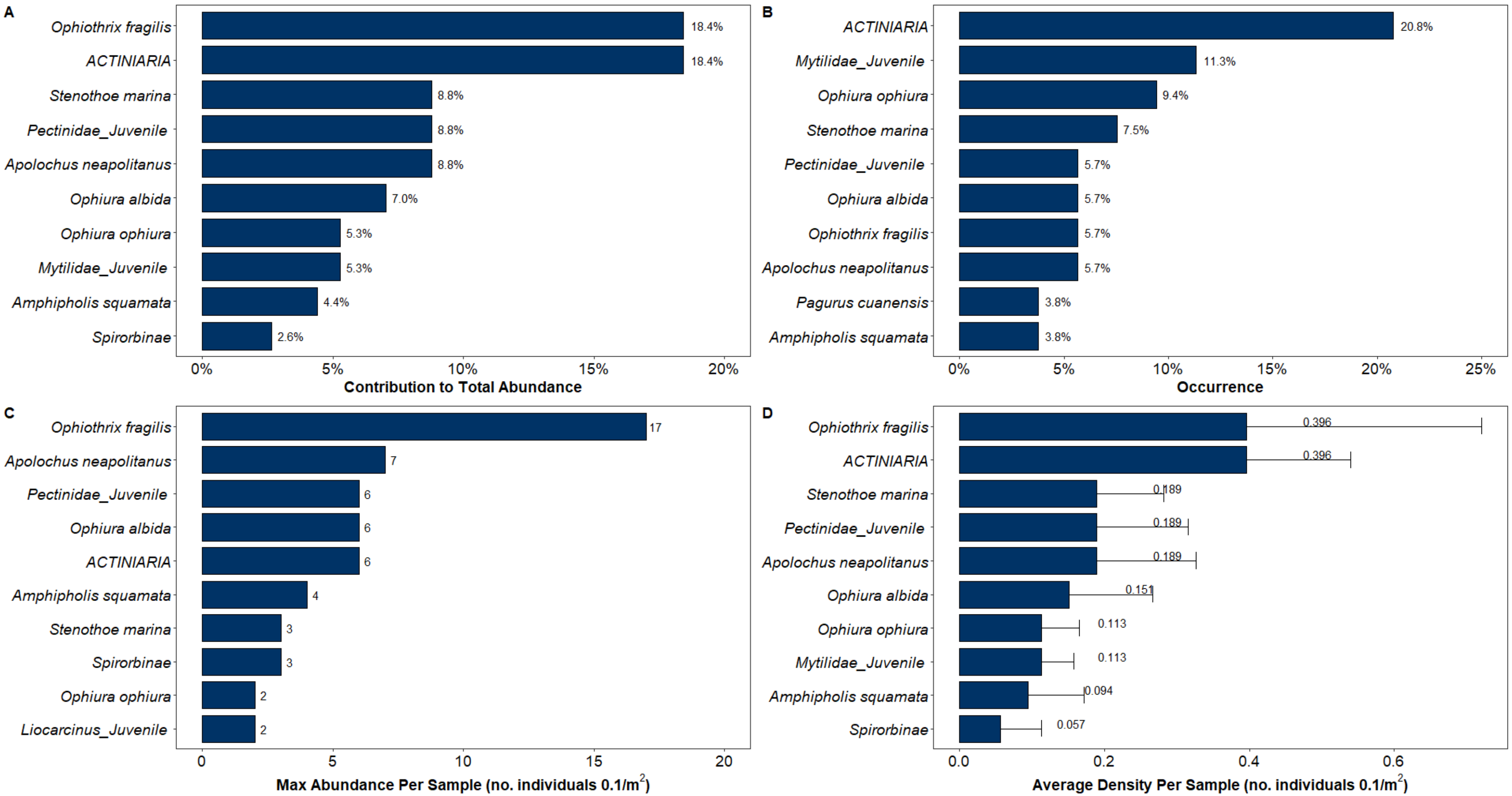

Figure 22 Percentage contributions of the top 10 epifaunal taxa to total abundance (a) and occurrence (b) from samples collected across all decommissioning stations. Also shown are the maximum densities of the top 10 taxa per sample (c) and average densities of the top 10 taxa per sample (d).

Figure 23 illustrates the relative contributions to total abundance, diversity, and biomass of the major taxonomic groups in the macrobenthic community sampled across all decommissioning stations. At partial decommissioning stations, Annelida taxa dominated infaunal abundance as they accounted for 25 % of all individuals recorded, while Echinodermata taxa dominated epifaunal abundance as they accounted for 39 % of all individuals recorded. Annelida taxa also contributed the most to infaunal diversity at 50 %, while Miscellaneous taxa dominated epifaunal diversity at 63 % (Figure 23). At full decommissioning stations, Miscellaneous taxa dominated both infaunal and epifauna abundance contributing respectively to 38 % and 43 % of all individuals recorded. Annelida taxa dominated infaunal diversity at 44 %, while Miscellaneous taxa dominated epifaunal diversity at 90 % (Figure 23).

Biomass was measured by major group without discriminating between infaunal and epifaunal species, however for ease of comparison is presented in Figure 23 under the infauna heading as infaunal taxa made up most of the macrobenthic community across all decommissioning stations. Biomass was dominated by Annelids contributing to 41 % of the total biomass at partial decommissioning stations, while it was dominated by Echinodermata taxa contributing to 37 % of the total biomass at full decommissioning stations.

At partial decommissioning stations, the highest infaunal abundance was recorded at station GS34 with 1,053 individuals recorded. The greatest epifaunal abundance of 17 individuals was recorded at stations GS31 and GS34. Infaunal diversity was the highest at station GS32 with 71 taxa counted, while epifaunal diversity was the highest at station GS31 with seven taxa counted (Figure 24). At full decommissioning stations, the highest infaunal abundance was recorded at station GS76 with 497 individuals recorded. Epifaunal abundance was the highest at station GS69 with four individuals recorded. Diversity was the highest at station GS79 for both infauna and epifauna with 55 and three taxa counted, respectively (Figure 24). In general, more epifaunal taxa were recorded at partial decommissioning than at full decommissioning stations.

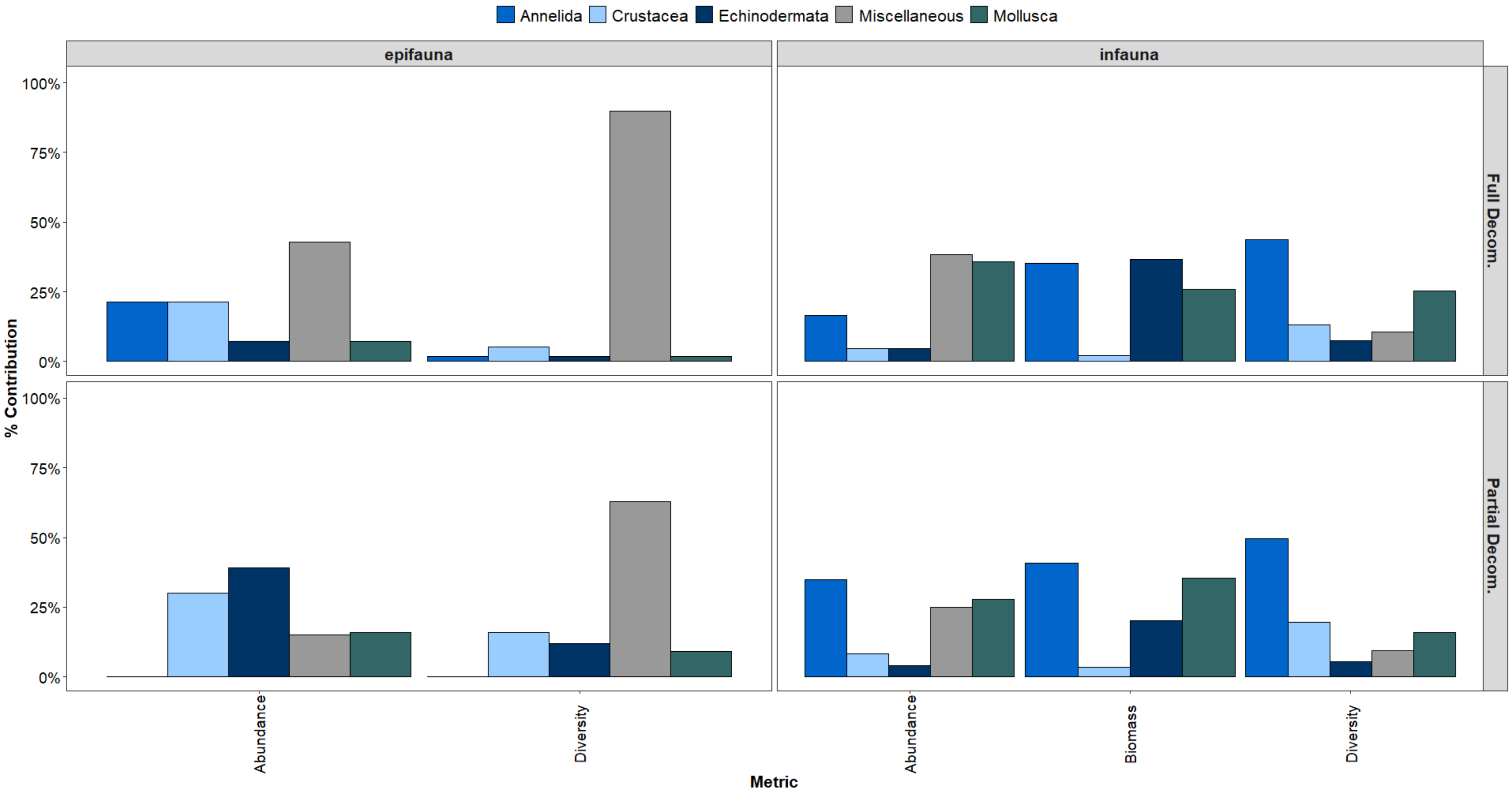

Figure 23 Relative contribution of the major taxonomic groups to the total abundance, diversity and biomass of the infaunal and epifaunal taxa sampled at full and partial decommissioning stations.

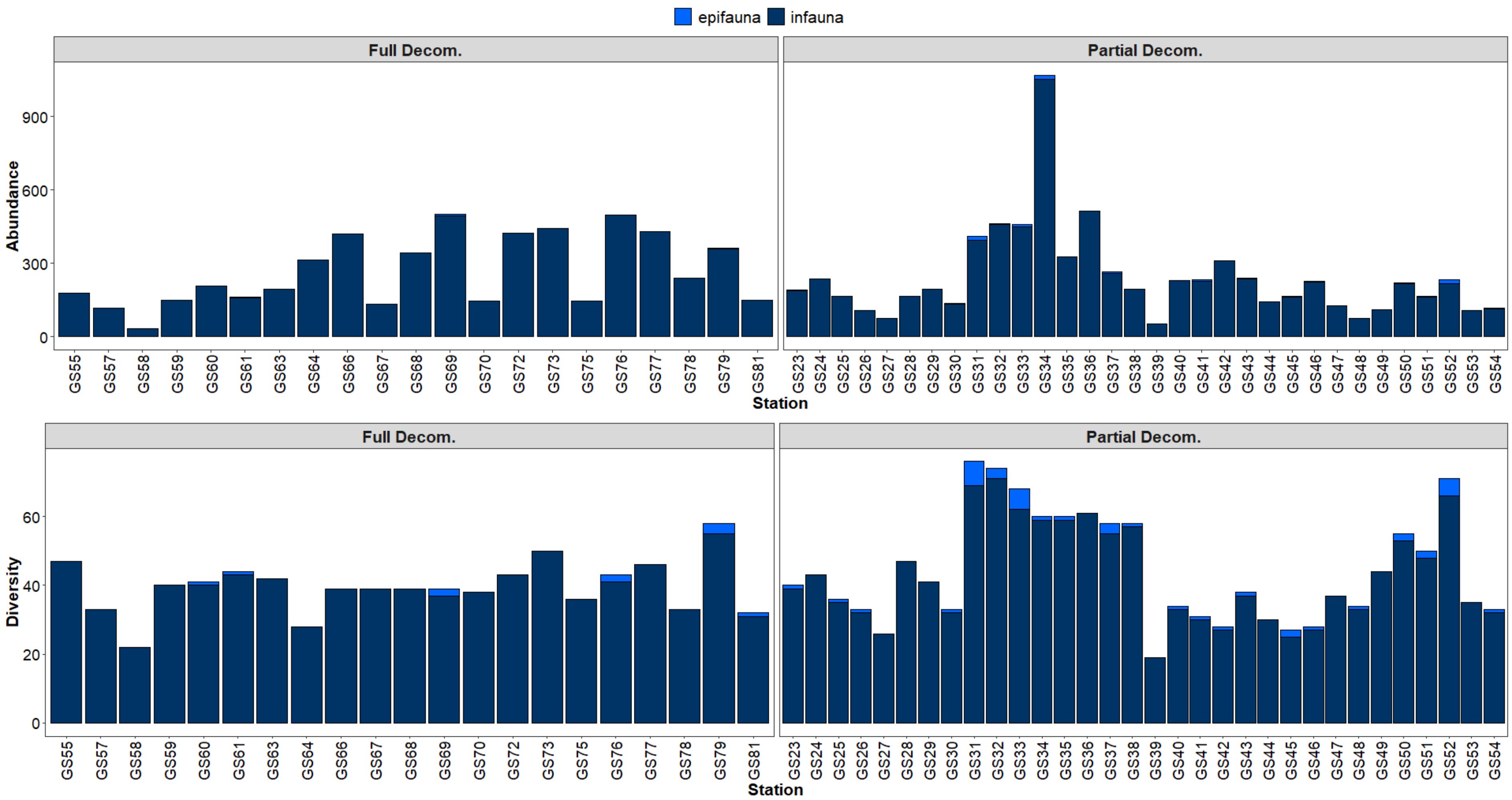

Figure 24 Abundance and diversity per station across full and partial decommissioning stations. Colours denote epifauna (light blue) and infauna (navy blue) contributions to abundance and diversity.

6.7. Notable Taxa

6.7.1. CCS

Three notable taxa were recorded across the CCS stations (Table 22).

The common whelk *Buccinum undatum* is an Economically important species as it as a significant fishery associated with it. However, only one specimen was recorded at station GS13.

The Ross warm *S. spinulosa* is a protected species under the OSPAR list of threatened and/or declining species and the Habitats Directive when in reef habitat form. Only four individuals were recorded at CCS stations with no signs of reef forming features. Three individuals were counted at station GS08 and one at station GS15.

The thumbnail crab *Thia scutellata* is a nationally scarce marine species with two specimens recorded at station GS20.

Table 22 Notable taxa recorded across CCS stations.

Taxon	Common Name	Designation	Total Abundance
Buccinum undatum	Common whelk	Economically Important	1
Sabellaria spinulosa	Ross Worm	OSPAR & Habitats Directive	4
Thia scutellata	Thumbnail Crab	Nationally scarce marine species	2

6.7.2. Decommissioning

Four notable taxa were recorded across all decommissioning stations (Table 23).

The ocean quog is protected under the OSPAR list of threatened and/or declining species and habitats and two juvenile specimens were counted: one at partial decommissioning station GS38 the other at full decommissioning station GS81.

The polychaete *G. gracilis* is an INNS that was first introduced in the UK, Liverpool Bay, in 1970 most likely by shipping from the east coast of North America. Only one specimen was recorded at partial decommissioning station GS28.

No evidence of *S. spinulosa* reef features were noted across all decommissioning stations, as only three individuals were recorded. Two individuals were counted at partial decommissioning station GS31 and one at partial decommissioning station GS37.

The thumbnail crab *T. scutellata* is a nationally scarce marine species and three individuals were found across all decommissioning stations: one individual each at partial decommissioning stations GS26 and GS38 and one specimen at full decommissioning station GS57.

Table 23 Notable taxa recorded across all decommissioning stations.

Taxon	Common Name	Designation	Total Abundance
Arctica islandica	Ocean quahog	OSPAR & Wales NERC S.42	2
Goniadella gracilis		Invasive & Non-Native	1
Sabellaria spinulosa	Ross Worm	OSPAR & Habitats Directive	3
Thia scutellata	Thumbnail Crab	Nationally scarce marine species	3

6.8. 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. To visualise the relationships between the sampled macrobenthic assemblages, a non-metric multi-dimensional scaling (nMDS) plot was generated on the abundance data. 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 indicates that the two-dimensional plot provides a good representation of the similarity between stations. 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.

6.8.1. CCS

The dendrogram resulting from the cluster analysis (Appendix XV) and associated Type 1 SIMPROF (similarity profile routine) permutation test of all nodes within the dendrogram identified four statistically significantly similar groups and two outlier stations (GS15 and GS18) that did not belong to any group ($p > 0.05$). The spatial distribution of these macrobenthic groups and outliers is presented in Figure 26.

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 XVI.

Macrobenthic Group A – Two stations GS09 and GS10 belonged to this group and were characterised by the polychaete *Pholoe baltica, K. bidentata* and the brittle star *A. filiformis* all together contributing to about 42 % of the group average similarity of 39.1 %.

Macrobenthic Group B – seven stations belonged to this group and were characterised by the polychaete *Lumbrineris cingulata*, the amphipod *Ampelisca spinipes*, Nemertea and Nematoda all together contributing to about 32 % of the group average similarity of 38.8 %.

Macrobenthic Group C – six stations belonged to this group and were characterised by the white catworm *Nephtys cirrosa* contributing to about 81 % of the group average similarity of 29.8 %.

Macrobenthic Group D – six stations belonged to this group and were characterised by, Nemertea, *N. cirrosa*, Nematoda, Actinaria all together contributing to about 51 % of the group average similarity of 21.1 %.

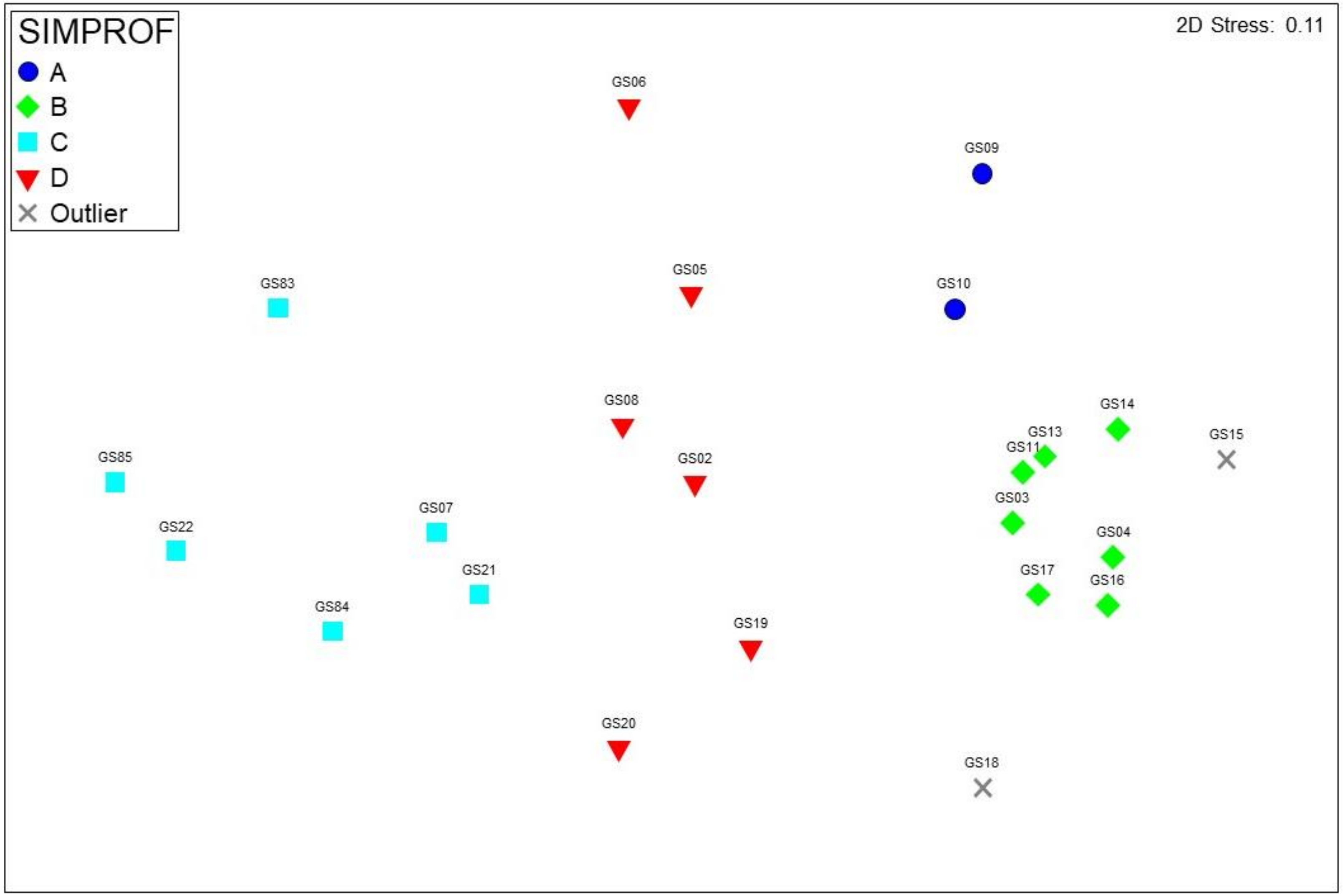

Figure 25 Two-dimensional nMDS ordination of macrobenthic communities at CCS stations based on square root transformed and Bray-Curtis similarity abundance data.

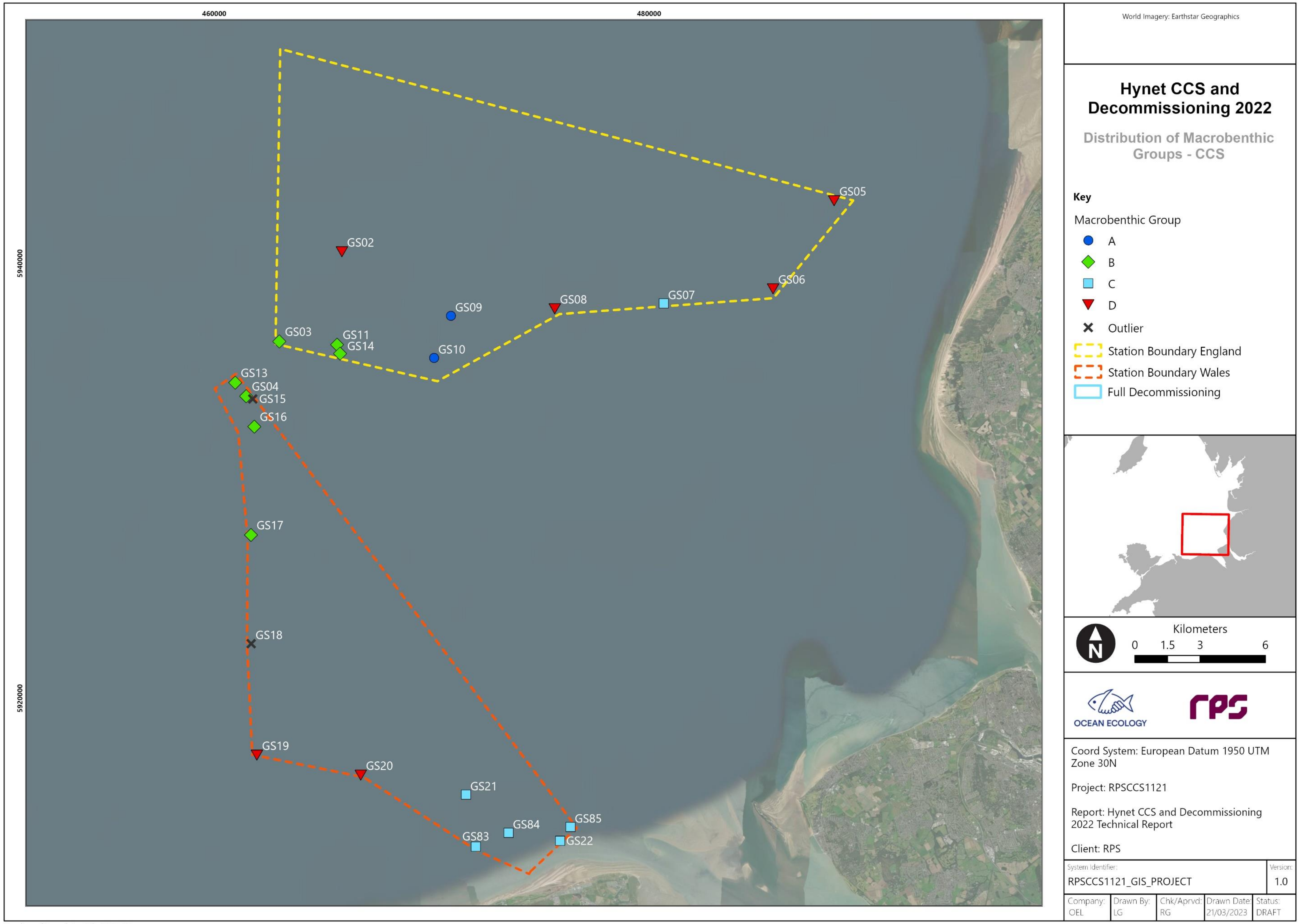

Figure 26 Spatial distribution of macrobenthic groups as determined from cluster analysis of abundance data.

6.8.2. Partial Decommissioning

The dendrogram resulting from the cluster analysis (Appendix XV) and associated Type 1 SIMPROF (similarity profile routine) permutation test of all nodes within the dendrogram identified seven statistically significantly similar groups and two outlier stations that did not belong to any group ($p > 0.05$). To enable a broad interpretation of the community present, a similarity slice at 35 % was used to amalgamate the seven SIMPROF groups into four broader Macrobenthic Groups (Figure 27). The spatial distribution of these macrobenthic groups is presented in Figure 28.

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 XVI.

Macrobenthic Group A – eight stations belonged to this group and were characterised by juveniles of Tellininae and *Nephtys*, *K. bidentata* and Nemertea all together contributing to about 54 % of the group average similarity of 49 %.

Macrobenthic Group B – eight stations belonged to this group and were characterised by Nematoda, the amphipod *Urothoe marina*, Nemertea, *K. bidentata*, and the polychaete *Paradoneis lyra* all together contributing to about 35 % of the group average similarity of 45.7 %.

Macrobenthic Group C – eight stations belonged to this group and were characterised by Nematoda, *K. bidentata*, Nemertea the polychaetes *Mediomastus fragilis* and *P. baltica* all together contributing to about 35 % of the group average similarity of 54.9 %.

Macrobenthic Group D – eight stations belonged to this group and were characterised by Nematoda, the oligochaete *Grania*, Nemertea and the basket shell *Varicorbula gibba* all together contributing to about 38 % of the group average similarity of 48.7 %.

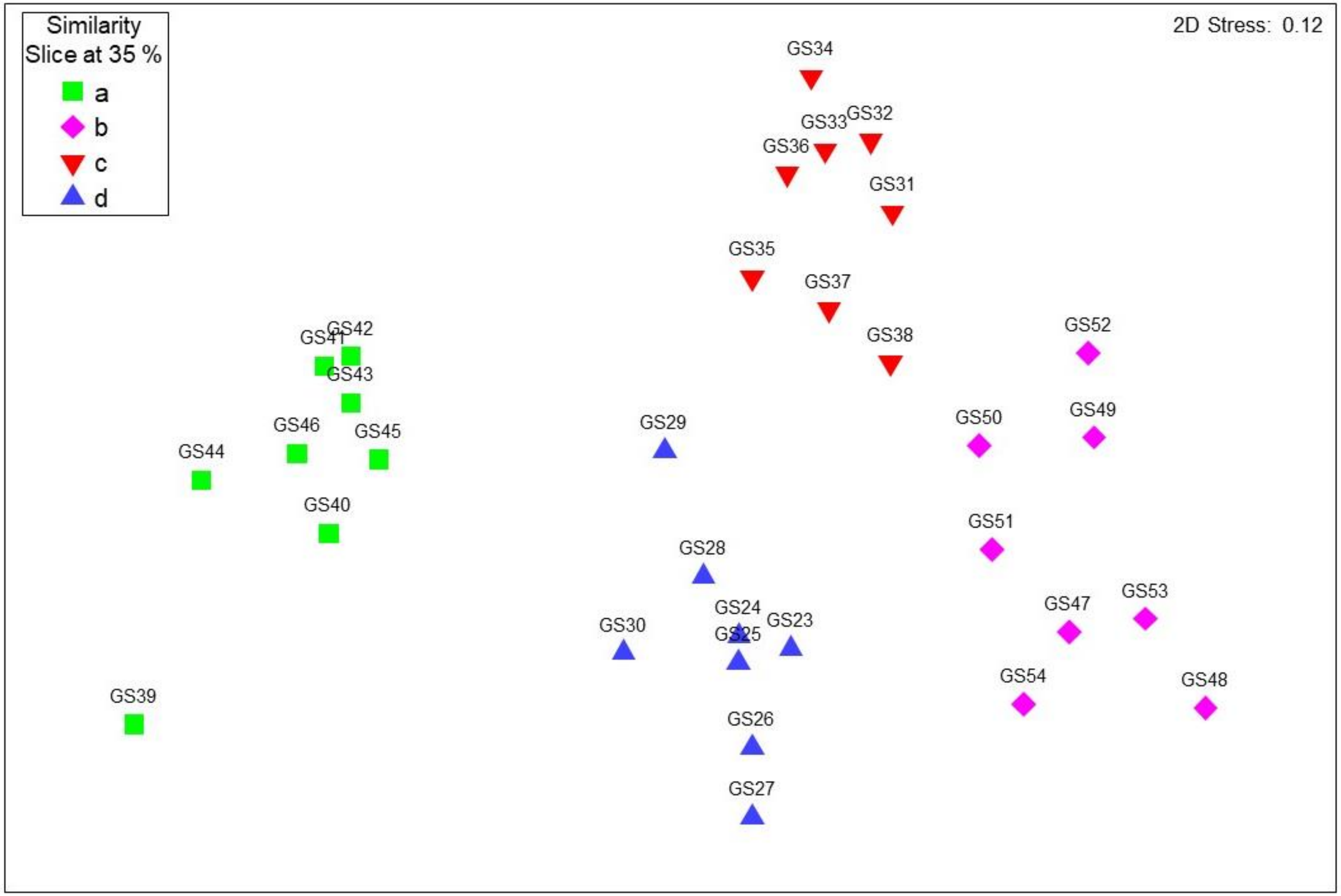

Figure 27 Two-dimensional nMDS ordination of macrobenthic communities at partial decommissioning stations based on square root transformed and Bray-Curtis similarity abundance data.

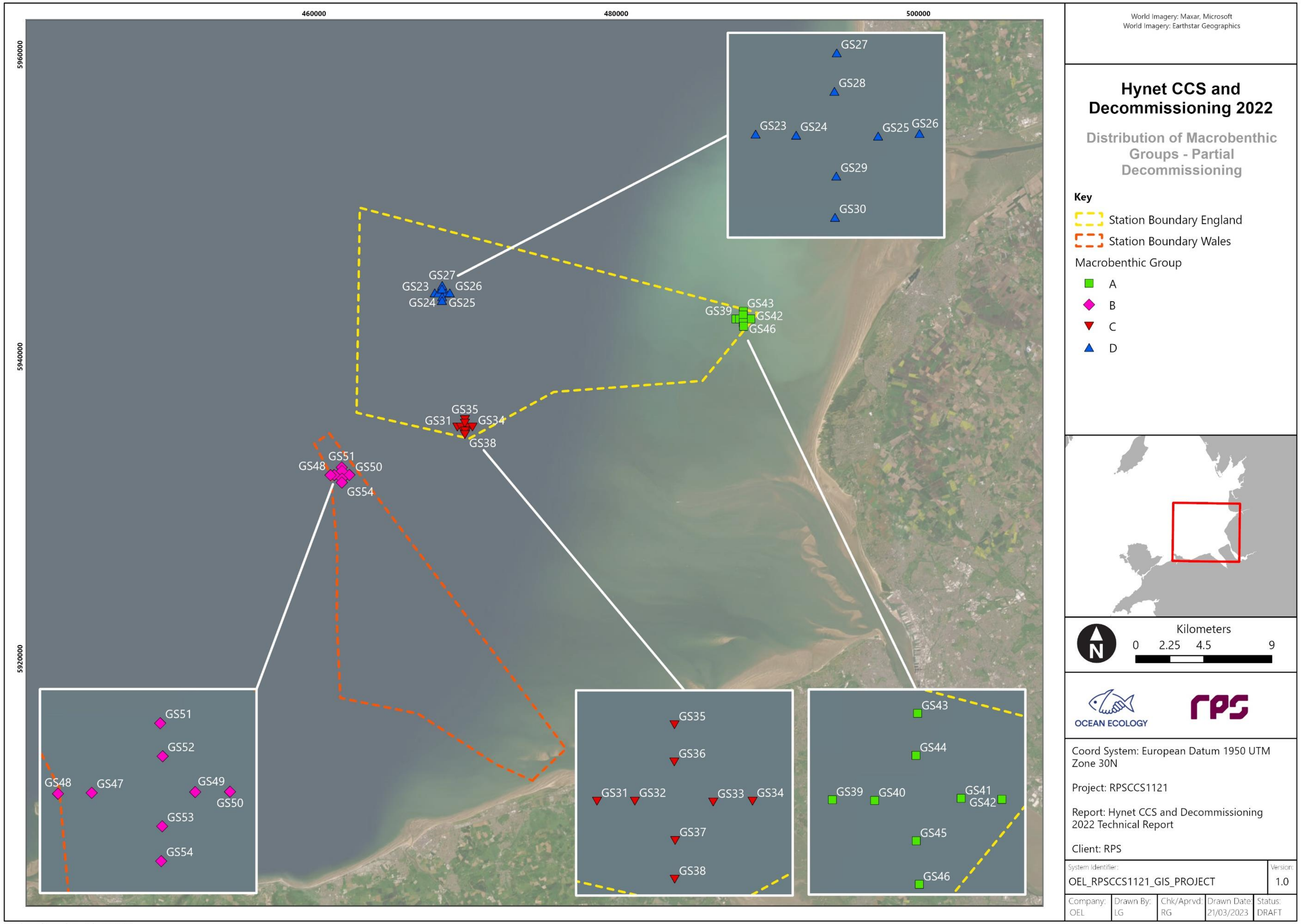

Figure 28 Spatial distribution of macrobenthic groups as determined from cluster analysis of abundance data.

6.8.3. Full Decommissioning

The dendrogram resulting from the cluster analysis (Appendix XV) and associated Type 1 SIMPROF (similarity profile routine) permutation test of all nodes within the dendrogram, identified three statistically significantly similar groups and four outlier stations that did not belong to any group ($p > 0.05$). To enable a broad interpretation of the community present, a similarity slice at 51 % was used to amalgamate the SIMPROF groups and outliers into two broader Macrobenthic Groups and one outlier station GS58. The spatial distribution of these macrobenthic groups is presented in Figure 30.

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 XVI.

Macrobenthic Group A – Nine stations belonged to this group and were characterised by Nematoda, the oligochaete *Tubificoides pseudogaster*, Nemertea, and juveniles of the bivalve Thracioidea all together contributing to about 34 % of the group average similarity of 57.29.

Macrobenthic Group B – 11 stations belonged to this group and were characterised by *K. bidentata*, Nematoda, *P. baltica*, the brittle star *A. filiformis* and the amphipod *Harpinia antennaria* all together contributing to about 47 % of the group average similarity of 57.82.

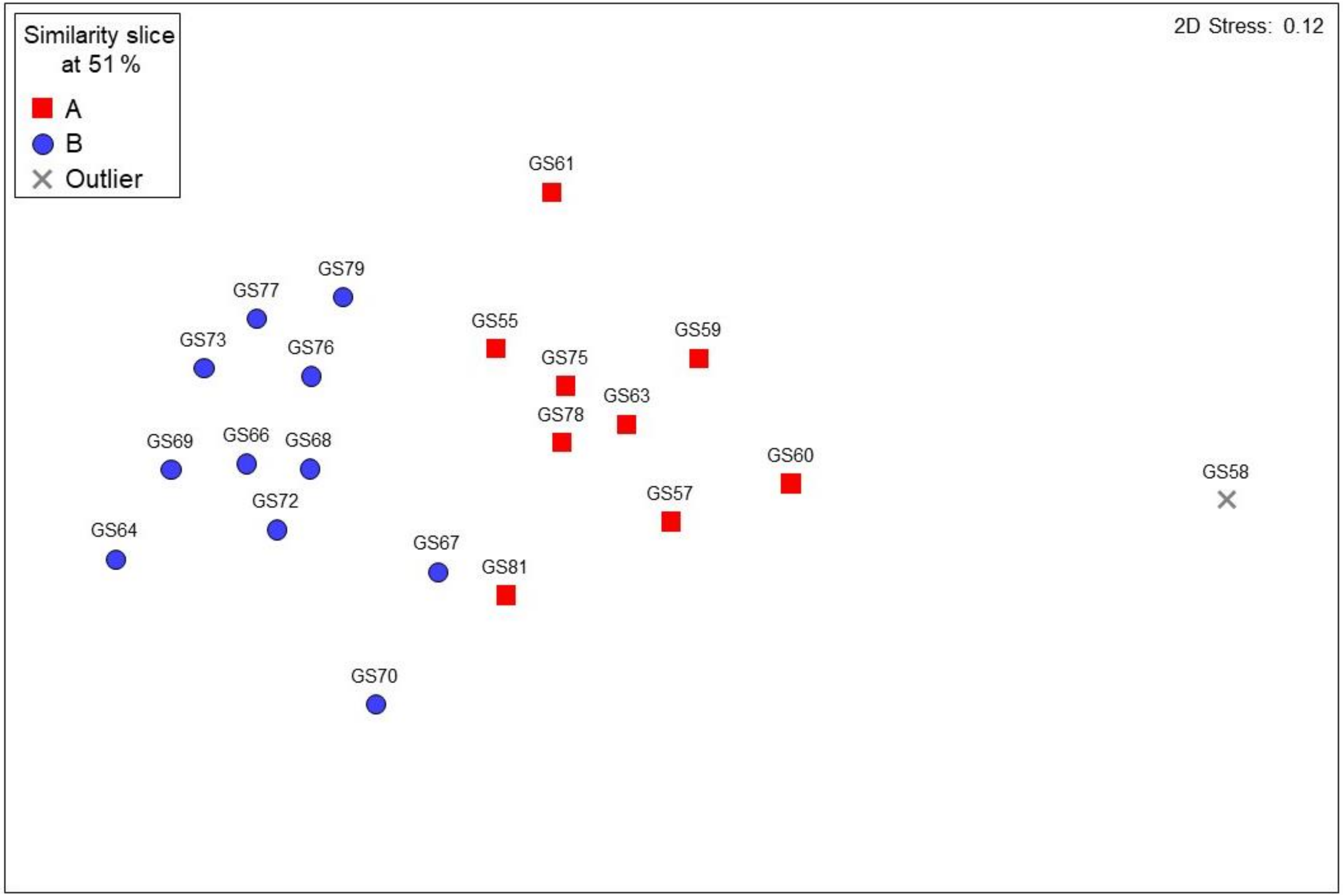

Figure 29 Two-dimensional nMDS ordination of macrobenthic communities at full decommissioning stations based on square root transformed and Bray-Curtis similarity abundance data.

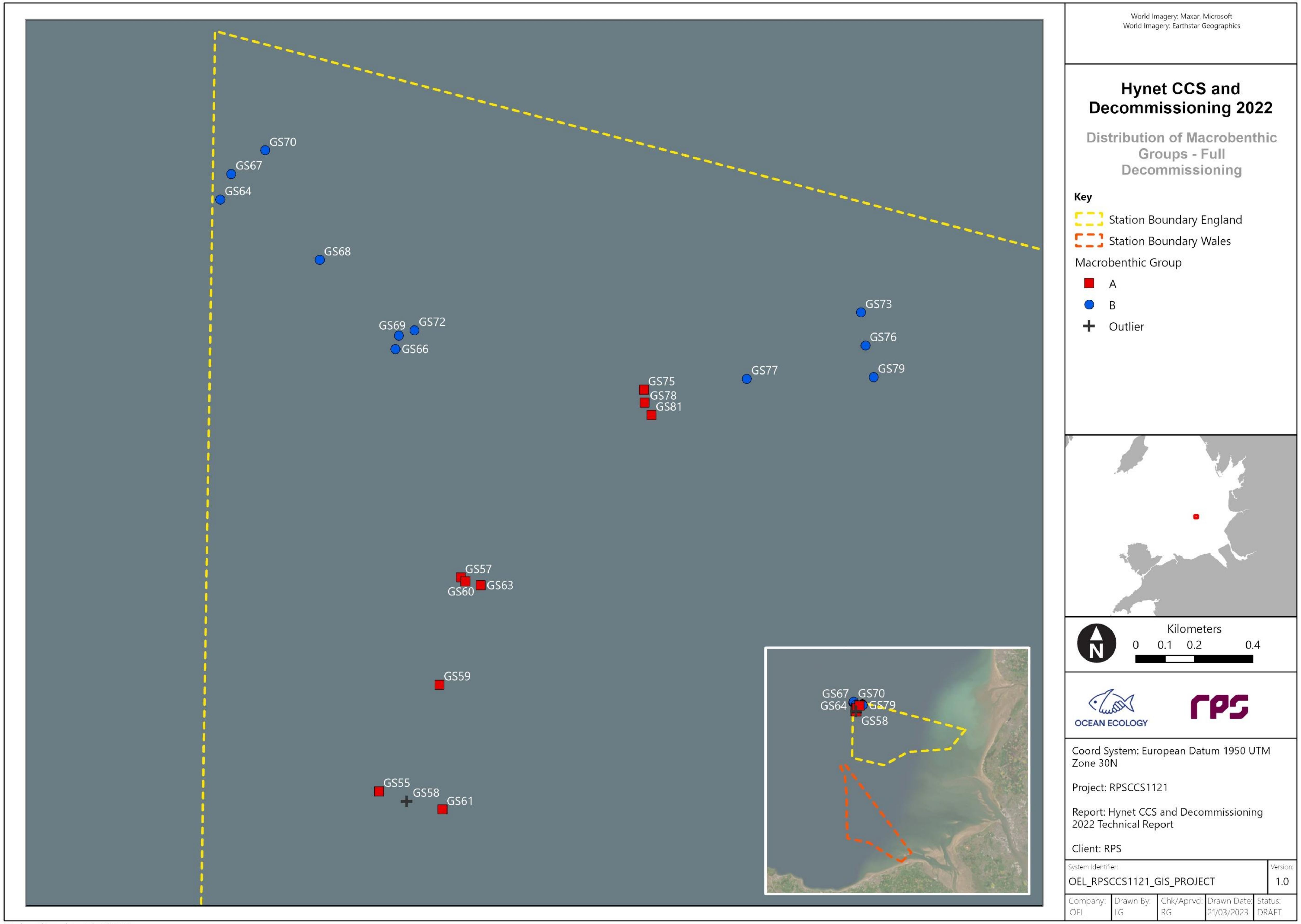

Figure 30 Spatial distribution of macrobenthic groups as determined from cluster analysis of abundance data.

6.9. Biotope Assignment

For each of the Macrobenthic Groups determined using cluster analysis, biotopes were assigned in consideration of industry standard practices and guidance (Parry 2019) based upon their faunal and physical characteristics.

6.9.1. CCS

Macrobenthic Group A best aligned with biotope A5.351 "*Amphiura filiformis, Mysella bidentata* and *Abra nitida* in circalittoral sandy mud". Only two stations belonged to this group: GS09, which was classified as BSH A5.3 based on PSA, and GS10 classified as BSH A5.4 based on PSA but with a relatively high mud contribution at 14 %; the latter being a biotope mismatch.

Macrobenthic Group B was made up of seven stations all classified as BSH A5.4 based on PSD data except for station GS13 which was classified as A5.1. To note that all stations had more than 20 % of gravel contributing to sediment composition. No infralittoral or circalittoral mixed sediment biotope matched the assemblage characterising this group. Of the coarse sediment biotopes, A5.142 "*Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel" shared some similarity with the community composition observed in this group characterised by *L. cingulata*, the pea urchin *Echinocyamus pusillus,* Nemertea, and *A. spinipes*. However other taxa were present in this group that were unmatched such as Nematoda, *P. balthica, Phoronis, P. lyra, Ampharete lindsstroemi, Glycinde nordmanni, Chaetozone zetlandica, Cerianthus lloydii, U. elegans* and *Nototropis vedlomensis*. Mixed sediment stations belonging to this group were therefore assigned to EUNIS classification A5.44 – Circalittoral mixed sediments due to the inability of matching the observed community with a specific known biotope. It should be noted that biotope A5.445 "*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittle star beds on sublittoral mixed sediment" was observed in the seabed imagery in proximity of the area covered by this group.

Macrobenthic Group C was made up of six stations all classified as BSH A5.2 based on PSD data. These stations are all located in proximity to the coast (Figure 26) and dominated by *N. cirrosa* suggesting that the biotope A5.233 "*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand" is present at these locations. This is also consistent with the results of the imagery analysis (Figure 16).

Macrobenthic Group D included six stations all classified as BSH A5.2 based on PSD data but station GS19 which was deemed to be representative of A5.1. None of the circalittoral fine sand or muddy sand biotopes matched the community observed for this group which was dominated by Nemertea, *N. cirrosa*, Nematoda, Actinaria and *K. bidentata*. Therefore, this group was assigned to EUNIS classification A5.25 – Circalittoral fine sand, with station GS19 assigned to A5.14 – Circalittoral coarse sediments.

6.9.1. Partial Decommissioning

Macrobenthic Group A was made up of eight stations all classified as BSH A5.2 based on PSD data. These stations were all located close to the coast (Figure 28) and dominated by *K. bidentata*, Nemertea, Nematoda, *Megaluropus agilis* and *Bathyporeia guilliamsoniana*. None of the sand biotopes matched the above community and therefore these stations were assigned to EUNIS classification A5.23 "Infralittoral fine sand".

Macrobenthic Group B included eight stations all having at least 10 % gravel in their sediments. Four stations were classified as BSH A5.1 and the other four as A5.4 based on PSD data. Due to the heterogeneity in the substrate characterising this group a diverse community was observed that did not match any one biotope. Part of the community aligned with that described in biotope A5.142 "*Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel" with *L. cingulata, E. pusillus*, Nemertea, and *A. spinipes* being among the characterising taxa. However other taxa also dominated the community but remained unmatched as no coarse or mixed sediment biotope aligned with it. These included *U. marina*, *P. lyra, Lysilla nivea, Grania, Polycirrus* and *Leptocheirus hirsutimanus*. Therefore, stations belonging to BSH A5.1 were assigned to biotope A5.142, while stations belonging to BSH A5.4 were assigned to EUNIS classification A5.44. It should be noted that biotope A5.445 "*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittle star beds on sublittoral mixed sediment" was observed in the seabed imagery in proximity of the area covered by this group.

Macrobenthic Group C was made up of eight stations all having at least 10 % mud in their sediments except for station GS38 which had only 4 %. Five stations belonged to BSH A5.4 based on PSD data while the remaining three stations were classified as A5.1, A5.2 and A5.3. As this group covered a range of substrates no one biotope matched the community observed at these stations. The community characterising this group included Nematoda, *K. bidentata*, Nemertea, *M. fragilis, P. baltica, P. lyra, Grania* and *T. pseudogaster*. Therefore, stations belonging to this group were assigned to EUNIS classifications A5.44, A5.14, A5.26 and A5.35 based on the corresponding BSHs determined by PSA.

Macrobenthic Group D included eight stations, seven of which were classified as BSH A5.2 based on PSD data and with station GS29 being classified as A5.3. None of the fine or muddy sand biotopes matched the community observed at these stations, which was characterised by Nematoda, *Grania*, Nemertea, *V. gibba, K. bidentata*, Chaetognatha, and *Polygordius*. All stations were therefore assigned to EUNIS classification A5.25 – Circalittoral fine sand, apart from station GS30 which was assigned to EUNIS classification A5.26 - Circalittoral muddy sand and station GS29 which was assigned to EUNIS classification A5.35.

6.9.1. Full Decommissioning

Macrobenthic Group A comprised of nine stations all classified as BSH A5.2 based on PSD data except for station GS81 which was classified as A5.3. None of the fine or muddy sand biotopes matched the community observed at these stations which was characterised by Nematoda, *T. pseudogaster*, Nemertea, Thracioidea, Chaetognatha, *E. pusillus*, and *K. bidentata*. All sand dominated stations were therefore assigned to EUNIS classification A5.26 "Circalittoral muddy sand" based on PSA and imagery analysis, while station GS81 was assigned to A5.35.

Macrobenthic Group B included 11 stations, of which six were classified as BSH A5.3 and five as A5.2 based on PSD data. Due to the heterogeneity in the substrate characterising this group a diverse community was observed that did not match any one biotope. Part of the community aligned with that described in biotope A5.351 "*Amphiura filiformis*, *Mysella bidentata* and *Abra nitida* in circalittoral sandy mud" with K. *bidentata, A. filiformis, Phoronis, P. baltica* and *Nucula nitidosa* being among the characterising taxa. However other taxa also dominated the community but remained unmatched as no sand or mud biotope aligned with them. These included Nematoda, *H. antennaria,* Nemertea, *Cylichna cylindracea* and *Parexogone hebes*. Therefore, stations belonging to BSH A5.3 were assigned to EUNIS classification A5.351 while stations classified as BSH A5.2 were assigned to EUNIS classification A5.26 "Circalittoral muddy sand" based on PSA and imagery analysis.

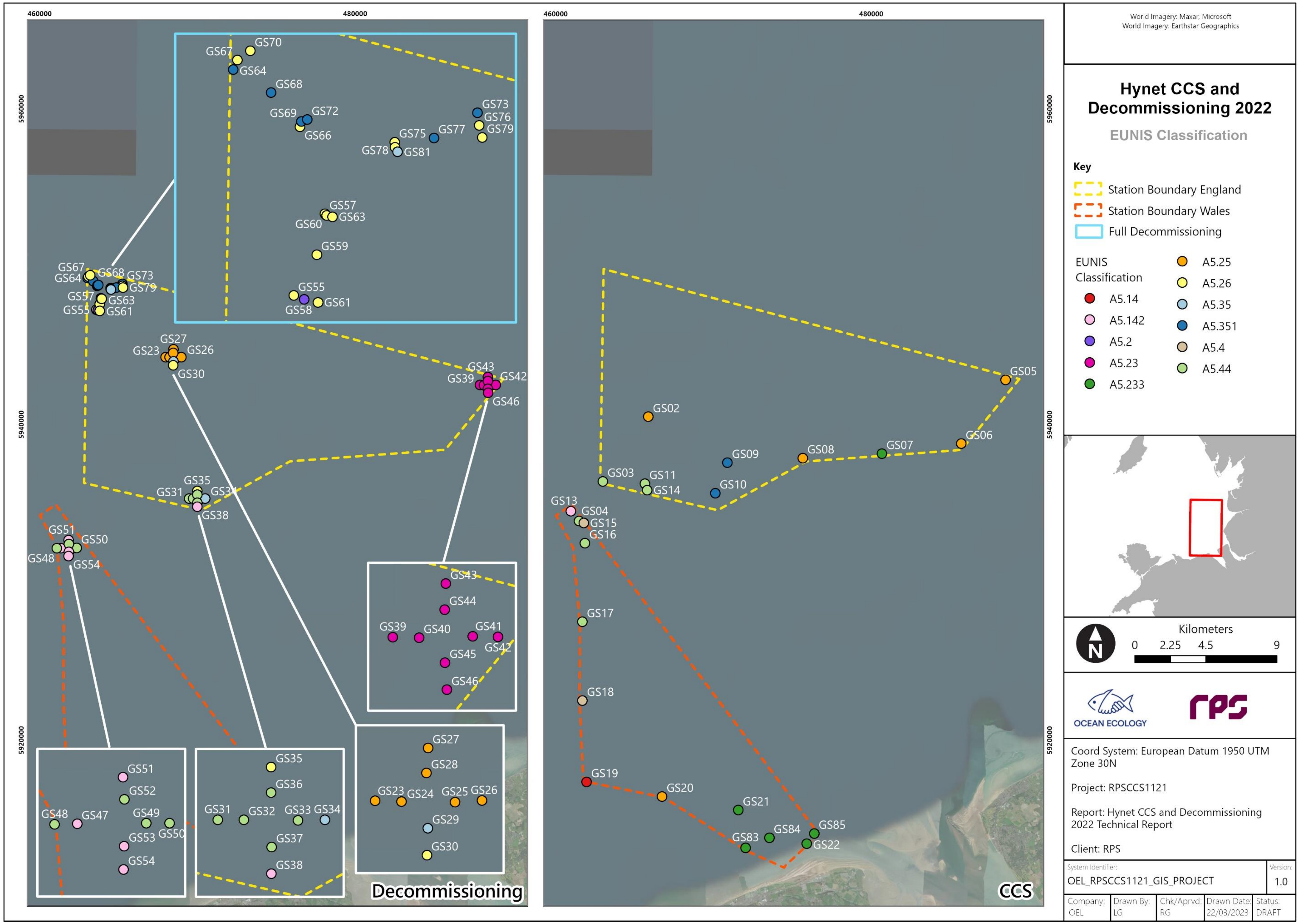

Figure 31 EUNIS Biotopes as determined from interrogation of sediment and macrobenthic data, with the support of seabed imagery analysis.

7. Discussion

This report presents the results and interpretation of the sediment, macrobenthic, and seabed imagery analysis with the aim to set out the environmental baseline conditions across the survey area considered for the repurposing and partial decommissioning of the oil and gas offshore infrastructure, and the development of the infrastructure and communication interconnection from shore to the offshore platform for CCS.

7.1. Sediment Composition

At CCS and partial decommissioning stations, the sediment was highly heterogeneous with different contributions of mud and gravel to the mostly sandy seabed. This heterogeneity was most likely due to the position of the site relative to the coastline and the river Dee estuary. Specifically, the position of the site ranged from within the estuary itself to a distance where longshore currents typical of estuaries can influence sediment mixing and composition. Conversely, the full decommissioning stations, which were the farthest away from the shore and estuary compared to the other sampling sites, displayed a more homogenous substrate with almost no gravel. A spatial pattern was observed in sediment grain size at decommissioning stations, with finer sediments typically found in proximity of platforms. This could be associated with a remanence of drill cuttings in and around the platforms which are typically made of fine sediments.

Based on PSA data the most commonly recorded EUNIS BSH was A5.2 sand and muddy sand, followed by A5.4 mixed sediment, which is suggestive of the heterogenous nature of the sediment in the region. This is in slight contrast to 2021 EUSeaMap existing broadscale habitat mapping of the area which indicated areas of circalittoral fine sand (A5.25), circalittoral muddy sand (A5.26), deep circalittoral sand (A5.27), deep circalittoral coarse sediment (A5.15) and circalittoral coarse sediment (A5.14) (Figure 2).

7.2. Sediment Chemistry

Several guidelines exist to assess the degree of contamination and likely ecological impacts of contaminants in marine sediments. These regulations defined the levels below which effects are of no concern and/or rarely occur (AL1, BAC, TEL) and the levels above which adverse biological effects are considerable and/or occur frequently (AL2, ERL, PEL). *Ad hoc* decisions need to be made when contaminant concentrations fall between these levels. To note that CEFAS ALs1 are typically the most conservative measures to assess sediment contamination and often result in “false positives”, meaning that non-toxic sediment samples fail to pass this screening test. Conversely, ALs2 tend to be rather permissive, allowing samples with relatively high contaminant concentrations to fall between AL1 and AL2 and thus requiring expert judgment to further assess their potential toxicity (MMO 2015, Mason et al. 2020). Recent studies have been revising these ALs with the goal of reducing the range of concentrations falling between AL1 and AL2 and minimise the number of samples requiring an *ad hoc* treatment; however, no policy has been made yet based on these recommendations and suggestions (MMO 2015, Mason et al. 2020).

Among all metals measured during the survey, As, Hg and Cd were the only metals with concentrations above reference levels at least at one station. Specifically, As was above CEFAS AL1 at GS23, and above the TEL at 43 stations and the ERL at 36 stations. Hg was measured at concentrations above the OSPAR BAC at seven stations and above the TEL at station GS58. Cd exceeded CEFAS AL1 at station GS34 and the OSPAR BAC at stations GS34 and GS38, all three of which are partial decommissioning stations. Hg and As concentrations exceeding the TEL has possibly to do with the TEL being based on North American data, and as such, it may not be representative of UK conditions (MMO 2015, Mason et al. 2020). In comparison, OSPAR BAC and CEFAS ALs are based on UK data and therefore are more suitable for the current assessment. Elevated metal concentrations in sediments do not necessarily imply toxicity to benthic communities (Rees et al. 2007), as the bioavailability of these metals is more important than simply concentration levels. Despite some stations reporting elevated metal concentrations, no macrobenthic anomalies were identified at these locations to suggest any adverse effects were present. In fact, no stations had metals concentrations above AL2, meaning that, overall, adverse biological effects were unlikely. TEL and ERL values have been used for reference where possible throughout this assessment as these are the only guideline values that provide a measure of environmental toxicity, compared to OSPAR BAC and CEFAS ALs that instead provide information on the degree of contamination in the sediments. Zn was the most abundant metal at all stations however it never exceeded any of the reference values and was not considered to be present at toxic levels. Zn is typically found in association with the clay/finer fraction of the sediments however no correlation was observed between grain size and Zn across the survey area. Similarly, no correlation between mud content and As, Hg or Cd concentrations was found across the survey area. To provide some context, the concentration of Cd, Hg and Zn were compared with existing data from the North Sea; no data was available for As (UKOOA 2001). Cd across the survey area ranged between 0.04 mg kg^{-1} and 0.48 mg kg^{-1} which is within the range of values for the North Sea spanning from 0.20 mg kg^{-1} and 5.56 mg kg^{-1}, with a mean background level of 0.43 mg kg^{-1}. Hg across the survey area ranged between 0.01 mg kg^{-1} and 0.11 mg kg^{-1} below the North Sea background level of 0.16 mg kg^{-1}. Zn across the survey area varied between 19.8 mg kg^{-1} and 62.5 mg kg^{-1} which is in line with the range of values for the North Sea spanning from 20.9 mg kg^{-1} (background) to 129.7 mg kg^{-1} within 500 m from an active platform.

Chrysene and Benzo[a]pyrene were the only PAHs to exceed CEFAS AL1 at partial decommissioning station GS36, and in general multiple PAHs exceeded one of the reference levels at this station. No obvious pattern emerged when comparing stations with elevated PAHs and elevated metal concentrations. A positive correlation (R^2 = 0.6) was observed between Chrysene, Benzo[a]pyrene and mud content with higher PAHs concentrations in muddier sediments apart from station GS36 which had the highest Chrysene and Benzo[a]pyrene concentrations but an average mud content. No relationship was observed between the concentration of PAHs and proximity to platforms that could have indicated dispersal of drill cuttings. No macrobenthic anomalies were identified at these locations to suggest any adverse effects were present.

THC was the highest (30,600 µg kg^{-1}) at partial decommissioning station GS36, where most PAHs were also found to exceed a number of reference levels. The THC background level for the North Sea is 6,890 µg kg^{-1}, however THC concentrations at location between 1 and 2 km from an active platform range between 32,710 µg kg^{-}1 and 33,810 µg kg^{-1} in line with the findings at station GS36 which was located in proximity of a platform (UKOOA 2001).

Both Pr/Ph ratio and CPI suggest a biogenic dominance of the source of hydrocarbons across all stations with stations located closer to land and/or in the path of longshore currents associated with the Dee estuary influenced by terrestrial inputs (Pr/Ph > 3). The CPI for the central sector of the North Sea is 2.04 which is comparable with the average CPI for the survey area of 2.2 (UKOOA 2001).

All Polychlorinated Biphenyls (PCBs) were measured BDL at all CCS stations and did not exceed CEFAS AL1 at any of the decommissioning stations.

All organotins measured were below the detection limit of 0.001 mg kg^{-1} at all stations.

7.3. Macrobenthos

A diverse macrobenthic assemblage was identified across the 23 CCS stations with a total of 2,001 individuals and 215 different taxa counted. Most stations were characterised by the presence of Nemertea and Nematoda, which occurred in 78 % of samples, and relatively high abundances of the brittle star A. *filiformis* (Figure 17). The epifaunal community was characterised by high numbers of *S. triqueter*, while Actinaria was the most frequently occurring taxon (Figure 18).

Similarly, a diverse macrobenthic assemblage was also identified across the 53 decommissioning stations with a total of 13,332 individuals and 322 taxa recorded. Most stations were characterised by the presence of Nemertea and *K. bidentata,* which occurred in 98 % of samples, and relatively high abundances of Nematoda (Figure 21). The epifaunal community was characterised by relatively high numbers of the common brittle star *O. fragilis* and Actinaria, with the latter being also the most frequently occurring taxon (Figure 22). High abundances and low frequency of *O. fragilis* in the epifaunal community sampled by grab aligned well with the findings of the seabed imagery analysis that reported the presence of brittle star beds at discrete locations in the same area.

Differences in community composition and structure between CCS and decommissioning stations were most likely driven by the different size fractions analysed. CCS sediment samples were sieved over a one mm screen compared to decommissioning stations which were sieved over a 0.5 mm screen which meant that a larger number of smaller bodied organisms were retained in the macrobenthic assemblage of decommissioning stations.

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). Macrobenthic groups identified by the multivariate cluster analysis showed a clear distinction across partial decommissioning stations with each macrobenthic group encompassing one asset: Douglas Process, Hamilton Main, Hamilton North, and Lennox platform (Figure 28). This spatial pattern in macrobenthic groups reflected changes in sediment composition. For instance, Macrobenthic Group A included stations all classified as BSH A5.2 and dominated by sand (> 97 %). Macrobenthic Group B seemed to show an affinity for coarser sediments including stations with at least 10 % of gravel. Conversely Macrobenthic Group C included stations with an affinity for finer sediments with all stations having at least 10 % of mud. En exception to this was station GS38 which fell into Macrobenthic Group C despite only having 4 % of mud. To note that this station plotted as an outlier based on the SIMPROF routine. Finally, Macrobenthic Group D included stations dominated by sand with very little gravel and variable mud content, with station GS29 having up to 35 % mud while all other stations had mud content ranging from 1.7 % to 5.9 %.

Among the full decommissioning stations, a clear spatial pattern was observed with Macrobenthic Group A showing an affinity for sandier sediments and including stations located in a north-south direction from the OSI and Macrobenthic Group B supported by muddier sediments and encompassing stations lying in an east-west direction from the OSI (Figure 30). Spatial patterns were not as obvious among CCS stations with two macrobenthic groups showing a tighter clustering around either coastal, infralittoral stations (Macrobenthic Group C) or offshore, circalittoral stations (Macrobenthic Group B) while Macrobenthic Group D covered a much wider area (Figure 26). Nevertheless, sediment composition was a key factor in determining the macrobenthic community structure across CCS stations with muddy sediment supporting Macrobenthic Group A, mixed sediments supporting Macrobenthic Group B, infralittoral sandy sediment supporting Macrobenthic Group C and circalittoral sandy sediments supporting Macrobenthic Group D.

7.4. Habitat/Biotope Mapping

PSD and macrobenthic data clearly indicated the presence of a heterogeneous substrate and a diverse macrobenthic community across the survey area. Despite sand being the dominant size fraction at all stations, the relative contributions of mud and gravel greatly varied among stations resulting in the presence of an intricate mosaic of substrates across the survey area (Figure 11). This resulted in a diverse macrobenthic community that did not exactly match any of the known EUNIS biotopes and complexes. Some of the macrobenthic groups identified bore some resemblance with EUNIS biotopes A5.142, A5.233 and A5.351 however most stations supported a macrobenthic community that was not indicative of one specific biotope and as such mapping was limited to a lower-level resolution at these locations (Figure 31). Seabed imagery was used to a certain extent in the determination of these biotopes, however due to the similarity in appearance of soft substrate habitats, it did not help in refining the habitat mapping based on grab data. Some differences were noted in the epibenthos characterising CCS and decommissioning stations based on seabed imagery with the former dominated by *P. miliaris*, *O. albida* and Serpulidae tubes while decommissioning stations displayed a sparser faunal cover most likely due to these stations being located in deeper waters further away from the coast. Nevertheless, the community observed across the survey area resembled that found across the Northwest region monitored as part of the RSMP (Cooper & Barry 2017) which was characterised by Spionidae, Nephtyidae, Cirratulidae, Amphiuridae, Oweniidae and Nemertea among others.

It should be considered that the lack of replicates at each station is likely to have led to increased variability within the dataset. Grabs sample a small area and so a single replicate is less likely to be entirely representative of the broader area of seabed (Downing & Downing 1992), and only a portion of the macrobenthic community is likely to be present in a single sample which can lead to a large number of statistically significant macrobenthic groups. For instance, the SIMPROF test run on abundance data from full decommissioning stations resulted in three statistically significant similar groups and four outlier stations based on 21 stations analysed. Additionally, relatively small changes in the number of individuals or taxa in a sample can lead to increased numbers of statistically significant groups as indicated by the relatively loose clustering of the macrobenthic groups (Warwick 1988). This was the case for CCS stations, Macrobenthic Groups A, C and D (Figure 25). Having said this, the sampling strategy and design adopted here met the purposes and satisfied the aims of this assessment which were to characterise seabed sediments and associated benthic communities and mapping key features and sensitive habitats.

8. References

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