GREEN VOLT

Technical Appendix 7.2

Benthic Analyses

Offshore EIA Report: Volume 2

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Floatation Energy Plc

Green Volt Benthic Analyses

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1. Executive Summary

This report summarises the findings of grab sampling for benthic fauna carried out at the Green Volt Offshore Wind Farm proposed development area, ~12 NM off Peterhead, Scotland. The biological samples were analysed in line with the NMBAQC guidance (Worsfold et al., 2010) and APEM's standard marine benthic sample processing methods.

Sampling was carried out during one survey on 1st May 2022. Eight 0.1m^2 Day grab samples were collected at depths between 64 m and 89 m; 500 ml subsamples were taken from each for particle size analysis (PSA), Total Organic Carbon content (TOC) and sediment chemistry. Each biological sample was sieved over a 1.0 mm mesh for analysis of macrobiota.

Sediment composition was sandy gravel for most samples, with small quantities of mud. Three samples fitted the habitat MC5211 (A5.251, SS.SSa.CFiSa.EpusOborApri) "*Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand", the remaining five belong to the habitat MC2211 (A5.611, SS.SBR.PoR.SspiMx), "*Sabellaria spinulosa* on stable circalittoral mixed sediment". Of these five samples, one (SFS7) appeared to be impoverished relative to the the main habitat, transitioning toward the habitat complex MB32 (MB32, SS.SCS.ICS) "Atlantic infralittoral coarse sediment".

The fauna was rich and diverse with 214 taxa recorded, mainly Annelida, Crustacea and Mollusca, with several minor phyla, including a few epifaunal sessile and colonial animals. The most common species were the polychaete worm *Sabellaria spinulosa*, the sipunculan *Nephasoma minutum*, the mussel *Modiolula phaseolina*, polychaete worms *Polycirrus* sp. and *Phisidia aurea*, and the green urchin *Echinocyamus pusillus*. Other Echinodermata and Crustacea were also widespread but less numerous. Most of the species are known to be widely distributed in suitable habitats but some were of conservation importance. Others represented range extensions, new UK records or important additional specimens of species previously known only from limited material. Many of the records that have been left at higher taxonomic levels in the dataset may include undescribed or poorly known species, and the specimens would be useful for future taxonomic research.

The chemical analysis of the sediment doesn't show concentrations over the recommended thresholds, with exclusion of concentration of Arsenic. Arsenic was found in concentration above the TEL, Threshold Effects Level, the maximum concentration at which no effects are observed, but largely below the PEL, Probable Effects Level, the lower limit of the range of concentrations at which adverse effects are always observed.

2. Introduction

The Green Volt site is located approx. 12 NM offshore of Peterhead, Scotland. It is a pioneering project which will use floating offshore wind to provide sustainable energy for the production and processing of offshore oil and gas. To achieve this, Flotation Energy is working closely with major oil and gas operators. The aim of this study was to establish the biological habitats and the physicochemical characteristics of the sea bottom in the study area to form a baseline for future monitoring.

3. Methods

3.1 Survey

The survey was conducted on 1st May 2022 from the Green Quest, an 18 m MCA CAT 2 vessel operated by Green Marine UK Ltd. The grabbing was conducted by personnel from Green Marine, sample assessment and preservation was conducted by Nicola Pennisi from APEM Ltd.

All grab sampling was completed on 1st May 2022. Grab samples were collected using a 0.1 m^2 Day grab. All samples were assessed on retrieval for suitability. Three sets of 0.5L subsamples were also collected for Particle Size Analysis (PSA), Total Organic Carbon (TOC) and sediment chemistry analyses for total hydrocarbon content, Polyaromatic Hydrocarbons (PAH) and metals.

A station log sheet was maintained providing information on sampling attempts at each station. For each sampling attempt, the following information was recorded:

- Station number;
- Sample position;
- Sample description;
- Time of collection.

For the macrobenthic samples, field sample processing was conducted in accordance with the guidance provided in Cooper & Mason (2018) and samples were sieved over a 1.0 mm mesh sieve. All material retained on the sieves was fixed with 4% buffered formaldehyde solution in seawater and placed in sample containers (labelled inside and outside), following guidance in Ware & Kenny (2011) and Davies *et al.* (2001).

3.2 Laboratory Methods

3.2.1 Biological samples

Macrobenthic samples were processed according to APEM's standard operating procedure for marine benthic sample analysis and in compliance with the North-east Atlantic Marine Biological Analytical Quality Control (NMBAQC) Scheme's Processing Requirement Protocol (Worsfold et al., 2010).

Benthic grab samples were sieved in a fume cupboard over a 1.0 mm mesh, to standardise the sizes of organisms recorded. To improve sorting efficiency, samples were also sieved through a stack of 4.0, 2.0, and 1.0 mm mesh sieves, if appropriate. All biota retained in the sieves were then extracted under low power microscopes, identified and enumerated, where applicable.

Taxa were identified to the lowest practicable taxonomic level, using the appropriate literature (Worsfold et al. 2020). For certain taxonomic groups (e.g. nemerteans, nematodes, and certain oligochaetes), higher taxonomic levels were used due to the widely acknowledged lack of appropriate identification tools for these groups. Where required, specimens were also compared with material maintained within the laboratory reference collection. Nomenclature followed the World Register of Marine Species (WoRMS, 2022), except where more recent revisions were known to supersede WoRMS.

Examples of taxa recorded from the surveys were set aside for inclusion in APEM's in-house reference collection. This collection acts as a permanent record of the biota recorded.

All samples were subject to internal quality assurance procedures, whereby the residues and identifications from each sample were secondarily checked by another analyst. To ensure consistency, taxonomic quality control throughout the project was conducted by the same individual.

3.2.1 Biomass estimation

The estimation of biomass was undertaken according to APEM's standard operating procedure and the NMBAQC Scheme guidance and TDP (Worsfold et al. 2020).

APEM use a non-destructive biomass procedure that is fully compliant with the methods outlined in the Clean Seas Environmental Monitoring Programme (CSEMP) Green Book (CSEMP, 2012). Animals were blotted dry before transfer to a tared analytical balance. Biomass values were recorded as blotted wet-weight, +/- 0.0001g. Taxa weighing less than 0.0001g were given a nominal weight of 0.0001g. Barnacles, ascidians, cnidarians and non-countable taxa were not weighed.

Faunal biomass analysis was undertaken at recorded taxon level and included juveniles.

3.2.2 Particle Size Analysis and Total Organic Carbon (TOC)

PSA was performed in accordance with NMBAQC Best Practice Guidance (Mason 2016), with the modification that the wet separation was performed at 2 mm rather than 1 mm, to determine the 'gravel' to 'sand and mud' proportions by weight. A combination of dry sieving and laser diffraction was used depending upon the characteristics of the sediment. The >2.0 mm fraction was analysed using nested British Standard sieves at 'half' phi intervals. The sub-2.0 mm fraction was analysed via laser diffraction (size range 0.04 µm to 2.0 mm). The laser and sieve data were mathematically merged and calculations of particle size summary parameters (percentages of mud, sand, and gravel, silt/clay ratio, sand/mud ratio, median, mean, d10, d90, etc.) calculated using GRADISTAT software (Blott & Pye, 2001).

Total organic carbon (TOC) was calculated as percentage loss on ignition (LOI). For this analysis 1 gram of sample was oven-dried at 70°C for 24 hours, left to cool in a desiccator and the weight taken. Samples were then transferred to a muffle furnace and incinerated at 550°C for 2 hours, then cooled in a desiccator and re-weighed. Although some alternative methods use temperatures of 450°C, 550°C is widely accepted as a safe temperature for LOI determination which oxidizes virtually all carbon forms but does not result in loss of structural water from most clays. LOI was then calculated as:

$$\text{LOI (\%)} = (\text{weight loss})/(\text{initial oven dry weight}) \times 100$$

3.3 Data analysis methods

3.3.1 Macrobiota

Truncation of the macrobiota data was undertaken before calculation of univariate and multivariate statistics. Juveniles were combined with adults of the same recorded taxon name for calculation of numbers of taxa and epitokes were also combined for the same taxon name.

For analyses based on numbers of individuals, non-countable taxa and fragments of individuals were also omitted from analysis.

3.3.2 Univariate analysis

Univariate community analyses were undertaken using the PRIMER (version 6) software package. Biological diversity within a community was assessed based on taxon richness (total number of taxa present) and evenness (considers relative abundances of different taxa). The following metrics were calculated:

- **Taxon richness (S)**: The total number of taxa in a sample.
- **Density (N)**: The number of individuals per unit area (e.g. per square metre).

- **Shannon-Wiener Diversity Index (H'(log$_e$)**: A widely used measure of diversity accounting for both the number of taxa present and the evenness of distribution of the taxa (Clarke & Warwick, 2001).
- **Margalef's species richness (d)**: A measure of the number of species present for a given number of individuals.
- **Pielou's Evenness Index (J')**: A representation of the uniformity in distribution of individuals spread between species in a sample. The output range is from 0 to 1, with higher values indicating more evenness or more uniform distribution of individuals.
- **Simpson's Dominance Index (1-λ)**: A dominance index derived from the probability of picking two individuals from a community at random that are from the same species. Simpson's dominance index ranges from 0 to 1, with higher values representing a more diverse community without dominant taxa.

3.3.3 Multivariate techniques

All multivariate analyses were carried out using PRIMER version 6 (Clarke & Warwick, 2001; Clarke & Gorley, 2006). Prior to calculation of Bray-Curtis similarity between macrobenthic samples, the data were square-root transformed to reduce right-skewness and down-weight the effects of a small number of numerically dominant taxa (Clarke & Warwick, 2001).

Cluster Analysis

Hierarchical clustering was carried out on a Bray-Curtis similarity matrix of the macrobenthic abundance data in order to visualise the biological similarity between samples. The hierarchical clustering technique compares the abundance of each taxon in each sample, with its abundance in each of the other samples. The result is a matrix of pairwise similarity indices comparing each sample with all other samples. This similarity matrix was then output diagrammatically as a dendrogram. The similarity profile (SIMPROF) test was carried out as part of the clustering routine. This permutational test distinguishes clusters of samples that cannot be statistically differentiated at the 5% significance level and identifies them on the resulting dendrogram using red lines. Black lines on the dendrogram denote samples that are statistically different from one-another at the 5% significance level.

Ordination Analyses using non-Metric Multidimensional Scaling

Non-metric multidimensional scaling (MDS) is a type of ordination method which creates a 2- or 3-dimensional 'map' or plot of the samples from the Primer resemblance matrix. The plot generated is a representation of the dissimilarity of the samples (or replicates), with distances between the replicates indicating the extent of the dissimilarity. For example, replicates that are more dissimilar are further apart on the MDS plot. No axes are present on the MDS plots as the scales and orientations of the plots are arbitrary in nature.

Each MDS plot provides a stress value which is a broadscale indication of the usefulness of plots, with a general guide indicated below (Clarke & Warwick, 2006):

- <0.05 Almost perfect representation of rank similarities;
- 0.05 to <0.1 Good representation;
- 0.1 to <0.2 Still useful;
- 0.2 to <0.3 Should be treated with caution;
- >0.3 Little better than random points.

An MDS plot for the macrobenthic samples was created using the same Bray-Curtis similarity matrix as the hierarchical clustering process described above.

SIMPER

Where differences between groups of samples were found, SIMPER analysis was used to determine which taxa were principally responsible for the differences between the statistically distinct groups of stations.

3.3.4 Particle Size Analysis

The laser and sieve data were mathematically merged to produce sediment classifications, following Folk (1954) and Blott & Pye (2012) and calculations of particle size summary parameters (percentages of mud, sand, and gravel, silt/clay ratio, sand/mud ratio, mean particle size, sorting, skewness and kurtosis, d10, d90) calculated using GRADISTAT software (Blott & Pye, 2001).

3.3.5 Biotope allocation

The data were further examined to determine the characteristic biota for each sampling station. A list of samples in each SIMPROF group identified during the hierarchical cluster analysis was compiled and the mean number of individuals of each taxon recorded in the samples assigned to each group was calculated. The resulting lists represent, in decreasing order, the numerically dominant taxa. Only the top 20 taxa are presented for each group. Separate listings were created for those taxa that were fully enumerated in the samples and those which were not countable (i.e. colonial taxa such as Bryozoa and hydroids). The lists for non-countable taxa therefore represent an average of the number of samples in which each of the taxa occurred, again sorted in decreasing order. The results were then examined in tandem with the particle size data so that a biotope could be assigned following JNCC's National Marine Habitat Classification for Britain and Ireland: Version 04.05 (Connor *et al*., 2004), with EUNIS codes corresponding to each biotope provided (EUNIS 2019).

3.3.6 Sediment chemistry

Sediment chemistry samples were analysed to determine the current levels of contamination across the survey area in comparison to OSPAR background levels.

Heavy and Trace Metals

Metals are generally not harmful to organisms at concentrations normally found in marine sediments and some are essential for normal metabolism but can become toxic above a critical threshold. In order to quantify potential effects on marine life, Long et al. (1995) defined "effect range low" (ERL) values as the lowest concentration of a metal that produced adverse effects in 10% of the data reviewed, whilst "effect range median" (ERM) values designate the level at which half of the studies reported harmful effects. Consequently, metal concentrations recorded below the ERL are not expected to elicit adverse effects, while levels above the ERM are likely to be toxic to some marine life.

Heavy metals were extracted using a hydrofluoric/boric acid digestion with the exception of mercury (Hg) which was extracted by a nitric acid/peroxide digestion. The metals were then analysed using either ICP-MS (Ni, V, Zn, Cu, Cr, As, Cd, Pb, Hg) or ICP-OES (Al, Fe, Ba).

Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are natural components of coal and oil and are also formed during the combustion of fossil fuels and organic material. They are one of the most widespread organic pollutants in the marine environment of the OSPAR area, entering the sea from offshore activities, operational and accidental oil spills from shipping, river discharges and the air.

Polycyclic aromatic hydrocarbons (PAHs) were analysed at each station using gas chromatography mass spectrometry (GC-MS). Normalised total PAH data was calculated by using a simple ratio approximation to allow comparison to OSPAR background assessment concentrations (BACs; OSPAR, 2014a). An ecological effects threshold level of 50 mg/kg (50 ppm) has been stated by OSPAR for total hydrocarbon (THC) concentrations.

4. Results

4.1 Macrobiota

Samples of adequate volume were successfully obtained at eight grab locations. Further details of the grab samples taken are provided below. Macrobiota data are presented in Appendix 1.

4.1.1 Samples obtained and processed

Grab sampling was undertaken at eight stations, with single replicates collected for macrobenthic analysis and subsamples for particle size analysis, total organic carbon and sediment chemistry at each station.

Samples collected at each station are listed in Table 1, below with sampling positions.

Table 1 Sampling stations and positions

Sampling station	Positions (OSGB36)		Type of sample
	Eastings (m)	Northings (m)	
SFS5	57°32'44.85"N	1°37'31.06"W	PSA/Chemistry
	57°32'26.19"N	1°37'31.58"W	MB
SFS6	57°33'17.63"N	1°35'12.24"W	PSA/Chemistry
	57°33'9.38"N	1°35'21.93"W	MB Qualitative only
SFS7	57°34'0.80"N	1°33'14.05"W	ALL
SFS8	57°34'37.53"N	1°30'41.45"W	ALL
SFS9	57°35'8.90"N	1°28'9.51"W	ALL
SFS10	57°35'45.55"N	1°25'57.19"W	PSA/Chemistry
	57°35'32.49"N	1°25'49.52"W	MB
NCP4	57°37'6.88"N	1°39'13.50"W	PSA/Chemistry
	57°37'9.65"N	1°39'15.22"W	MB
NCT5	57°32'47.40"N	1°36'21.10"W	PSA/Chemistry
	57°32'16.90"N	1°36'26.49"W	MB

4.1.2 Univariate Statistics

The complete benthic dataset for the subtidal grab samples is provided in Appendix 1. A total of 214 benthic taxa were identified from the 8 analysed subtidal benthic grab samples. The most frequently recorded taxa were the Green Urchin *Echinocyamus pusillus* and the polychaete worms *Glycera lapidum* (aggregate) and *Polycirrus* spp., all of which were present in all eight samples, as well as Nematoda (Thread Worms) and Nemertea (Ribbon Worms). The most abundant taxa recorded were the honeycomb worm *Sabellaria spinulosa*, the Sipuncula *Nephasoma minutum* and the Bean Horse-Mussel *Modiolula phaseolina*. A total of 164 *S. spinulosa*, 127 *N. minutum* and 105 *M. phaseolina* individuals were recorded across the survey. These three taxa were most abundant in samples NCP4 (43 *S. spinulosa*, 38 *N. minutum*, 31 *M. phaseolina*) and NCP5 (35 *S. spinulosa*, 37 *N. minutum*, 29 *M. phaseolina)*. Numerically, Polychaetes dominated the samples, accounting for 51.43% of counted individuals. Non-countable taxa (e.g. algae, bryozoans) included 42 (19.63%) of the taxa.

The univariate diversity indices are presented in Table 2. The numbers of taxa per sample ranged from 21 in Sample SFS10 to 107 in Sample NCP4. Numbers of individuals per m² were also lowest in sample SFS10 (360) and highest in sample NCP4 (3,920). Total biomass (grammes per m² for infaunal animals) ranged from 0.785 g/m², in sample SFS10, to 20.21 g/m² in sample NCP4.

Margalef's species richness index (*d*) ranged from 5.02, in sample SFS10, to 15.34 in sample SFS5. Pieliou's Evenness (*J'*) ranged from 0.82, in sample SFS6, to 0.93 in samples SFS9. Shannon-Wiener diversity ($H'\log_e$) ranged from 2.62, in sample SFS10, to 3.85 in sample NCP5. Simpson's dominance index (1- λ) ranged from 0.91, in samples SFS8 and SFS10, to 0.97 in sample SFS5 and NCP5.

Table 2 Univariate statistics

Sample	Number of Taxa (S)	Density (individuals per m²)	Total Biomass (g per m²)	Margalef's species richness (*d*)	Mean Pielou's Evenness (*J'*)	Mean Shannon Wiener Diversity) ($H'(\log_e)$)	Mean Simpson Dominance (1-λ)
SFS5	104	3310	7.5770	15.34	0.85	3.81	0.97
SFS6	70	2030	4.8740	10.16	0.82	3.29	0.93
SFS7	54	1620	3.4070	8.65	0.85	3.23	0.94
SFS8	28	490	1.3390	5.64	0.86	2.71	0.91
SFS9	25	530	2.0250	5.79	0.93	2.97	0.96
SFS10	21	360	0.7850	5.02	0.89	2.62	0.91
NCP4	107	3920	20.2100	13.73	0.86	3.66	0.96
NCP5	102	3880	9.8190	14.76	0.83	3.85	0.97
Min	**21**	**360**	**0.785**	**5.02**	**0.82**	**2.62**	**0.91**
Max	**107**	**3920**	**20.21**	**15.34**	**0.93**	**3.85**	**0.97**
Mean	**63.88**	**2017.5**	**6.25**	**9.89**	**0.86**	**3.27**	**0.94**

4.1.3 Cluster analysis

The results of SIMPROF cluster analysis on the macrobenthic data for each station are presented in Figure 1. Black lines denote significant structure within the group to that point and red lines connect samples that cannot be significantly differentiated at the 95% confidence interval. The SIMPROF test identified three groups that can be considered statistically distinct from one-another at the 95% confidence level.

Group C comprised three samples (SFS8, SFS9 and SFS10), separating from the other two cluster groups at 20.55% similarity. This group had low abundances compared to the other two groups, containing an average of 46 countable specimens across an average of 26 taxa, with an average of 1.8 individuals per recorded taxon. This group was characterised mostly by polychaetes including *Chaetozone zetlandica*, *Polycirrus* spp. and *Glycera lapidum*

(aggregate), along with the bivalve *Goodallia triangularis* and the green urchin *Echinocyamus pusillus*.

Group A included only one sample (SFS7), separating from Group B at 43.95% similarity. This sample had moderate diversity compared with the other samples, containing 162 countable individuals (slightly below the mean value for all samples of 201.75) belonging to 54 taxa (compared to the mean value of 65 across all samples).

Group B contained half the samples (SFS5, SFS6, NCP4 and NCP5) and comprised the most abundant and biodiverse samples, with an average number of individuals of 328.5 per sample from 97 taxa.

Both Groups A and B were characterised by higher abundance then Group C (A: average of 3 individuals per taxon; B: average of 3.4 individuals per taxon), both with high numbers of individuals of the Honeycomb worm *Sabellaria spinulosa* (200 individuals per m^2 in group A and 360 individuals per m^2 in Group B) the green urchin *Echinocyamus pusillus* (220 individuals and 63 individuals per m^2, respectively) and the Sipuncula *Nephasoma minutum* (120 and 285 individuals per m^2, respectively).

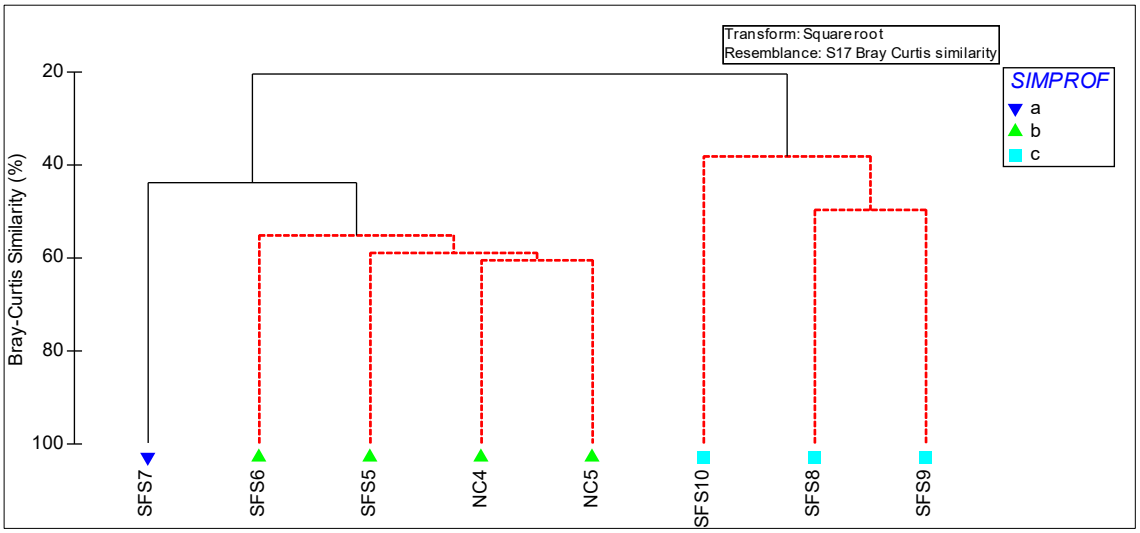

Figure 1 SIMPROF Cluster dendrogram of Bray-Curtis similarity between square-root transformed macrobenthic data

4.1.4 Biotope composition

The macrobenthic samples were divided across three cluster groups (a, b and c). These have been assigned to two habitat groups, although none fitted perfectly with any described biotope.

Groups A and B were assigned to the biotope *Sabellaria spinulosa* on stable circalittoral mixed sediment (SS.SBR.PoR.SspiMx, EUNIS MC2211). Group B was the closest fit to the described biotope but numbers of *S. spinulosa* may not have been high enough to be considered a reef. Group A represented an impoverished version, showing transitional qualities with the habitat complex Atlantic infralittoral coarse sediment (SS.SCS.ICS, EUNIS MB32), as well as with the biotope described below ("*Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand", SS.SSa.CFiSa.EpusOborApri, EUNIS MC5211).

Group C was assigned to the biotope *Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand (SS.SSa.CFiSa.EpusOborApri, EUNIS MC5211). However, there was some transition towards Atlantic infralittoral coarse sediment biotopes, such as *Moerella* spp. with venerid bivalves in infralittoral gravelly sand (SS.SCS.ICS.MoeVen, EUNIS MB3233).

4.1.5 Notable Taxa

The biota was rich and diverse in most samples, with species typical of similar habitats in other areas. There were large numbers of honeycomb worms, *Sabellaria spinulosa*, which would be considered a priority habitat, if reef-forming. The hydroid *Tamarisca tamarisca* is listed as Nationally Scarce (Sanderson, 1996). Several other recorded taxa were poorly known or rarely recorded, including some that were recently described or may include undescribed species. Of these, the most interesting may be the syllid worm *Trypanosyllis troll* and an amphipod that may be *Metopa boeckii*, both previously recorded from Norwegian waters (Ramos et al., 2010; Tandberg, 2010) but are so far not formally reported from British waters. The worm *Goniadella gracilis* is currently listed as non-native (Minchin et al., 2013) but there is limited evidence for this.

4.2 Particle Size Analysis and Total Organic Carbon

The PSA data show that all of the samples consisted of predominantly sand, with varying proportions of gravel and low proportions of silt/clay. Stations NCP5, SFS7, SFS9 and SFS10 had the highest proportions of sand (74-91%), with moderate proportions of gravel. Stations NCP4, SFS5, SFS6 and SFS8 had relatively high proportions of gravel (31-47%). The sandier samples were moderately to poorly sorted; gravelly samples were poorly to very poorly sorted. Kurtosis results showed stations NCP5, SFS7, SFS9 and SFS10 to be leptokurtic, indicating a distribution more concentrated about the mean size value and with heavy tails on either side. Stations NCP4, SFS5, SFS6 and SFS8 show a platykurtic distribution, a flattened distribution of size fractions.

Table 3 Summary particle size data from each subtidal grab station

Station	Mean particle diameter (µm)	Gravel (%)	Sand (%)	Mud (%)	Statistics calculated using Folk and Ward (1957) formulae			Classification Folk (1954)
					Sorting	Skewness	Kurtosis	
SFS5	31.8	65.2	3.0	31.8	Poorly Sorted	Coarse Skewed	Platykurtic	Sandy Gravel
SFS6	41.9	55.6	2.5	41.9	Very Poorly Sorted	Coarse Skewed	Platykurtic	Sandy Gravel
SFS7	8.1	90.8	1.1	8.1	Moderately Sorted	Coarse Skewed	Leptokurtic	Gravelly Sand
SFS8	33.5	66.5	0.0	33.5	Poorly Sorted	Very Coarse Skewed	Platykurtic	Sandy Gravel
SFS9	12.6	87.4	0.0	12.6	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Gravelly Sand
SFS10	6.5	90.0	3.5	6.5	Moderately Sorted	Coarse Skewed	Very Leptokurtic	Gravelly Sand
NCP4	46.1	51.4	2.6	46.1	Very Poorly Sorted	Symmetrical	Very Platykurtic	Sandy Gravel
NCP5	22.5	74.5	3.0	22.5	Poorly Sorted	Coarse Skewed	Mesokurtic	Gravelly Sand

4.3 Sediment Chemistry

4.3.1 Sediment heavy and trace metals

Heavy and trace metal concentrations recorded are listed in Table 3.

The current Coordinated Environmental Monitoring Programme (CEMP) environmental focus around the heavy metals is on cadmium, mercury and lead (OSPAR, 2014b). Cadmium and lead occur within the natural environment but can be toxic, whilst mercury is extremely toxic to humans and biota (OSPAR, 2009a). None of the concentrations of these metals exceed the OSPAR threshold in the analysed samples, so it is considered unlikely they will have an effect on the biota.

Sediment heavy and trace metals

Heavy and trace metal concentrations recorded are listed in Table 4 and Figure 2 and Figure 3. The low levels recorded for Cadmium and Mercury prohibits graphical representation but the values are included in Table 4.

The current environmental focus of the Coordinated Environmental Monitoring Programme (CEMP) around heavy metals is on cadmium, mercury and lead (OSPAR, 2014b). Cadmium and lead occur within the natural environment but can be toxic whilst mercury is extremely toxic to humans and biota (OSPAR, 2009a). Cadmium did not exceed the Background Concentration (BC), the Background Assessment Concentration or the Threshold Effects Level (TEL), the maximum level at which no effects are observed, at any stations. Lead concentration was fairly consistent between stations (8.50% RSD) ranging between 8.6 mg/kg and 10.8 mg/kg, falling below all comparable threshold levels. Similarly, mercury was also recorded in low concentrations and consistently below the limit of detection for the analytical method used (0.001 mg/Kg). All heavy and trace metal were found in concentration below the Background

Concentration (BC), the concentration that it should naturally occur in undisturbed environment. In the majority of the station, with exclusion of stations SFS9 and SFS10, arsenic was recorded above the Threshold Effects Level (TEL), the maximum concentration at which no effects are observed, which is lower that the BC, in station. In stations SFS8 and NCP4 higher concentrations of heavy and trace metals were observed, compared with other stations, but always below the threshold limits.

Table 4 Concentration of heavy and trace metals (mg/Kg)

mg/Kg	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Vanadium	Zinc	Aluminium	Barium	Iron	Mercury
Limit of Detection	**0.5**	**0.2**	**2**	**2**	**2**	**0.5**	**1**	**3**	**10**	**1**	**45**	**0.01**
SFS 5	13.7	<0.2	21.1	3.2	10.5	8.9	34.7	19.2	22000	274	12400	<0.01
SFS 6	9.6	<0.2	17.9	3.2	8.9	12.2	24.3	14.6	15100	230	7540	<0.01
SFS 7	10.6	<0.2	8.1	2.7	9.4	4.6	23.2	11.6	15400	224	5860	<0.01
SFS 8	11.9	<0.2	19.3	2.9	10.8	6.6	38.8	20.1	27500	359	16500	<0.01
SFS 9	7.1	<0.2	9	2.7	9.4	3.7	19.1	10.5	20200	285	6620	<0.01
SFS 10	4.9	<0.2	10.3	3.1	8.6	2.9	15.4	11.5	19500	295	6850	<0.01
NCP4	12.5	<0.2	15.2	4.2	10.3	6.6	34.4	21.4	25700	317	12400	<0.01
NCP5	10.8	<0.2	10.7	2.9	9	4.7	25.9	18.1	16900	224	7620	<0.01
Min	4.9	<0.2	8.1	2.7	8.6	2.9	15.4	10.5	15100	224	5860	<0.01
Max	13.7	<0.2	21.1	4.2	10.8	12.2	38.8	21.4	27500	359	16500	<0.01
Mean	10.14	<0.2	13.95	3.11	9.61	6.28	26.98	15.88	20287.50	276.00	9473.75	<0.01
Median	10.7	<0.2	12.95	3	9.4	5.65	25.1	16.35	19850	279.5	7580	<0.01
% RSD	28.63		36.30	15.50	8.50	48.75	30.48	27.39	22.60	17.61	40.24	
TEL	7.24	0.7	52.3	18.7	30.2	15.9	-	124	-	-	-	0.13
PEL	41.6	41.6	160	108	112	42.8	-	271	-	-	-	0.7
OSPAR ERL	-	1.2	-	-	47	-	-	-	-	-	-	0.15
NOAA ERL	8.2	1.2	81	34	46.7	20.9	-	150	-	-	-	-
BC	15	0.2	60	20	25	30	-	90	-	-	-	-
BAC	25	0.31	81	27	38	36	-	122	-	-	-	0.07

Colour coding is applied in sequence from greatest to smallest value. Therefore exceedance of the highest value also implies exceedance of lower thresholds (e.g. ERL>BAC>BC).
TEL = Threshold Effects Level: Maximum concentration at which no effects are observed (Source: CCME, 1999)
PEL = Probable Effects Level: Lower limit of the range of concentrations at which adverse effects are always observed (Source: CCME, 1999)
ERL = Effects Range Low: 10th percentile values in effects (Sources: OSPAR, 2014a; Buchman, 2008) [consistent with Spencer & MacLeod, 2002])
BC = Background Concentration (Source: OSPAR, 2014a)

BAC = Background Assessment Concentration (Source: OSPAR, 2014a; designed by OSPAR for testing whether concentrations are near background levels. Mean concentrations significantly below the BAC are said to be near background)

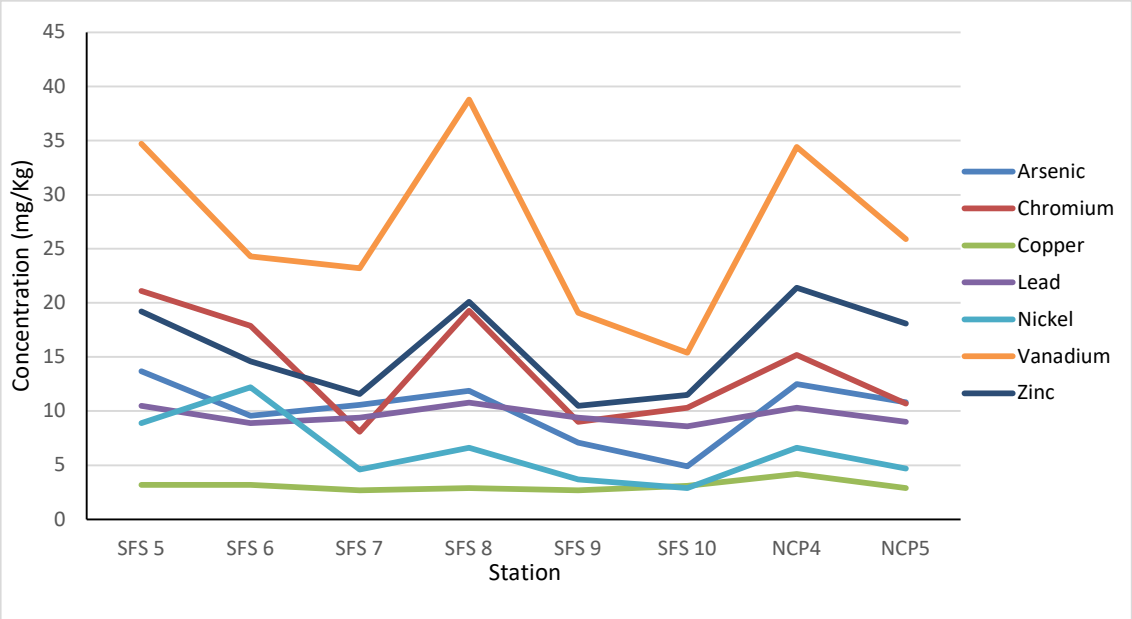

Figure 2 Heavy and trace metal concentration (mg/Kg): As, Cr, Cu, Pb, Ni, V, Z

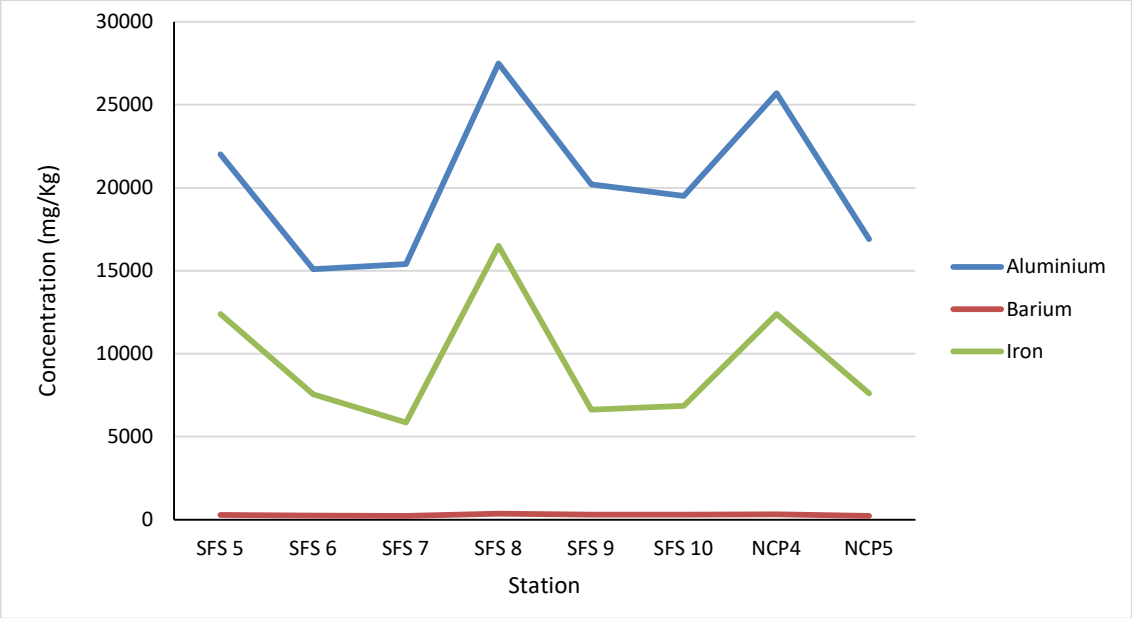

Figure 3 Heavy and trace metal concentration (mg/Kg): Al, Ba, Fe

Total Hydrocarbon Concentration (THC)

The total hydrocarbon concentrations (THC) are presented in Table 5.

THC concentrations ranged from 0.52 mg/kg at station SFS9 to 6.18 mg/kg at station NCP4, with a mean of 3.44 mg/kg and an intermediate variability of 55.90% RSD.

Table 5 Summary of hydrocarbon data

Station	THC (mg/kg)	Total n-alkanes (mg/Kg)	Carbon Preference Index	Pristane/Phytane Ratio	Proportion of Alkanes (%)	Total PAHs (mg/Kg)	NPD (mg/Kg)
SFS 5	4.07	0.0981	0.0025	2.37	2.41	<0.034	<0.014
SFS 6	4.60	0.1217	0.0020	2.03	2.65	<0.034	<0.014
SFS 7	3.40	0.0727	0.0014	1.60	2.14	<0.034	<0.014
SFS 8	1.10	0.0369	0.0014	1.85	3.35	<0.034	<0.014
SFS 9	0.52	<0.028	0.0040	1.59	n/a	<0.034	<0.014
SFS 10	2.75	0.0521	0.0011	9.01	1.89	0.055	<0.014
NCP4	6.18	0.0876	0.0020	6.18	1.42	<0.034	0.020
NCP5	4.92	0.0641	0.0019	6.46	1.30	<0.034	<0.014
Min	0.52	0.0369	0.0011	1.59	1.30	0.055	0.02
Max	6.18	0.1217	0.0040	9.01	3.35	0.055	0.02
Mean	3.44	0.0762	0.0020	3.89	2.17	0.055	0.02
Median	3.74	0.0727	0.0020	2.20	2.14	0.055	0.02
%RSD	55.90	37.76	44.59	74.41	33.08		

Total and Aliphatic n-Alkanes

Total n-alkane concentrations as well as the individual aliphatic concentrations are presented in Table 5.

Total n-alkane (nC10-37) concentrations ranged from 0.037 mg/kg at station SFS8 to 0.122 mg/kg at station SFS6 with a mean of 0.076 mg/kg.

The carbon preference index (CPI) is a useful tool to indicate the likely sources of concentrations of n-alkanes. The lower the CPI the greater the anthropogenic inputs and values greater than 4 tend to imply a greater biogenic n-alkanes (Jaffé et al., 1996). Petrochemical derived n-alkanes exhibit a wide distribution range, no predominance of odd over even n-alkanes and thus CPI values close to 1 (Aboul-Kassim & Simoneit, 1996). The nC10-37 carbon preference index ranged from 0.0011 at station SFS10 to 0.004 at station SFS9 with a mean of 0.002.

Pristane/phytane (Pr/Ph) ratios (Table 5) ranged from 1.59 at the station SFS9 to 9.01 at station SFS10.

PAHs

Concentrations of polycyclic aromatic hydrocarbons (PAH) individual aromatics are presented in Table 6. There are no values that exceed the OSPAR Effect Range Low (ERL) for any of the PAHs. There are no values that exceed the Cefas Action Level (cAL 1) for any of the PAHs.

Table 6 Concentrations of PAHs (ug/Kg) considered priority substances or priority hazardous substances

Station	Naphthalene (mg/Kg)	Anthracene (mg/Kg)	Benzo [b] fluoranthene (mg/Kg)	Benzo [k] fluoranthene (mg/Kg)	Benzo [a] pyrene (mg/Kg)	Indeno [123,cd] pyrene (mg/Kg)	Benzo [ghi] perylene (mg/Kg)
SFS 5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SFS 6	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0011
SFS 7	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SFS 8	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SFS 9	<0.0001	<0.0001	<0.0001	<0.0001	0.0031	<0.0001	<0.0001
SFS 10	<0.0001	<0.0001	0.0033	0.0022	0.0031	0.0029	0.0027
NCP4	0.0021	<0.0001	0.0012	<0.0001	<0.0001	0.0011	0.0011
NCP5	<0.0001	<0.0001	0.0011	<0.0001	<0.0001	0.0013	0.0011
Min	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Max	0.0021	<0.0001	0.0033	0.0022	0.0031	0.0029	0.0027
Mean	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Median	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
% RSD			66.55			55.84	53.33
OSPAR Effect Range Low (ERL)	160				430	240	85
Cefas Action Level (cAL 1)			100	100	100		100
BC	5	3			15	50	45
BAC	8	5			30	103	80

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6. APPENDICES

Appendix 1 Biological and physicochemical data matrices

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GREEN VOLT

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