Whitsand and Looe Bay MCZ and surround subtidal sediment data analysis and reporting (2017)

First published May 2021

Natural England Research Report NECR357

www.gov.uk/natural-england

Natural England Research Report NECR357

Whitsand and Looe Bay MCZ and surround subtidal sediment data analysis and reporting (2017)

Anita Franco, Krysia Mazik, Louise Roberts

Published May 2021

ISBN: 978-1-78354-749-4

Project details

This report should be cited as: A., Mazik K., Roberts L., 2017. Whitsand and Looe Bay MCZ and surround subtidal sediment data analysis and reporting. An IECS report to Natural England (Contract Ref. RP03061). Report No. YBB333-F-2017, April 2017.Natural England Project manager

Natural England Project Manager

Andrew Stranger

Contractor

Institute of Estuarine & Coastal Studies (IECS)

Author

Anita Franco, Krysia Mazik, Louise Roberts

Keywords

Further information

Acknowledgements

We are very grateful to Natural England, as well as ReMEDIES and LIFE funding, for their major contribution to essential survey costs this year. More than ever, we are indebted to Lisa at The Bylet Bed & Breakfast for putting us up and putting up with us. In this most unusual year, dominated by COVID-19 restrictions, we are very grateful to the many residents of the Isles of Scilly who helped us overcome numerous logistical issues and make the survey a success.

the
INSTITUTE
of
ESTUARINE
and
COASTAL
STUDIES

UNIVERSITY OF Hull
Institute of Estuarine and Coastal Studies

Whitsand and Looe Bay MCZ and surround subtidal sediment data analysis and reporting

Contract Ref. RP03061

Report to
Natural England

Institute of Estuarine and Coastal Studies
University of Hull

5th April 2017

Authors:
Anita Franco, Krysia Mazik,
Louise Roberts

Report: YBB333-F-2017

Institute of Estuarine & Coastal Studies (IECS)
The University of Hull
Cottingham Road
Hull
HU6 7RX
UK

Tel: +44 (0)1482 466771
Fax: +44 (0)1482 466772

E-mail: iecs@hull.ac.uk

Web site: http://www.hull.ac.uk/iecs

Project Personnel

This report was written and researched by Dr. Anita Franco (IECS Senior Fish Ecologist), Dr. Krysia Mazik (IECS Senior Benthic Ecologist) and Dr. Louise Roberts (IECS Assistant Ecologist), with contribution from Shona Thomson (IECS GIS & Coastal Geographer) who undertook the mapping requirements.

Suggested citation

Franco A., Mazik K., Roberts L., 2017. Whitsand and Looe Bay MCZ and surround subtidal sediment data analysis and reporting. An IECS report to Natural England (Contract Ref. RP03061). Report No. YBB333-F-2017, April 2017.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

EXECUTIVE SUMMARY

The Whitsand and Looe Bay Marine Conservation Zone, along the south Cornwall coast, was designated in 2013. The area has been monitored since 2001 by Cefas in relation to the Rame Head dredge disposal site, occurring to the SE of Whitsand Bay. An area of deep mud habitat has been observed within the MCZ boundary, to the N of the Rame Head South disposal site (PL031). This is atypical for the area, which consists mostly of coarse sediment and sand habitat. Following the MCZ designation, there has been uncertainty of the effect of the disposal upon the MCZ itself, in particular regarding the origin of the deep mud habitat. A subtidal baseline survey (sedimentological, contaminants and infauna) of the MCZ was undertaken in 2015 by the Environment Agency on behalf of Natural England. The results are interpreted here within the context of the condition and origin of the deep mud habitat, and historical data of the MCZ, Rame Head disposal site and surrounding subtidal areas (including also Plymouth Sound and Estuaries SAC).

Sediments are significantly muddier (35-43 % mud) in the deep mud habitat than in the rest of the MCZ where sedimentary habitats are dominated by subtidal sandy substrata (with > 90 % sand and < 6% mud), being mostly slightly gravelly sands located at relatively shallow depth (down to 25 m approximately). Whilst the mud habitat shows similarities with the Rame Head site in terms of depths and higher mud content, the gravel content is higher within the disposal site. Analysis of the finer sediment fractions revealed consistency over time (typically 31- 35 % fine sediment) and a high similarity with the muddy sediments of Plymouth Sound.

Contaminant levels within the deep mud habitat are consistent with previous years, and are mostly below regional background levels, confirming previous assessments. Concentrations of PAH and PCB compounds were above OSPAR BACs, also seen in previous years. A moderate likelihood of toxicity to bottom dwelling organisms is found when comparing contaminant concentrations to available standards for samples from both in the MCZ deep mud habitat and within the rest of the MCZ. Overall the deep mud habitat shows contaminant levels higher than in the MCZ, but lower than at the Rame Head disposal site.

Macrofaunal analysis of the deep mud habitat indicates a community consistent with that of circalittoral sandy muds in the deep mud habitat, which does not differ markedly with the disposal site in terms of species composition. Numbers of species, abundance and diversity within the deep mud habitat are not markedly different from those in Plymouth Sound and Tamar estuaries. Species found are those most associated with areas subject to frequent disturbance, which could be natural or anthropogenic.

Rame Head South is a dispersive disposal site in a hydrologically dynamic area, and therefore the dispersal of dredge material is expected, and has been reported along a predominant SE direction from the disposal site. There is an eddy on the eastern side of Whitsand Bay, likely to influence the transport of fine particles particularly given the slow tidal currents. However whilst this appears to suggest the transport route of fine particles, it cannot prove that the deep mud habitat is a product of dredge disposal at the Rame Head site, since natural sediment transport is also occurring.

The 2015 data and previous surveys were not designed specifically to address the origin of the deep mud habitat, creating uncertainty in the data, which is further compounded by a lack of historical data in the area prior to disposal onset. Given the evidence available, and the associated uncertainty, it can be concluded that a common origin for the fine sediments in the Rame Head disposal site and in the deeper area of the MCZ is likely. However, the evidence does not allow to establish the degree to which the mud habitat in the MCZ originates directly

from the disposal site or is the result of natural processes (e.g. transport from Plymouth Sound and Tamar estuaries area). Regardless of the origin of the mud habitat, results suggest the habitat has been present since the Cefas surveys of 2001, being relatively stable and well established in terms of sediment, contaminants and community, differing little from surrounding muddy sediment areas. Furthermore, the macrofaunal community in the deep mud habitat in the MCZ appears to be typical of the substratum and hydrodynamic conditions in the area and doesn’t show signs of stress.

1. INTRODUCTION

The Whitsand and Looe Bay Marine Conservation Zone (MCZ) was designated under the Marine and Coastal Access Act (2009) in December 2013, along with 26 other MCZs. It is located along the South Cornwall coast, between Hore Stone near Talland Bay to the West and a point between Queener Point and Long Cove on Rame Head to the East (Figure 1). It is situated on a wave-exposed coastline, extending from the mean high water mark out to a depth of about 25 m (Defra, 2015). Features of Conservation Interest for this MCZ include intertidal rock, a variety of intertidal soft sediment habitats and seagrasses (Defra, 2015).

The Whitsand and Looe Bay MCZ Summary Site Report (Defra, 2015) identified an area of deep mud habitat on the eastern side of Whitsand Bay measuring approximately 2.05 km^2. This habitat is atypical for the area, where subtidal coarse sediment and sand habitats dominate, and it is located directly to the north of the Rame Head South dredge disposal site (PL031). As such, questions have been raised about the source of this mud habitat and whether it is a natural or anthropogenic feature (for example, as a result of disposal activities at PL031).

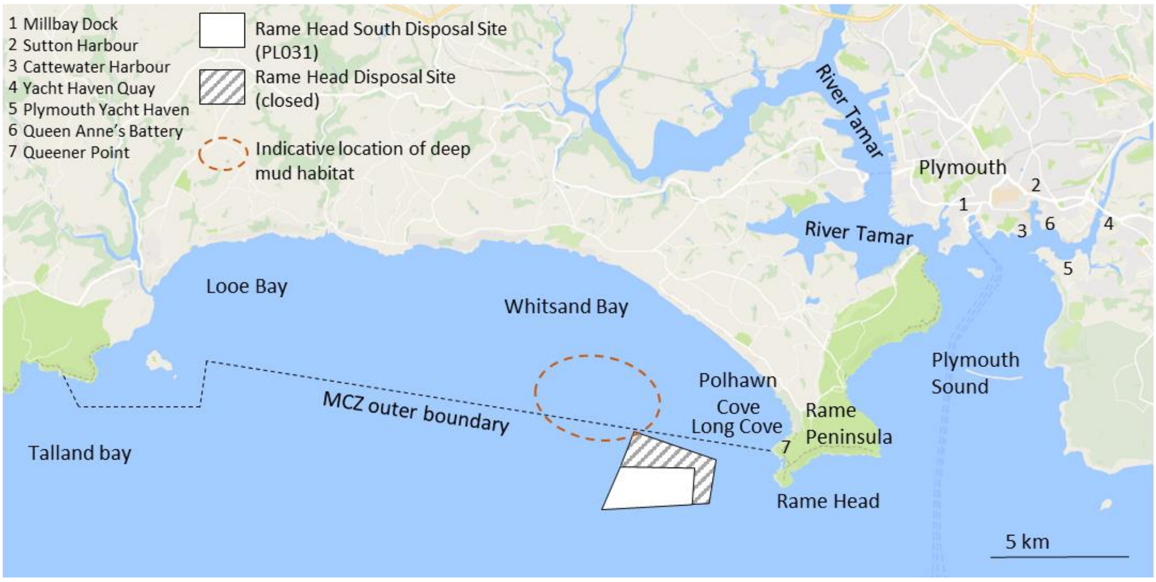


Figure 1 Whitsand and Looe Bay and surrounding areas (Tamar and Plymouth estuaries).

The disposal of dredged material at the Rame Head disposal site has occurred for over a century, with the southern part of the site (Rame Head South, PL031) being currently active. The main source of material is from maintenance and capital dredging from the ports, harbours, and navigation channels within the Tamar and Plym estuaries and Plymouth Sound (Elliott & Mazik, 2011). Dispersion modelling has been undertaken to determine the transport pathways of sediments following placement at the Rame Head disposal site (e.g. Siddorn et al., 2003; Okada et al., 2009). The sediments, associated contaminants and benthic fauna in the disposal site and surrounding area (including the MCZ) have also been monitored since 2001 by Cefas as part of the SLAB5 project to advise DEFRA on the status of dredge material disposal sites around the coast of England. These data have also been used to determine the fate of sediments deposited at Rame Head disposal site and to demonstrate a lack of impact on the local ecology and public amenities (e.g. Cefas, 2005, 2015; Elliott & Mazik, 2011). Results of these studies have shown that natural prevailing current patterns may favour the transport of fine sediments into the east side of Whitsand Bay (especially around Polhawn Cove). There is considerable dispersal around the disposal site, but a clear signal of the dredged material has only been detected to the NW and SE of the disposal site. However, there is still a degree of uncertainty surrounding the fate of the dredged material from the disposal site and its effect on the integrity of the designated features within the MCZ.

Following the establishment of the Whitsand and Looe Bay MCZ, a subtidal baseline survey of the Whitsand and Looe Bay MCZ has been undertaken in June-July 2015 by the Environment Agency (EA) on behalf of Natural England in order to gain evidence and obtain a baseline dataset (sedimentological, contaminants and infaunal data) that would inform future monitoring strategies and feature condition assessments (Green & Godsell, 2016)

1.1 Project aim and objectives

Following the collection of more sedimentological, contaminants and infaunal data from the Whitsand and Looe Bay MCZ and the surrounding subtidal area, Natural England commissioned the Institute of Estuarine and Coastal Studies (IECS, University of Hull) to conduct an investigation into the nature and origin of the mud in the MCZ, to determine whether or not it may be a natural feature or a result of disposal activities and to assess the ecological condition of the mud habitat. Objectives of the study are:

1. To interpret the 2015 EA data (infauna, particle size analysis (PSA), and contaminants) from within and in close proximity to the MCZ to assess as best possible the condition and origin of the deep mud habitat present within the MCZ.
2. To place any findings from (1) in context with any existing data for the mud habitat.

The approach applied in this study involved the collation, comparison and interpretation of different lines of evidence, including data and information obtained from surveys of the Whitsand and Looe Bay MCZ (from here on referred as to the MCZ), the Rame Head dredge disposal site and surrounding subtidal areas (including also the Plymouth Sound and Estuaries SAC), and available published and grey literature characterizing historical seabed conditions at the study site. For this purpose, statistical analysis of data was combined with the interpretation of results from survey reports (where source data could not be obtained) and available literature.

2. MATERIALS AND METHODS

In order to address the project objectives, the following steps were undertaken:

a. A detailed analysis of the 2015 data was undertaken to assess the current condition of sediment characteristics, contamination and macrofauna of the deep mud habitat present within the MCZ, with spatial comparison with the surrounding subtidal areas within and outside the MCZ (Objective 1);
b. Previous available survey data were collated and a spatial-temporal analysis was undertaken including 2015 survey data, with particular attention to temporal changes in the deep mud habitat within the MCZ and, when available, spatial comparison with the Rame Head South dredge disposal site and the Plymouth Sound and Estuaries SAC that were hypothesised as possible sources of the mud (Objectives 1 and 2);
c. The results of (1) and (2) were integrated and discussed in the light of previous assessments and of available literature characterising the ecological and environmental processes in the study area (Objective 2).

2.1 Data collated

Sediment particle size (PS) distribution, contaminants and macrofaunal data were available from the 2015 benthic grab survey undertaken by the EA at Whitsand and Looe Bay MCZ and in the surrounding subtidal areas (Green & Godsell, 2016). From here on this dataset will be identified as **2015 WLOB**.

In order to put the 2015 data into the context of other surveys, additional datasets were collated for comparison:

- 2015 Plymouth Sound TRAC benthic survey undertaken by Natural England and the EA (Project RP02821); this dataset will be identified from here on as **2015 PLYM**;
- 2013 Whitsand and Looe Bay rMCZ benthic survey undertaken by Cefas on behalf of the EA and Defra (Project MB0120; Defra, 2015; Arnold & Godsell, 2016); this dataset will be identified from here on as **2013 WLOB**;
- 2011 Plymouth Sound & Estuaries EA Benthic Grab survey and Plymouth Outer WFD EA Benthic Invertebrate Survey undertaken by Natural England and the EA; this dataset will be identified from here on as **2011 PLYM**;
- 2001 to 2009 and 2014 Rame Head disposal site monitoring undertaken by Cefas for the Marine Management Organisation and Defra (Dredged Material Disposal Site Monitoring Around the Coast of England (SLAB5) project); this dataset will be identified from here on as **2001-2009 and 2014 SLAB5**;

These included PS data (as measured in support of biological and/or contaminant analysis), contaminants and macrofaunal data.

In addition, monthly capital and maintenance disposal returns to Rame Head South disposal site (PL031) for the years 2001 to 2009 were obtained from the Marine Management Organisation. Disposal volumes were also available for more recent years (2010 – 2015), albeit on an annual basis.

All the data included in this study were collated and used with permission of the Marine Management Organisation and Natural England.

For the purpose of the analyses, the sample data were categorised *a priori* according to survey/year of collection and the spatial distribution of the sampling stations into the following zones:

- Location within the Whitsand and Looe Bay MCZ boundary; this was further distinguished into:
    - **MCZ-E_Mud**, the deep mud habitat area in the MCZ, as identified in the biotope map given in Defra (2015);
    - **MCZ-E,** the remaining eastern part of the MCZ area;
    - **MCZ-W**, the western part of the MCZ area;
- Location within nearby dredge disposal sites (DS); this was further distinguished into:
    - **DS(curr)**, Rame Head South disposal site currently operational (PL031);
    - **DS(past)**, Rame Head disposal site currently closed (PL030 and PL050);
    - **DS(offsh)**, disposal site located further offshore, in front of Plymouth area, currently closed (PL020);
- Marine area in front of the Whitsand and Looe Bay MCZ (Mar, excluding disposal sites); this was further distinguished into:
    - **Mar-W**, SW of the MCZ;
    - **Mar**, SE of the MCZ;
- Location within the Plymouth Sound and Estuaries SAC (SAC); this was further distinguished into:
    - **SAC_PlymS**, outer part of the SAC, within Plymouth Sound or at the SAC marine boundary;
    - **SAC,** middle part of the SAC;
    - **SAC_Tam**, upper part of the SAC, within the Tamar Estuary MCZ.

As shown in Appendix 1, the data availability varied with survey component, year and zone. In particular, spatial coverage of the different areas changed between years, depending on the survey aims, and sampling methods did not always allow for the assessment of all components (e.g. Hamon grab samples collected in 2013 were not suitable for contaminant analysis, as they did not allow to collect undisturbed surficial sediment samples). In addition, there were changes in the grab sampling methodology and in the sample analysis methods between years (as specified in the sections below on specific survey components), and this, on occasions, limited the ability to compare the data. As such, an integrative analysis of the datasets altogether was not possible, as resulting patterns might be due to variable data coverage of different areas or methodological differences over the years rather than reflecting actual spatial or temporal patterns.

Subsets of data for given years, zones and based on common methods were selected to answer specific questions on mud condition and possible origin of it. The data selection and the type of analysis also depended on the data availability for the component being assessed and the specific hypotheses to be tested. Multiple analyses allowed multiple lines of evidence to be gathered in support of the assessment of the available data against the specified objectives. Further details on these analyses are given in the individual sections below for the specific components.

2.2 Data analysis

2.2.1 SEDIMENT PARTICLE SIZE (PS)

2015 WLOB

The PS data available from the WLOB survey in 2015 included 42 stations, distributed as follows:

- 5 stations (WLOB61 to WLOB65) in MCZ-E_Mud, with water depth ranging 28 to 32 m;
- 21 stations (WLOB1 to WLOB18 and WLOB71 to WLOB73) in MCZ-E, with water depth ranging 7 to 25 m;
- 1 station (WLOB32) in MCZ-W, with water depth of 8 m;
- 12 stations in Mar, with 5 stations (WLOB67, WLOB69, WLOB70, WLOB83 and WLOB84) located between the MCZ and the Rame Head disposal site, at a water depth between 26 and 33 m, and 7 stations (WLOB34, WLOB35, WLOB74, WLOB75, WLOB77, WLOB78 and WLOB80) located to the E-SE of the disposal site, at a water depth between 13 and 21 m (except for WLOB77, where water depth was 32 m);
- 3 stations (WLOB41, WLOB43 and WLOB45) in Mar-W, with water depth between 27 and 32 m.

There were no samples collected from the Rame Head disposal site in 2015. See Green and Godsell (2016) for details on sampling methods and sample analysis.

Raw data (PS distribution at 0.5 phi intervals) were analysed using Gradistat (Blott & Pye, 2001). Particle size was analysed both as metric (μm) and phi units, according to the Wentworth Scale (with metric particle size increasing with decreasing phi value). The Wentworth scale combines numerical intervals with rational definitions of particle size (e.g. fine, sand, coarse silt etc.), as shown in Table 1. The conversion between grain size in mm and phi is achieved as follows (Bale & Kenny, 2005):

$$\varphi = -\frac{\log_{10} mm}{\log_{10} 2}.$$

Particle size distribution summary statistics (based on Folk and Ward graphical measures) were obtained, including:

- Textural group (sediment type);
- Mean and median grain size (both in μm and Phi units), as measures of average and central tendency;
- Sorting coefficient, i.e. the standard deviation or variability about the mean of the sample;
- Skewness, assessing the degree of departure from a normal distribution in terms of asymmetry;
- Kurtosis, assessing the degree of departure from a normal distribution in terms of peakedness (this is indicative of the concentration of the particles relative to the mean);
- Bulk sediment components (% gravel, % sand, % mud);
- Sediment size classes (at 1 phi interval, from % very coarse gravel to % clay);

Broadscale habitats (Eunis Level 3) were allocated to sample stations based on these results.

Table 1. Sediment grain size scale adopted in the Gradistat program, with conversion key between measurement units (phi and mm/µm) and descriptive terminology (Blott & Pye, 2001).

Grain size		Descriptive terminology			
phi	mm/µm	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
			Very large boulders		
−11	2048 mm				
			Large boulders	Very large	
−10	1024				
			Medium boulders	Large	
−9	512	Cobbles			
			Small boulders	Medium	Boulders
−8	256				
			Large cobbles	Small	
−7	128				
			Small cobbles	Very small	
−6	64				
			Very coarse pebbles	Very coarse	
−5	32				
			Coarse pebbles	Coarse	
−4	16	Pebbles			
			Medium pebbles	Medium	Gravel
−3	8				
			Fine pebbles	Fine	
−2	4				
		Granules	Very fine pebbles	Very fine	
−1	2				
		Very coarse sand	Very coarse sand	Very coarse	
0	1				
		Coarse sand	Coarse sand	Coarse	
1	500 µm				
		Medium sand	Medium sand	Medium	Sand
2	250				
		Fine sand	Fine sand	Fine	
3	125				
		Very fine sand	Very fine sand	Very fine	
4	63				
			Very coarse silt	Very coarse	
5	31				
			Coarse silt	Coarse	
6	16	Silt			
			Medium silt	Medium	Silt
7	8				
			Fine silt	Fine	
8	4				
			Very fine silt	Very fine	
9	2	Clay			
			Clay	Clay	

Similarity in sediment characteristics and spatial gradients were investigated by means of multivariate ordination analysis using principal component analysis (PCA). The ANOSIM test was applied to identify significant differences in sediment characteristics between zones. Multivariate analyses were carried out in PRIMER v. 6.1.10 (Plymouth Routines in Marine Ecological Research. Clarke & Warwick, 2001).

A first round of analysis was undertaken on the summary data for the whole particle size distribution in order to characterise the nature and distribution of the sediments sampled in 2015. A Spearman's rank correlation (r) analysis between sediment variables was undertaken and highly co-linear variables (r (as absolute value) >0.8) were removed. The resulting subset of variables is shown in Table 2, along with the correlated variables which were excluded from subsequent analysis. The variables were normalised and Euclidean distance was calculated for the analysis.

Table 2. Sediment summary statistic variables as selected after correlation analysis and correlated variables (with Spearman's correlation coefficient r (absolute value) >0.8) not included in further analyses. Particle size distribution descriptors (mean, median, sorting, skewness and kurtosis) are based on grain size in metric units (μm).

Selected variables	Correlated variables (abs(r)>0.8)
MEAN	MEDIAN (+) ; % V FINE SAND (+)
SORTING	% SAND (-)
SKEWNESS	
KURTOSIS	
% GRAVEL	% MEDIUM GRAVEL to % V COARSE SAND (all +)
% MUD	% SAND (-); % V COARSE SILT to % CLAY (all +)
% V COARSE GRAVEL	
% COARSE GRAVEL	
% COARSE SAND	
% MEDIUM SAND	
% FINE SAND	

A second round of analysis was undertaken on 2015 data by considering the finer sediment fractions (<63 μm) only, applying multivariate analysis to the associated raw data (i.e. sediment muddy fractions at 0.5 phi intervals). This approach aimed at investigating in detail the sediment fraction that is mostly related with possible sources from dredged material, considering that more than half of the dredged material is clay and silt (hence <63 μm), and therefore gives a better chance to identify similarities between samples that may be related to the spatial transport of dredged material. This approach is consistent with the one adopted by Okada et al. (2009), who found that the modal size of 40 μm appears to be a robust signal for dredged material and therefore applied their analysis to the sediment fraction <63 μm only.

Spatial - temporal analysis

Different sampling methods were applied during the benthic surveys (e.g. type of grab) and for the processing of the sediment PS samples. In addition there were spatial inconsistencies in the survey design (e.g. zones covered in some years and not in others) due to the different aims of the sampling programmes. These factors (as summarised in Appendix 2) limited the data comparability and the scope of the analyses that could be undertaken.

A preliminary analysis was undertaken by considering bulk sediment data only (gravel, sand and mud %) for all available datasets. Only the PS samples collected in support of biological samples (with Hamon or Day grab) were used in this analysis, taking into consideration comparability of the type of sediment sample with those collected in the 2015 WLOB survey. In addition, the analysis was also undertaken by selecting only samples classed as mud or muddy according to the textural group allocated on the basis of the particle size analysis in order to provide background PS information to the analysis of macrofaunal data. It should be noted that the sampling effort and spatial coverage of different areas changed between years (Table 3), and therefore these results can be considered as only indicative of broad differences between areas. Furthermore, there were differences in the sediment analysis methods between these 2001-2009 dataset and the 2013-2015 ones (see Appendix 2), and these prevented a detailed comparison of sediment particle size distributions between these datasets. Although these methodological differences may have also affected the quantification of the bulk sediment components, the error associated with these estimates was considered to be smaller (albeit not negligible) compared to a more detailed analysis. This was taken into consideration when interpreting the magnitude of possible differences in bulk sediment composition between the years.

Table 3. Number of sample PS data (all samples in support of biology) available by survey and zone.

Survey	Whitsand and Looe Bay MCZ			Disposal site			Marine area near MCZ		Plymouth Sound & Estuaries SAC		
	MCZ-E	MCZ-E_Mud	MCZ-W	DS(curr)	DS(past)	DS(offsh)	Mar	Mar-W	SAC_PlymS	SAC	SAC_Tam
2001 SLAB5	2	1		5	2		4				
2002 SLAB5	1			2	1		3				
2003 SLAB5	1			2			3				
2004 SLAB5	1			1	1		3				
2005 SLAB5	1			2			4				
2006 SLAB5	3			1	2		5				
2007 SLAB5	2	1		3		1	4				
2008 SLAB5	2	1		4		1	4				
2009 SLAB5	2	1				1	4				
2011 PLYM									29	17	5
2013 WLOB	24	10	2								
2015 PLYM									17	16	7
2015 WLOB	21	5	1				12	3			

The detailed analysis of PS distribution could only be undertaken on the 2015 WLOB data in combination with the 2015 PLYM and 2013 WLOB data[1], as these dataset were comparable in terms of sampling and sediment analysis methods (Appendix 2). The variable spatial coverage of these datasets however limited the scope of the comparison. A spatial comparison was undertaken between 2015 WLOB and 2015 PLYM to identify similarities in sediment characteristics between the deep mud habitat in the MCZ and areas located within Plymouth Sound and Estuaries SAC, where the dredged material dumped at Rame Head disposal site originates. A temporal comparison was undertaken between 2013 WLOB and 2015 WLOB data to identify interannual differences in the sediment characteristics, although the comparison could only be limited to areas within the MCZ, as no data from adjacent marine areas or elsewhere were available in 2013. Unfortunately neither of these datasets included samples collected from the Rame Head disposal site and therefore a direct comparison of sediment grain size distribution characteristics with sediment from that area was not possible at this stage.

The detailed analyses mentioned above were undertaken by considering the finer sediment fractions (<63 μm) only, according to the approach and methods as applied for 2015 WLOB data only. In addition, in order to better focus the analysis on the muddy sediments that might be affected by dispersal of material between different zones, the analysis was carried out only on those samples that were classed as mud or muddy according to the textural group allocated on the basis of the particle size analysis. This selection included samples classed as Gravelly Mud, Slightly Gravelly Sandy Mud, Sandy Mud, Gravelly Muddy Sand, Slightly Gravelly Muddy Sand, Muddy Sand, Muddy Sandy Gravel, and Muddy Gravel.

---

[1] Data from 2011 PLYM were also comparable with 2015 WLOB, but they were not considered suitable for the purpose of this analysis due the differences in both spatial coverage and temporal validity of these data compared to 2015 WLOB.

Table 4. Disposal returns (wet tonnes) for Rame Head South in relevant survey periods as selected for the analysis.

Survey	Survey month(s)	Returns on survey month		Returns 6 months prior (cumulative)		Annual returns (cumultive for survey year)		
		Capital dredging	Maintenance dredging	Capital dredging	Maintenance dredging	Capital dredging	Maintenance dredging	Total
2001 SLAB5	June	0	32162	616845	357326	508409	586662	1095071
2002 SLAB5	June	0	0	0	0		11984	11984
2003 SLAB5	June	0	9791	0	79636	9	94271	94280
2004 SLAB5	June	7440	0	55369	109160	93800	147904	241704
2005 SLAB5	June	0	0	0	134662	0	140321	140321
2006 SLAB5	June	0	0	0	0	0	0	0
2007 SLAB5	June	0	88158	0	10725	0	98883	98883
2008 SLAB5	June	0	24538	0	0	0	24538	24538
2009 SLAB5	July	0	0	0	34598	0	38598	38598
2013 WLOB	Sep-Dec	na	na	na	na	0	60398	60398
2014 SLAB5	Jun-Jul	na	na	na	na	na	na	73198
2015 WLOB	Jun-Jul	na	na	na	na	na	na	1814

An additional line of evidence was explored by analysing the temporal correlation between disposal volumes at the Rame Head South disposal site (PL031) and the mud content at the deep mud habitat within the MCZ and at the active disposal site. The analysis was based on the PS sample data as collected in support of the biological analysis and available for the two areas over the years (Table 3), and the disposal returns (from capital dredging, maintenance dredging, and their sum) on the month of the survey (available for 2001-2009 only), as cumulative volume for the 6 months prior (available for 2001-2009 only) or as annual total volumes (available also for 2013, 2014 and 2015) (Table 4). A Spearman's rank correlation analysis was applied to the data.

Considering that the superficial layer of the seabed sediments may be more affected by the sediment redistribution between the disposal site and the mud habitat, particle size data collected in support of contaminant analysis were also subjected to the temporal correlation analysis with disposal returns.

2.2.2 CONTAMINANTS

2015 data

Contaminant concentrations from surficial sediments collected in 2015 were given for heavy metals (Al, As, Cd, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Zn), organotins (TBT; anti-fouling paint), PAHs (polyaromatic hydrocarbons, 10 compounds; products of fuel burning, oil, coal and tar refining), PCBs (polychlorinated biphenyls, 7 compounds; coolants and hydraulic fluids), chlorocarbons (pesticides, HCB and HCBD) and PBDEs (polybrominated diphenyl ethers, 6 compounds; flame retardants) (Green & Godsell, 2016).

Data were available from 22 stations from the 2015 WLOB and 2015 PLYM surveys, as distributed within the Whitsand and Looe Bay MCZ (3 in MCZ-E_Mud, 6 in MCZ-E and 1 in MCZ-W), in the adjacent marine area (2 in Mar), and within the Plymouth Sound and Estuaries SAC (5 in SAC_PlymS, 4 in SAC, 1 in SAC_Tam).

Table 5. Available standards used for the assessment of sediment contamination status. (* OSPAR background assessment concentrations were also available for these elements, but they were not used in this assessment; see text). Note that comparison with OSPAR BACs requires normalisation of PAHs and PCBs values to 2.5 % organic carbon.

Contaminant group and compound			Unit (dw)	RBL	BAC	ISQG	PEL	ERL	ERM
Trace metals	Arsenic	As	mg/kg	34	(*)	7.24	41.6		
	Cadmium	Cd	mg/kg	0.19	(*)	0.7	4.2		
	Chromium	Cr	mg/kg	105	(*)	52.3	160		
	Copper	Cu	mg/kg	72	(*)	18.7	108		
	Mercury	Hg	mg/kg	0.77	(*)	0.13	0.7		
	Nickel	Ni	mg/kg	50	(*)				
	Lead	Pb	mg/kg	108	(*)	30.2	112		
	Zinc	Zn	mg/kg	153	(*)	124	271		
PAHs	Naphthalene	N	µg/kg		8	34.6	391	552	3160
	Phenanthrene	P	µg/kg		32	86.7	554	552	3160
	Fluoranthene	Fl	µg/kg		39	113	1494	1700	9600
	Pyrene	Py	µg/kg		24	153	1398	1700	9600
	Benzo(a)anthracene	BaA	µg/kg		16	74.8	693	1700	9600
	Chrysene + Triphenylene	Chrysene	µg/kg		20	108	846	1700	9600
	Benzo(a)pyrene	BaP	µg/kg		30	88.8	763	1700	9600
PCBs	PCB - 028	CB#28	µg/kg		0.22				
	PCB - 052	CB#52	µg/kg		0.12				
	PCB - 101	CB#101	µg/kg		0.14				
	PCB - 118	CB#118	µg/kg		0.17				
	PCB - 138	CB#138	µg/kg		0.15				
	PCB - 153	CB#153	µg/kg		0.19				
	PCB - 180	CB#180	µg/kg		0.10				

Sediment contamination levels were compared with existing standards for condition assessment, including background values as available as Cefas regional (Western Channel) baseline levels (RBLs; Cefas, 2011) for trace metals and OSPAR Background Assessment Concentrations (BACs; OSPAR, 2008) for PCBs (Table 5). OSPAR BACs were also available for trace metals, but regional concentrations were deemed more appropriate for this assessment as they take into account natural regional variability around the coast of England and Wales, whereas OSPAR BACs integrate values for the whole North Atlantic (Cefas, 2011; Bolam et al., 2015).

Where available, sediment guidelines for the assessment of potential toxicity effects on marine biota were also considered. These included the International Council for the Exploration of the Sea and available for PAH and PCB compounds, Interim Sediment Quality Guidelines (ISQGs) as developed by the Canadian Council of Ministers of the Environment (CCME, 2001) and available for trace metals and PAHs, and Effects Range Low/Effects Range Median (ERL/ERM) assessing PAHs sediment toxicity on benthic fauna (Long et al., 1998). The Canadian ISQG represent the concentration below which adverse effects are expected to occur rarely, with probable effects levels (PELs) being also used to represent the concentration above which adverse biological effects are expected to occur frequently (CCME, 2001). In particular, concentrations above PEL are associated with high likelihood of toxic effect on bottom dwelling organisms (e.g., decreased abundance, diversity and growth), whereas concentrations between ISQG and PEL indicate moderate likelihood of these effects. As for the ERL/ERM standards, these are based on the 10^{th} and 50^{th} percentiles of the observed effects based on a large dataset and can be used as informal benchmarks to aid in the interpretation of sediment chemistry (Long et al., 1998). The sediment standards as specified in the guidelines mentioned above and used in this assessment are summarised in Table 5.

Existing spatial gradients in the contaminant distribution was investigated through a multivariate ordination analysis (PCA) and differences between areas were tested using ANOSIM. The analysis was undertaken on trace metals, and PAHs, PCBs and PBDEs totals (as sum of the measured compounds). Values below detection limit (reported as <MRV in the datasets) were standardised as 0.5·MRV for the purpose of the analysis. Particular attention was given to concentrations of As, Cu, Zn and Pb, as these have been reported as first order indicators for the presence of dredged material in the study area (Okada et al., 2009).

A Spearman's rank correlation analysis wad also undertaken between contaminants data collected in 2015 from the Whitsand and Looe Bay area (12 stations within and outside the MCZ) and the distance from the Rame Head South disposal site in order to test a distance-decay hypothesis. Particular attention was paid to those stations located along the NW-SE direction relative to the disposal site. This is the prevailing direction of tidal currents in the area (Cefas, 2005, 2007, 2015) and therefore correlations with distance along this gradient helps to test the hypothesis of sediment transport from the disposal site. For reference, the contamination levels observed in 2015 were put into context of those measured at the disposal site, although it is noted that samples were not collected from this latter area and the available data for the disposal site refer to previous years (2001-2008).

Spatial - temporal analysis

Contamination levels in the deep mud habitat area within the MCZ as sampled in 2015 were compared with previous data from the same area, as available from the 2001 – 2009 SLAB5 surveys. When available, data from samples collected at the active disposal site and from the Plymouth Sound and Estuaries SAC areas were also considered to provide reference contamination associated with the dredged material at the disposal site and at origin, respectively. Considering the variability in sediment types within areas as associated with mud content (see for example results for sediment within SAC_PlymS), the analysis was undertaken only by selecting the samples that were classed as mud or muddy according to the textural group allocated on the basis of the particle size analysis.

Data from previous surveys were harmonised to allow the comparison with 2015 data by selecting comparable subsets of contaminants as measured in 2015. In addition, as MRVs for the same contaminant changed between years (e.g. MRV was 0.1 µg/kg for most PAH compounds measured between 2001 and 2009, and between 1 and 5 µg/kg for the same compounds in 2015), values below the minimum detection limit in the combined dataset were standardised to the higher MRV available and treated as described above for the 2015 data. PCA and ANOSIM were applied to the data as previously described, with a focus on the variability between years. The temporal correlation between disposal volumes at the Rame Head South disposal site and the contaminant concentrations at the deep mud habitat within the MCZ and at the active disposal site was also explored, as described for the sediment analysis.

2.2.3 MACROFAUNA

Due to habitat variability (estuarine and coastal sediment) within the survey area as a whole, sample treatment in terms of sieving was variable and samples were therefore not directly comparable. The data set was therefore split into samples passed through a 1 mm sieve (coastal sediments) and those passed through a 0.5 mm sieve (estuarine sediments) and the two sub-sets analysed separately. A number of samples passed through a 1 mm sieve were also passed through a 0.5 mm sieve. In this case, the two fractions were summed to give a total abundance value relating to the 0.5 mm sieve fraction.

In addition to the abundance of individual species in the sample (as number of individuals per 0.1 m^2 grab sample), summary univariate statistics were derived from the sample data to characterise the diversity of the benthic invertebrate community. These were calculated using PRIMER v. 6.1.10 (Clarke & Warwick, 2001) and included:

1. Total number of species, S;
2. Total benthic abundance, N;
3. Shannon-Wiener diversity, H', calculated as $H' = -\sum p_i \log_2 p_i$, with p_i being the proportion of individuals of the i^{th} species in the sample (n_i/N) and the sum being undertaken for all the *S* species present in the sample. This index incorporates both species richness and evenness (a measure of the distribution of the individuals between the species). Higher values indicate higher diversity.
4. Pielou's Evenness index, J', calculated as $J' = H' / \log_2 S$, with *H'* and *S* as defined above. This index gives a measure of the relative abundance of each species with values ranging between 0 and 1. Low values (close to 0) indicate that a community is dominated by one or few species and indicate low diversity. Communities where there is an even spread of the individuals between the species (J' values approaching 1) are considered to be diverse.

The main questions addressed by the analysis were the following:

a. Is the identified mud biotope different in terms of community structure to the dredge disposal site and to the surrounding habitats also classed as mud or mixed muddy sediment?
b. Can it be considered impoverished?
c. Does the muddy habitat contain species tolerant of frequent disturbance / smothering?
d. Does the community structure of the muddy habitat differ to that typical for the biotope?

2015 data

Spatial patterns in the 2015 data, collected from Whitsand Bay (WLOB) and Plymouth Sound (PLYM), were examined in relation to sediment type in order to highlight community types characterising sandy, mixed and muddy sediments and to answer the question: *'does the community structure of the muddy habitat differ to that typical for the biotope?'*

The analysis was based on the 1 mm sieve fraction data and included data collected in 2013 from Whitsand Bay, as an indication of recent temporal variability. Community types between the two areas (WLOB and PLYM) were compared (visually), using Multi-dimensional scaling (nMDS) to assess the similarity of the community types in the different substrata and, more specifically, to assess the similarity of the assemblage in the deep mud habitat within the MCZ with that in Plymouth Sound. It is of note that a Day grab was used in Plymouth Sound and a

Hamon grab was used in Whitsand Bay. Also, sediment descriptions were provided for some samples but not others. Therefore, community types were identified according to sediment type and samples without sediment descriptions were classified according to the predominant sediment type of the samples with which they were grouped. SIMPER analysis was used to identify the characterising species.

Spatial - temporal analysis

This analysis aimed to address the questions:

a. *Is the identified mud biotope different in terms of community structure to the dredge disposal site and to the surrounding habitats also classed as mud or mixed muddy sediment?*
b. *Can it be considered impoverished?*
c. *Does the muddy habitat contain species tolerant of frequent disturbance / smothering?*

The analysis was undertaken on the 1 mm benthic dataset, as filtered to select only samples that were classed as mud or muddy according to the textural group allocated on the basis of the particle size analysis. Available data for all years were included in a single analysis, and possible patterns as associated to changes in sampling methods (0.1 m^2 Day grab vs. 0.1 m^2 Hamon grab), sample locations and coverage of spatial areas in different years were taken into account when interpreting the results.

Comparison of univariate statistics (S, N, H’, J’) and community structure was carried out between years and areas using one-way Analysis of variance (ANOVA), also taking into account sediment characteristics. Standard community analysis techniques (MDS, SIMPER and ANOSIM) were applied in PRIMER v. 6.1.10 (Clarke & Warwick, 2001).

3. RESULTS

3.1 Sediment particle size

3.1.1 2015 WLOB

Most of the sediment samples analysed in 2015 (33 out of 42 samples) showed unimodal particle size distribution, with the modal size ranging between 108 µm and 2400 µm (i.e. between very fine sand and granules). These included all the samples collected within the MCZ (except for three stations on the deep mud habitat area), all the samples collected in the marine area SW of the MCZ and half of the samples taken from the marine area SE of the MCZ. These samples were mostly identified as slightly gravelly sand (with also a few samples identified as sand, gravelly sand and muddy sandy gravel) and were generally poorly to moderately sorted, with a mostly symmetrical distribution of grain sizes and mostly mesokurtic.

The only samples that showed a multi-modal distribution came from stations located on the deep mud habitat area within the MCZ (WLOB63-65), in the marine area southwards (WLOB67, WLOB69 and WLOB84), and in the marine area east of the disposal site (WLOB35, WLOB77 and WLOB78). The samples belonging to the first two groups showed an additional mode located within the muddy fraction of the sediment particle size distribution, at either 19 µm (WLOB69) or 9 µm (remaining stations), whereas the additional modes for the samples from the last group were in the size range of very coarse sand to granules (between 1700 and 26950 µm).

The sample particle size distribution was analysed in Gradistat and the summary statistics extracted (Appendix 3), although it should be noted that the information given by these estimates is likely to be less accurate for multi-modal distributions given the normality assumption when calculating summary distribution statistics as mean, sorting, skewness and kurtosis.

The ordination analysis (PCA) highlighted the main differentiation between the sediment samples collected from the deep mud habitat in the MCZ (MCZ-E_Mud), the remaining eastern part of the MCZ (MCZ-E) and the marine area SW of the MCZ (Marine-W) (Figure 2).

The samples collected from the deep mud habitat in the MCZ (MCZ-E_Mud) were mostly slightly gravelly muddy sands characterised by a higher mud content (mostly ranging 35 to 43 %) and higher kurtosis (mostly leptokurtic grain size distributions) compared to the other two areas, and with no or almost no gravel content (<1 %) (Table 6, Appendix 3). The mean grain size in these samples ranged between 51 and 119 µm (i.e. coarse silt to very fine sand). It is of note that, although most of samples from this zone were classed as subtidal mud, one sample (WLOB062) showed a lower mud content (15%) hence being classed as subtidal sand (Figure 2A). The only PSA sample available from the western part of the MCZ showed a marked similarity with this latter sample as shown by the closeness of these two sample points in the PCA plot (Figure 2) and the sediment summary characteristics in Appendix 3.

The samples collected in the shallower areas in the remaining eastern part of the MCZ were characterised mostly by slightly gravelly sandy sediments, with a marked dominance of sand fractions (sand ≥94 %) and the predominant modal size ranging within fine-medium sand classes (215 to 305 µm), whereas the mud content was 1 % on average.

The samples collected from the marine area SW of the MCZ were more similar to those in MCZ-E_Mud than in MCZ-E (as suggested by the closeness of the sample points in Figure 2), mostly due to a higher mud content (5 % on average) than in sediments from MCZ-E. These marine sample stations were also had water depth (27 to 32 m) more similar to the deep mud habitat within the MCZ (28 to 32 m) compared to the shallower (7 to 25 m) stations in the remaining eastern part of the MCZ. However, the sediment samples from Marine-W were coarser (muddy sandy gravel to gravelly sand) than those from the deep mud habitat, as highlighted by the larger mean grain size (1870 µm on average) and higher gravel content (15 to 58 %) than in MCZ-E_Mud.

The samples form the marine area SE of the MCZ (Marine) showed a wide variability in their sediment characteristics. In particular three samples showed the highest similarity with those from the deep mud habitat in the MCZ (i.e. sample points closest to those from MCZ-E_Mud in Figure 2), sharing a higher mud content (29 to 42 %) and the absence of gravel as in the sediments found in MCZ-E_Mud. These were samples collected from the stations located just to the south of this zone (WLOB67, WLOB69 and WLOB84, Figure 2A), at a similar depth (26 to 33 m) as in the deep mud habitat within the MCZ and where the subtidal mud habitat extended outside the MCZ area (Figure 2B). Three other samples (the points on the top right part of the PCA plots in Figure 2) had markedly coarser sediments compared to all the other samples, showing the highest gravel content (≥65 %) and relatively high variability in the grain size distribution (i.e. poor sorting), with multiple modes at sizes between 1700 µm (very coarse sand) and 26950 µm (pebble). These were stations located E-SE of the Rame Head dredge disposal site (WLOB35, WLOB77 and WLOB78; Figure 2A), on subtidal coarse or mixed sediment habitat (Figure 2B). The remaining stations from the marine zone SE of the MCZ showed a higher similarity with those found within the eastern part of the MCZ, both in terms of water depth range (13 to 21 m) and sediment characteristics, being mostly slightly gravelly sands with a sand component of ≥88 % (closer to 100% in most cases) and no or almost no mud (max 6 %) (Figure 2, Appendix 3).

The ANOSIM test was applied to the selected set of variables and a significant difference was detected overall between zones (Global R statistics = 0.602, P = 0.01%, 9999 permutations). Pairwise comparisons highlighted a main differentiation between the samples collected on the deep mud habitat within the MCZ (MCZ-E_Mud) and those taken either within the remaining eastern part of the MCZ area (MCZ-E) or in the marine area SW of the MCZ (Marine-W), as indicated by the associated pairwise R statistics having values close to 1 (0.99 and 0.98, respectively). A SIMPER analysis applied to the sediment data highlighted that the differentiation between the deep mud habitat within the MCZ and the rest of the eastern MCZ was mostly due to the higher mud content and kurtosis in sediments from the deep mud habitat and the higher skewness, fine sand content and medium sand content in the sediments from MCZ-E (Table 6). A higher mud content in the sediments also differentiated the deep mud habitat within the MCZ from the marine area SW of the MCZ, along with higher fine sand content and lower gravel content, mean grain size and kurtosis (Table 6). There was no differentiation between MCZ-E_Mud and the adjacent marine area (Marine) most likely because of the heterogeneity in sediment characteristics between the stations distributed in this latter zone, as described above.

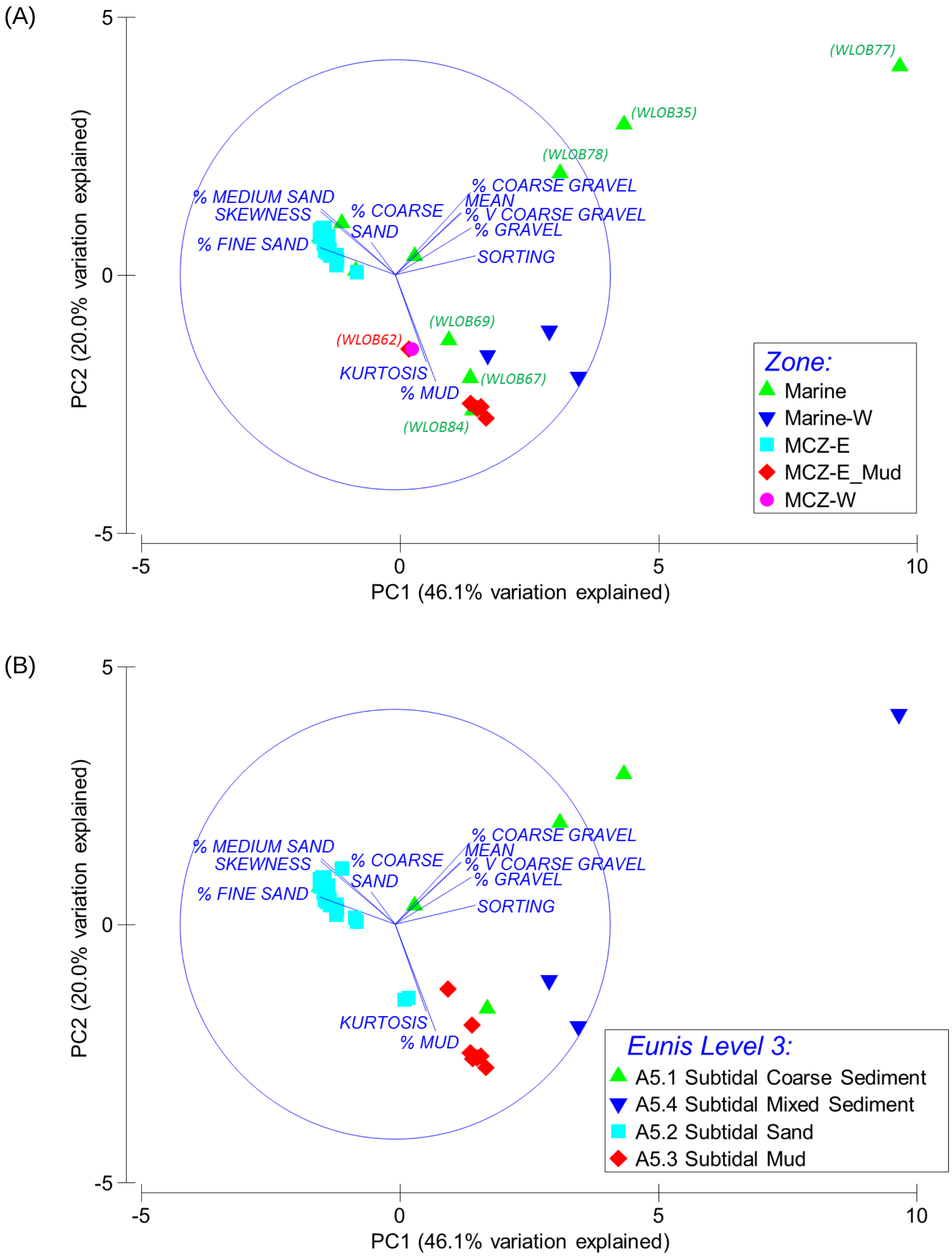


Figure 2. Ordination (principal component analysis, PCA) plot on selected sediment summary statistics for the 2015 Whitsand and Looe Bay rMCZ benthic sample data (RP02821). Symbols identify PSA samples as categorised by (A) sampling location within geographical zones as described in the text, and (B) Eunis Level 3 broadscale habitat as identified from sediment data. The names of the samples referenced in the text are given in parentheses in (A).

Table 6. Mean and % coefficient of variation (in parenthesis) of analysed sediment summary variables in the different zones.

Sediment variable	MCZ-E_Mud	MCZ-E	MCZ-W	Marine	Marine-W
MEAN (µm)	69.6 (40.5%)	240.8 (16%)	118 (-)	1193.2 (144%)	1870.6 (30%)
SORTING (µm)	3.5 (20.1%)	1.7 (7.7%)	2.5 (-)	3.9 (98.5%)	2.5 (18.1%)
SKEWNESS	-0.3 (46.8%)	0.04 (183.1%)	-0.1 (-)	-0.1 (185.7%)	-0.3 (-15.1%)
KURTOSIS	1.5 (13.9%)	1.0 (6.4%)	1.6 (-)	1.0 (17.2%)	2.6 (19.3%)
% GRAVEL	0.3 (151.9%)	0.3 (201.8%)	1.8 (-)	18.2 (167%)	42.6 (56.4%)
% MUD	34.6 (33%)	0.95 (145.3%)	17.3 (-)	11.1 (145.9%)	4.7 (22.4%)
% V COARSE GRAVEL	0 (-)	0 (-)	0 (-)	0.7 (346.4%)	0 (-)
% COARSE GRAVEL	0 (-)	0 (-)	0 (-)	5.3 (209.7%)	0 (-)
% COARSE SAND	3.5 (25.2%)	7.6 (59%)	2.4 (-)	13.4 (86.7%)	5.1 (126.3%)
% MEDIUM SAND	4.8 (32.4%)	36.8 (24.2%)	8.3 (-)	18.9 (88.9%)	1.3 (163.9%)
% FINE SAND	21.7 (29.8%)	43.8 (16.7%)	32.8 (-)	20.1 (80.1%)	0.7 (140%)

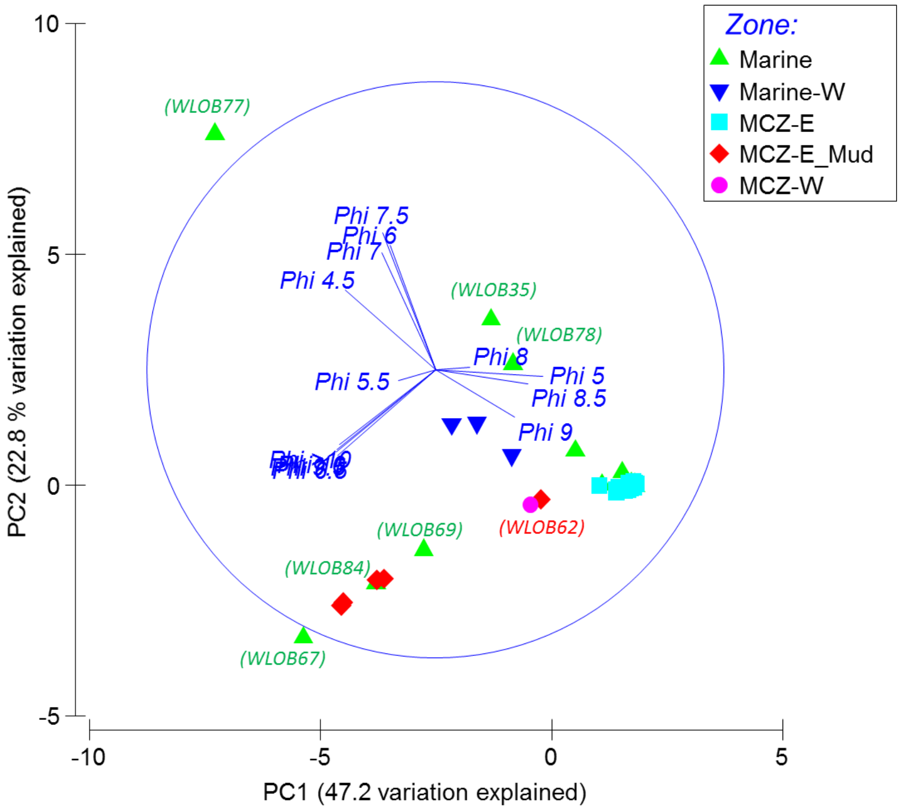


Figure 3. Ordination (principal component analysis, PCA) plot on mud fractions (<63 µm, >4 phi) of sediments collected in 2015 (Whitsand and Looe Bay rMCZ benthic survey, RP02821). Symbols identify samples as categorised by sampling location within geographical zones and the names of the samples referenced in the text are given in parentheses.

The multivariate analysis was also applied to the mud fractions only, measured as % weight of fractions in the sediment between 4.5 phi (44.2 µm, coarse silt) and >10 phi (<98 µm, clay) at 0.5 phi intervals. The resulting spatial pattern in mud fractions distribution and similarities between sampling stations and zones (Figure 3) was highly similar to the one observed in the analysis conducted on the whole sediment sample (Figure 2). This was also confirmed by the ANOSIM analysis that highlighted an overall significant difference between zones (Global R statistics = 0.662, P = 0.01%, 9999 permutations), and in particular a significant differentiation between the mud fractions in the deep mud habitat (with higher content of clay and medium to fine silt) and those in the remaining eastern part of the MCZ (with higher content of very fine silt, coarser clay fractions and coarse to medium silt) and in the marine area SW of the MCZ (with higher content of medium to fine silt and coarse silt). As observed for the whole sediment samples, the marine area SE of the MCZ (Marine) showed a variability in the mud components, with stations closer to MCZ-E_Mud (WLOB67, WLOB69 and WLOB84) sharing similar characteristics of the mud component of the sediment as those found in this area, stations to the E-SE of the Rame Head dredge disposal site (WLOB35, WLOB77 and WLOB78) showing sediments with dominating coarser muddy fractions, and the remaining marine stations being more similar to those found in the MCZ-E (Figure 3).

3.1.2 SPATIAL-TEMPORAL ANALYSIS

Temporal changes in bulk sediment composition

Interannual changes in bulk sediment composition were analysed for the sample data collected between 2001 and 2015. Particular attention was given to assessing the mud content variability in the deep mud habitat within the MCZ in relation to the variability in other areas. However, these assessments and the results below should be taken as indicative, as in several years (particularly between 2001 and 2009) only one sample was available for the deep mud habitat and other areas, and therefore a high uncertainty is associated with the suitability of these individual samples to represent the sediment characteristics of an area as a whole.

The mud content in the deep mud habitat within the MCZ (MCZ-E_Mud) didn’t show a substantial variability between years, with most values being between 31and 35 %, and a higher value (41 %) recorded only in 2001 (Table 7). Except for the sample collected in 2001, there appears to be a decrease in mean gravel content and a correspondent increase in sand in the samples collected within the deep mud habitat area over the years. The decrease in gravel content appears to be particularly evident in 2015, when less than 1 % gravel was recorded in the samples on average, compared to mean values between 7 and 11 % in previous years (Table 7). However, gravel content values recorded in the deep mud habitat in 2013 were highly variable between stations, with most of them (7 stations out of 10) comprised between 0.02 and 0.9 % hence at comparable levels to those recorded in 2015.

The comparison of the deep mud habitat in the MCZ with sediment from the Rame Head disposal site is only relevant to the years when both areas were samples, i.e. 2001, 2007 and 2008. Although it may appear that sediments in the samples collected in the deep mud habitat area were less gravelly and sandier than those in the current disposal site on average, in most cases the values recoded for the deep mud habitat were comprised within the range of variability between samples collected in the disposal site area in the different years. The only exception was in 2007, when the sediment sample taken from the deep mud area had a slightly lower gravel content and a slightly higher sand content than all the samples collected in the current disposal site (Table 7). Mud content values recorded in the deep mud habitat within the MCZ were within the range of variability observed at the disposal site.

When considering samples with a muddy component in the sediments (hence classed as mud or muddy according to the textural group description), the deep mud habitat showed mud content similar to that one measured for the active disposal site and the surrounding marine area. However, gravel content in these latter two areas was notably higher (albeit highly variable; Figure 4), denoting the predominantly mixed nature of the sediments in these areas compared to mud sediment in the deep mud habitat. Muddy substrata within the rest of the MCZ occurred mostly on the subtidal mixed sediment habitat surrounding the deep mud habitat, with a lower content in mud and higher gravel content than those in this latter habitat (Figure 4). A notable increase in mud content and decrease in sand was observed in the muddy sediments collected from the Plymouth Sound and Estuaries SAC areas, although a marked variability between samples was recorded in these areas (Figure 4).

Table 7. Mean annual and total content of bulk sediment classes in samples collected by zone. Zones are losely arranged according to a distance gradient from the deep mud habitat area within the MCZ (MCZ-E_Mud).

Bulk class	Year	Mar-W	MCZ-W	MCZ-E	MCZ-E_Mud	Mar	DS(curr)	DS(past)	DS(offsh)	SAC_PlymS	SAC	SAC_Tam
Mud %	**2001**			2%	41%	17%	24%	6%				
	2002			24%		16%	32%	1%				
	2003			1%		15%	24%					
	2004			2%		21%	22%	12%				
	2005			2%		21%	30%					
	2006			1%		20%	33%	16%				
	2007			1%	31%	15%	21%		9%			
	2008			1%	35%	14%	38%		11%			
	2009			4%	33%	15%			9%			
	2011									26%	42%	59%
	2013		2%	7%	33%							
	2015	5%	17%	1%	35%	11%				21%	35%	58%
Sand %	**2001**			98%	57%	53%	45%	73%				
	2002			53%		83%	68%	38%				
	2003			99%		48%	55%					
	2004			55%		66%	28%	49%				
	2005			60%		69%	54%					
	2006			81%		69%	29%	56%				
	2007			88%	59%	58%	53%		88%			
	2008			80%	55%	67%	47%		87%			
	2009			68%	61%	66%			84%			
	2011									60%	30%	30%
	2013		82%	85%	60%							
	2015	53%	81%	99%	65%	71%				71%	38%	33%
Gravel %	**2001**			0.2%	2%	30%	31%	21%				
	2002			23%		2%	0%	61%				
	2003			0%		37%	21%					
	2004			43%		13%	49%	39%				
	2005			38%		10%	16%					
	2006			17%		10%	38%	28%				
	2007			11%	10%	27%	27%		3%			
	2008			18%	11%	18%	15%		2%			
	2009			28%	7%	20%			7%			
	2011									14%	28%	11%
	2013		16%	8%	7%							
	2015	43%	2%	0.3%	0.3%	18%				8%	27%	10%
Total Mud %		5%	7%	4%	34%	16%	28%	9%	10%	24%	39%	58%
Total Sand %		53%	81%	88%	61%	66%	49%	57%	86%	64%	34%	32%
Total Gravel %		43%	12%	8%	5%	18%	23%	33%	4%	12%	27%	10%

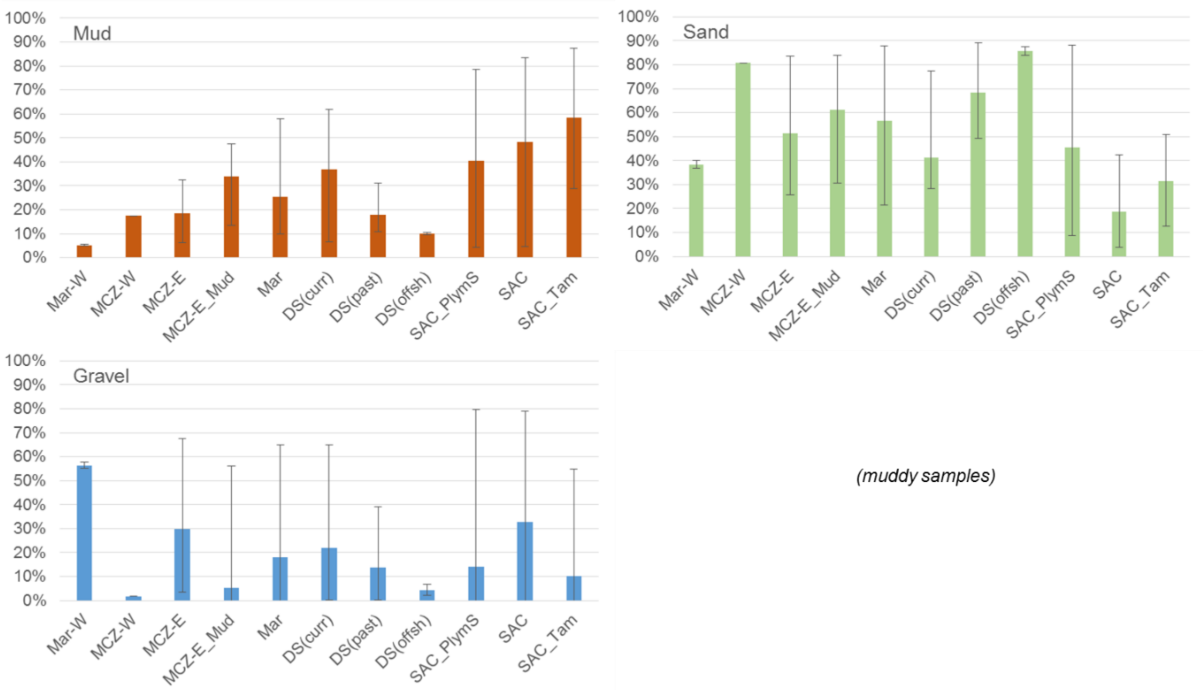


Figure 4. Mean and range (min-max) of bulk sediment classes in muddy samples collected by zone over the years.

Detailed analysis of mud fractions in muddy sediment samples

The sample particle size distribution from the 2015 PLYM and 2013 WLOB datasets were analysed in Gradistat and the sample descriptive statistics extracted. The ordination analysis (PCA) was applied to selected muddy samples from all the datasets (Figure 5) and the main spatial and temporal differences were investigated as detailed below.

SPATIAL COMPARISON WITH 2015 PLYM

Forty sediment sample data were available from the Plymouth and Estuaries SAC area in 2015. Most of the samples were collected in the outer part of the SAC, within Plymouth Sound or at the SAC marine boundary (17 samples; this area was identified as SAC_PlymS), or in the middle part of the SAC (identified as SAC, with 16 samples), whereas only 7 samples were taken from the upper part of the SAC, within the Tamar Estuary MCZ (identified as SAC_Tam).

Sediments classed as subtidal mud habitat (A5.3, Eunis level 3) in 2015 PLYM were present mostly on the NE part of Plymouth Sound (north of the main breakwater, at a water depth ranging 8 to 13 m) and in shallower areas (depth 3 to 6 m) within the Tamar Estuary. The muddy sediments in Plymouth Sound are slightly gravelly muddy sand or slightly gravelly sandy mud, with a mud content ranging 21 to 78 % and the samples mostly showing bimodal grain size distribution with finer modal sizes between 6.7 µm (very fine silt) and 9.4 µm (fine silt). In turn, the muddy sediments from the Tamar Estuaries are mainly sandy mud with a slight gravelly component on occasions and with a mud content ranging 47 to 79 %. Samples from this area showed either unimodal or bimodal grain size distribution, with the finer modal size also ranging between 6.7 µm and 9.4 µm. The samples collected from the middle part of the SAC area and the western arm of the Tamar Estuaries MCZ were mostly representative of subtidal mixed sediments (Eunis habitat A5.4), being gravelly mud and muddy gravels occurring at variable depth (2.5 to 26 m, with shallower areas upper in the estuary) and with a variable mud content (4 to 77 %). Most of these samples were multi-modal, often showing a finer modal grain size at 9.4 µm. The samples collected from the outer part of the SAC area were mostly classed as subtidal sand sediments (Eunis habitat A5.2), being slightly gravelly sand occurring at depth between 9 and 27 m and with a mud content between <1 and 16 %. These sediment samples were all unimodal, with the modal grain size ranging mostly between 152 µm (fine sand) and 1700 µm (very coarse sand).

The spatial comparison between WLOB and PLYM datasets in 2015 was restricted to samples that were classed as mud or muddy according to the textural group. The resulting selected subsets of data included 12 samples from the 2015 WLOB survey (including all samples from MCZ-E_Mud, four samples from Mar (the three samples located on the deep mud habitat just outside the MCZ, and the south-easternmost sample), the sample from MCZ-W and two samples from Mar-W; no samples from MCZ-E were included) and 28 samples from the three identified SAC areas (SAC_Plym, SAC and SAC_Tam) for the 2015 PLYM survey. The ANOSIM test was applied to these data and it revealed a significant differentiation between the areas (Global R statistics = 0.210, P = 0.3%, 9999 permutations). In particular, the samples (mud fraction only) within the deep mud habitat showed a significant differentiation from those collected in the middle and upper SAC areas (SAC and SAC-Tam) and this was mainly ascribed to the predominance of finer mud components (>5 phi, medium silt to clay) in the SAC muddy sediments, whereas the coarse silt component (4 to 4.5 phi) dominated in the muddy sediments within the Whitsand and Looe Bay MCZ (Figure 5C). No significant differences were detected between MCZ-E_Mud and SAC_Plym or between this latter area and Mar.

TEMPORAL COMPARISON WITH 2013 WLOB

Thirty-six sediment sample data were available from the Whitsand and Looe Bay MCZ in 2013. Most of the samples were collected in the eastern part of the MCZ (34 samples, of which 10 were located on the part of the MCZ (MCZ-W). No data were available for the marine areas outside the MCZ boundaries in this year.

The 2013 WLOB samples located on the deep mud habitat within the MCZ were mostly classed as subtidal mud habitat (A5.3, Eunis level 3), being slightly gravelly muddy sand with a mud content ranging 26 to 48 % and at a depth between 25 and 33 m. The only sample from this area that was not classed as subtidal mud (WLOB070) was from the SE corner of the deep mud biotope area within the MCZ (according to the biotope map from Defra, 2015); this sample was classed as subtidal mixed sediment, being muddy sandy gravel with 13 % mud content and collected at a depth of 30 m. The samples from MCZ-E_Mud showed either unimodal or bimodal grain size distributions with the main modal size being mostly at 108 µm (very fine sand). Only two samples (WLOB005 and WLOB069[2], located respectively at the centre and MCZ margin of the habitat) showed an additional modal size within the mud grain size range (specifically at 9 µm, fine silt). The samples collected in 2013 from the area MCZ-E were classed as subtidal sand or mixed sediments, being mostly slightly gravelly sand and gravelly muddy sand sediments sampled at a depth ranging between 12 and 28 m and with a variable mud content (7 to 32 % for muddy sediments, 0 to 4 % for the others). All the sand samples showed unimodal grain size distribution, with the modal grain size being mostly 215 µm (fine sand), whereas multi-modal distributions were observed for the mixed sediments

---

[2] It should be noted that, although the station ID names may appear similar between the 2013 and 2015 WLOB datasets, there is no correspondence between the location of the stations (e.g. WLOB004 in 2013 is located in MCZ-E_Mud, whereas WLOB04 in 2015 is located in MCZ-E).

samples, with modal grain size mostly ranging between 108 µm and 26950 µm (very fine sand and pebble, respectively; a finer modal size of 9 µm was detected only in one sample form the MCZ-E area in 2013, namely WLOB026). The two samples collected from the western part of the MCZ were classed as subtidal coarse sediment, being gravelly sand with a low mud content (1 to 2.5 %) and sampled at depth of 11 and 23 m. Both samples had a unimodal grain size distribution, with the modal size being 855 and 1200 µm (coarse and very coarse sand, respectively).

The temporal comparison between WLOB 2013 and 2015 was restricted to samples that were classed as mud or muddy according to the textural group and to sampling zones that spatially overlapped between the two datasets. Spatial overlap of the two datasets when considering muddy or mud sediments occurred for the deep mud habitat area only (with 4 stations in 2015 and 10 stations in 2013), whereas the other areas were not sampled or had not muddy sediments in one of the two years. The ANOSIM test was applied to these data and it showed that there was not a significant change in the mud fractions of the sediments in the deep mud habitat within the MCZ between 2013 and 2015, as also suggested by the large overlapping of the two groups of sample points in the PCA plot (Figure 5).

When looking at the individual sample distribution and sediment classification within the deep mud habitat in the MCZ between 2013 and 2015, it was noted that samples from two stations that almost overlapped on the SE side of the deep mud biotope area (namely station WLOB62 in 2015 and WLOB006 in 2013) had different sediment characteristics between the two years. In 2013, these sediments were classed as subtidal mud, with a mud content of 31 %, whereas in 2015 they were classed as sediments subtidal sand, with a mud content of 15 % (hence outside the range of variability between 26 and 47 % recorded for the subtidal mud stations in the MCZ over the two years). This might indicate a possible contraction of the mud habitat between 2013 and 2015 in the SE corner of the biotope area within the MCZ. However, whether this is a trend or part of the natural inter-annual variability in the sediment small-scale movement in the area cannot be assessed based on two years only[3]. Further data from this area will therefore be required.

Correlation with disposal returns at Rame Head South

None of the correlations explored to assess the relationship between the changes in mud content in sediments from the deep mud habitat within the MCZ or from the active disposal site and the interannual variability in disposal volumes at Rame Head South disposal site gave significant results (P > 0.05).

---

[3] It is of note that even surveys conducted in previous years had no PSA sample data from this part of the deep mud biotope.

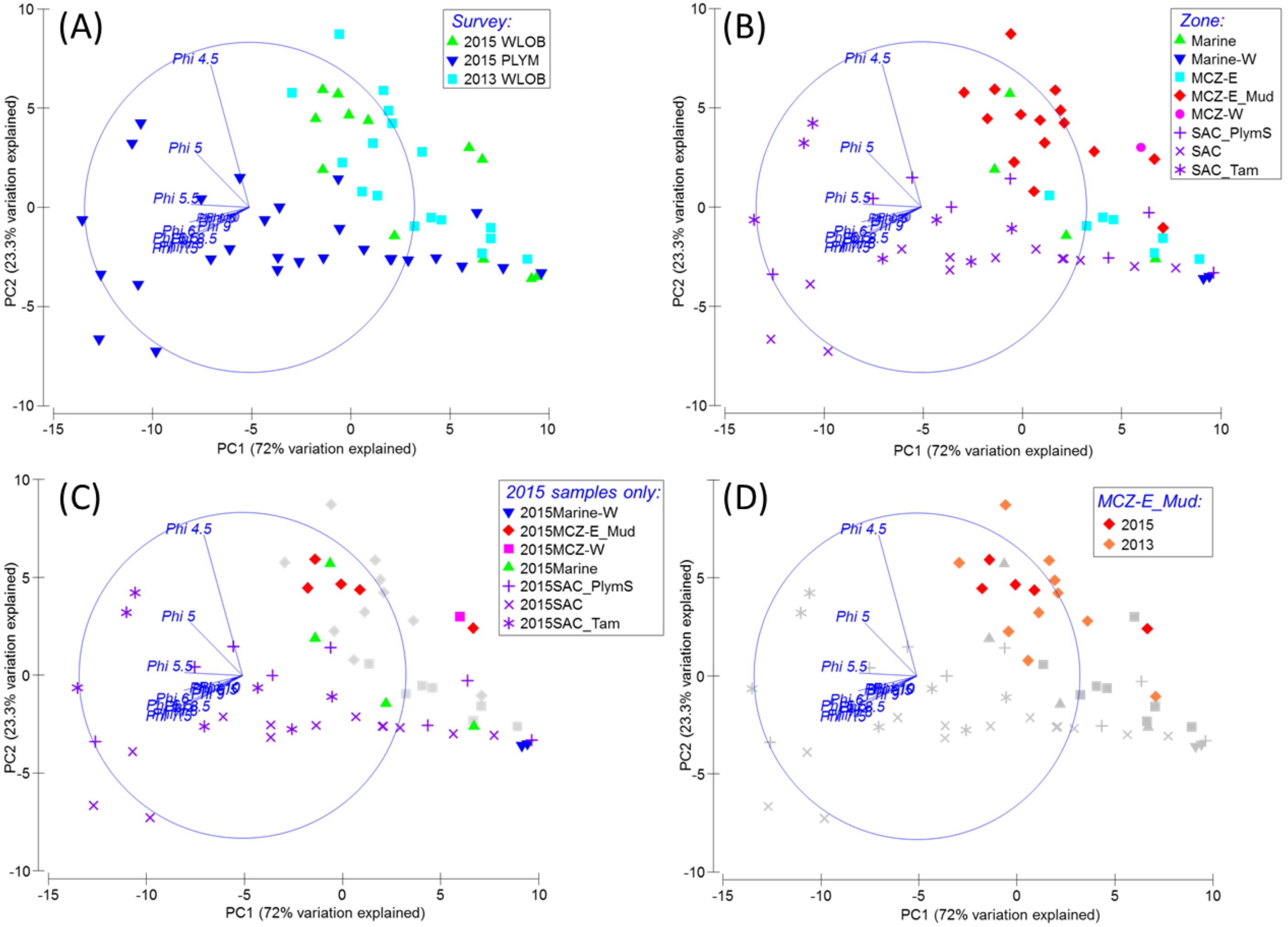


Figure 5. Ordination (principal component analysis, PCA) plot on mud fractions (<63 µm, >4 phi) of selected muddy sediment samples from the 2015 and 2013 surveys. Symbols identify PSA samples as categorised by (A) survey and (B) sampling location within geographical zones as described in the text. (C) and (D) show highlighted in colour only the samples relevant to the spatial comparison (2015 WLOB vs. 2015 PLYM) and the temporal comparison (2015 WLOB vs. 2013 WLOB, samples from MCZ-E_Mud area only).

3.2 Contaminants

3.2.1 2015 DATA

Trace metals

Data on twelve trace metal compounds were available in 2015, including Aluminium (Al), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Lithium (Li), Manganese (Mn), Nickel (Ni), Lead (Pb), and Zinc (Zn).

Sediments sampled in the deep mud habitat within the MCZ showed generally trace metal concentrations below regional background levels (RBL), with the exception of sample WLOB63 that showed higher levels for Cd and Cr (Table 8). Similarly, the sediments collected from the remaining eastern part of the MCZ or in the marine area nearby showed concentrations that were below RBL for most trace metals (except for Cr in two samples from MCZ-E). As, Cu and Zn concentrations were above RBL in those samples from Plymouth Sound that were collected on muddier sediments (NE part of the Sound), whereas all samples collected from the middle and upper part of the estuarine SAC showed concentrations above RBL, in particular for As, Cd, Cu, Pb and Zn (Table 8).

Table 8. Trace metal concentrations (mg/kg) in surficial sediments sampled in 2015 – Comparison with regional background levels (see Table 5 for reference). Values above RBL are highlighted in yellow (*). Grey cells indicate contaminants for which no standard was available.

Zone	Station	Mud	Org C	Al	As	Cd	Cr	Cu	Fe	Hg	Li	Mn	Ni	Pb	Zn
		%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
MCZ-E_Mud	WLOB64	42.4	0.8	57300	29	0.118	91.3	34.5	25500	0.326	157	426	28.1	41.2	95
	WLOB62	15.2	<0.2	48800	30.9	0.129	103	33.3	26800	0.11	159	424	28.4	41.7	96.3
	WLOB63	43.1	0.9	59500	29.8	0.253*	223*	40.4	26300	0.222	204	533	29	29.7	112
Mar	WLOB69	28.7	0.4	31700	29	0.051	31.1	16.1	18500	0.135	50.1	305	17.9	36.3	66.4
	WLOB84	39.5	0.4	52200	31.6	0.142	96.3	33.7	24200	0.151	154	433	28.1	41.9	97.7
MCZ-E	WLOB09	1.2	<0.2	34500	11.2	0.029	41.8	9.42	22400	0.037	45.3	419	26.5	16.8	51.4
	WLOB11	5.6	<0.2	37100	16.2	0.038	47.2	11.7	25400	0.163	51.2	429	26.5	27.5	66.8
	WLOB18	1.7	<0.2	38200	9.3	0.033	49.1	12.2	25500	0.022	44.5	511	28.8	15.1	50.6
	WLOB01	0.0	<0.2	32500	11.6	0.029	35.7	7.31	21900	0.0155	40.4	506	27.6	11.7	46.7
	WLOB13	1.8	<0.2	52000	18.1	0.119	147*	25.2	27200	0.0806	161	509	29.8	26.8	81.9
	WLOB15	2.8	<0.2	50000	34	0.149	155*	26.7	27900	0.479	121	519	25.2	31.9	83.5
MCZ-W	WLOB32	17.4	0.2	53600	28.7	0.132	114*	31.6	28300	0.92*	161	471	28.4	36.2	93.7
SAC_PlymS	PSC15A-1	54.9	1.5	71900	51.8*	0.19	91	77.7*	30800	0.484	157	483	34.3	87.7	160*
	PSC15B-2	0	<0.2	16500	32.7	0.032	27.7	14.7	16500	0.0411	28.2	486	16.7	35.5	53.6
	PSC15D-4	32.6	1.5	57700	41.7*	0.153	90.2	58.5	27400	0.636	144	455	30.9	63.4	127
	PSC15H-8	2.5	<0.20	37900	22.6	0.047	38.5	13.5	26300	0.243	57.9	419	25.7	47.5	83.8
	PSC15I-7	1.8	<0.2	36000	14.4	0.039	37.3	11.8	22300	0.111	51.3	349	22.5	28.3	61.7
SAC	NE PLYM 23	25.9	3.8	65300	61.6*	0.203*	85.2	122*	33600	0.58	130	570	36.7	191*	240*
	NE PLYM 26	40.1	2.5	78300	98.2*	0.319*	110*	199*	42000	0.628	145	667	46.4	159*	341*
	NE PLYM 27	33.1	2.1	70200	95.5*	0.325*	96.4	158*	38600	0.76	135	664	39.8	145*	280*
	NE PLYM 30	74.5	1.9	80000	444*	1.06*	110*	977*	48000	0.803*	138	1000	49.5	865*	899*
SAC_Tam	NE PLYM 36	69.9	3.1	66800	95.6*	0.555*	89	172*	36400	0.42	120	675	41.6	96.1	294*

Table 9. Trace metal concentrations (mg/kg) in surficial sediments sampled in 2015 – Comparison with Canadian Interim Sediment Quality Guidelines (see Table 5 for reference). Values above ISQG but below PEL are highlighted in yellow (*), whereas values above PEL are highlighted in dark orange (**). Grey cells indicate contaminants for which no standard was available.

Zone	Station	Mud	Org C	Al	As	Cd	Cr	Cu	Fe	Hg	Li	Mn	Ni	Pb	Zn
		%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
MCZ-E_Mud	WLOB64	42.4	0.8	57300	29*	0.118	91.3*	34.5*	25500	0.326*	157	426	28.1	41.2*	95
	WLOB62	15.2	<0.2	48800	30.9*	0.129	103*	33.3*	26800	0.11	159	424	28.4	41.7*	96.3
	WLOB63	43.1	0.9	59500	29.8*	0.253	223**	40.4*	26300	0.222*	204	533	29	29.7	112
Mar	WLOB69	28.7	0.4	31700	29*	0.051	31.1	16.1	18500	0.135*	50.1	305	17.9	36.3*	66.4
	WLOB84	39.5	0.4	52200	31.6*	0.142	96.3*	33.7*	24200	0.151*	154	433	28.1	41.9*	97.7
MCZ-E	WLOB09	1.2	<0.2	34500	11.2*	0.029	41.8	9.42	22400	0.037	45.3	419	26.5	16.8	51.4
	WLOB11	5.6	<0.2	37100	16.2*	0.038	47.2	11.7	25400	0.163*	51.2	429	26.5	27.5	66.8
	WLOB18	1.7	<0.2	38200	9.3*	0.033	49.1	12.2	25500	0.022	44.5	511	28.8	15.1	50.6
	WLOB01	0.0	<0.2	32500	11.6*	0.029	35.7	7.31	21900	0.0155	40.4	506	27.6	11.7	46.7
	WLOB13	1.8	<0.2	52000	18.1*	0.119	147*	25.2*	27200	0.0806	161	509	29.8	26.8	81.9
	WLOB15	2.8	<0.2	50000	34*	0.149	155*	26.7*	27900	0.479*	121	519	25.2	31.9*	83.5
MCZ-W	WLOB32	17.4	0.2	53600	28.7*	0.132	114*	31.6*	28300	0.92**	161	471	28.4	36.2*	93.7
SAC_PlymS	PSC15A-1	54.9	1.5	71900	51.8**	0.19	91*	77.7*	30800	0.484*	157	483	34.3	87.7*	160*
	PSC15B-2	0	<0.2	16500	32.7*	0.032	27.7	14.7	16500	0.0411	28.2	486	16.7	35.5*	53.6
	PSC15D-4	32.6	1.5	57700	41.7**	0.153	90.2*	58.5*	27400	0.636*	144	455	30.9	63.4*	127*
	PSC15H-8	2.5	<0.20	37900	22.6*	0.047	38.5	13.5	26300	0.243*	57.9	419	25.7	47.5*	83.8
	PSC15I-7	1.8	<0.2	36000	14.4*	0.039	37.3	11.8	22300	0.111	51.3	349	22.5	28.3	61.7
SAC	NE PLYM 23	25.9	3.8	65300	61.6**	0.203	85.2*	122**	33600	0.58*	130	570	36.7	191**	240*
	NE PLYM 26	40.1	2.5	78300	98.2**	0.319	110*	199**	42000	0.628*	145	667	46.4	159**	341**
	NE PLYM 27	33.1	2.1	70200	95.5**	0.325	96.4*	158**	38600	0.76**	135	664	39.8	145**	280**
	NE PLYM 30	74.5	1.9	80000	444**	1.06*	110*	977**	48000	0.803**	138	1000	49.5	865**	899**
SAC_Tam	NE PLYM 36	69.9	3.1	66800	95.6**	0.555	89*	172**	36400	0.42*	120	675	41.6	96.1*	294**

When assessing trace metal concentrations for the likelihood of toxic effects on bottom dwelling organisms, all sediments samples in 2015 showed values above ISQG for at least one metal (e.g. As in all samples; Cr, Cu, Hg and Pb in samples from all areas) indicating a moderate likelihood of this effect (Table 9). Most samples from the middle and upper part of the estuarine SAC also showed a high likelihood for toxic effects, as indicated by concentrations above PEL, in particular associated with As, Cu, Pb, Zn, whereas in the deep mud habitat within the MCZ, only one sample showed concentration above PEL (for Cr; Table 9).

The ordination analysis (PCA) on trace metals highlighted that a main spatial gradient in the broad scale distribution of these contaminants existed in particular between samples within the Plymouth Sound and Estuaries SAC (in particular those in the upper and middle estuarine areas, SAC and SAC_Tam) and the samples within Whitsand Bay and in adjacent marine areas (Figure 6). Higher metal concentrations were generally recorded in the first group of samples from the SAC area, with a sample taken from the middle section of the Tamar river (station NE PLYM 30) showing particularly high concentrations of As, Cu, Pb and Zn (Figure 7), as well as Cd, Mn and Fe (Table 8). The difference in trace metals contamination between SAC and the other areas (particularly SAC_PlymS and MCZ-E) was significant even when excluding this latter station (ANOSIM: Global R statistics = 0.369, P = 0.5 %), whereas the deep mud habitat within the MCZ didn't show significant differentiation from any of the other zones. It should be noted that the above described differentiation is likely the result of the variability in mud content between stations in different areas, as suggested by the significant (P < 0.01) positive correlations (with Spearman's rank correlation coefficient r between 0.5 and

0.9) of trace metal concentrations (except for Mn) with the mud and organic content in the sediments (Figure 7), these two variables were also highly significantly correlated with each other (r = 0.8, P < 0.001). In fact, the result was not significant (ANOSIM, P > 0.05) when only muddy samples (including samples from all areas except for MCZ-E) were considered in the comparison of trace metal contamination between areas.

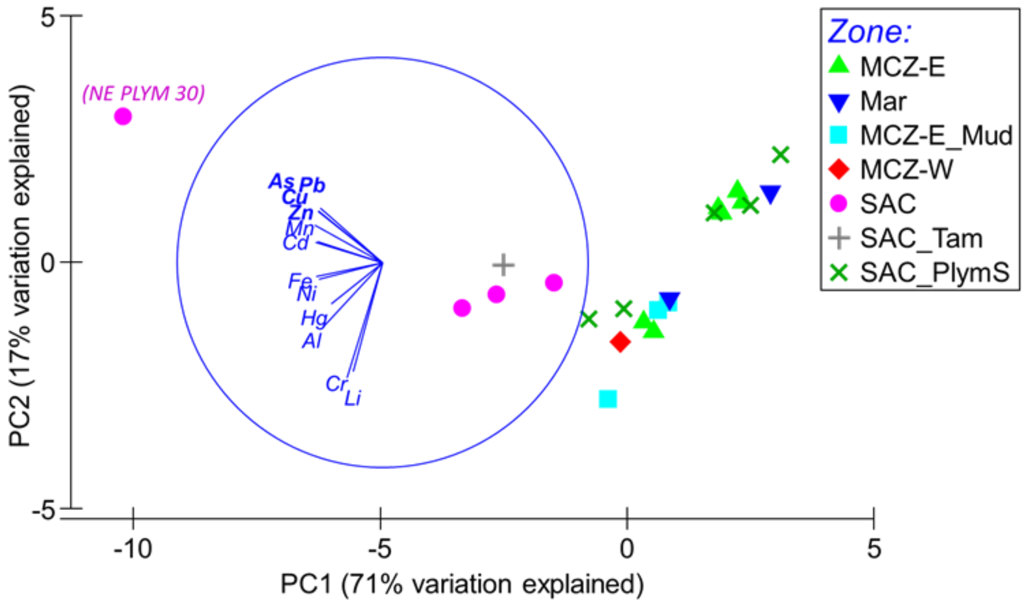


Figure 6. Ordination (principal component analysis, PCA) plot on trace metal concentrations in sediment samples from the 2015 surveys (WLOB and PLYM). Symbols identify samples as categorised by sampling location within geographical zones as described in the text. Contaminants in bold are primary indicators of presence of dredge material (Okada et al., 2009).

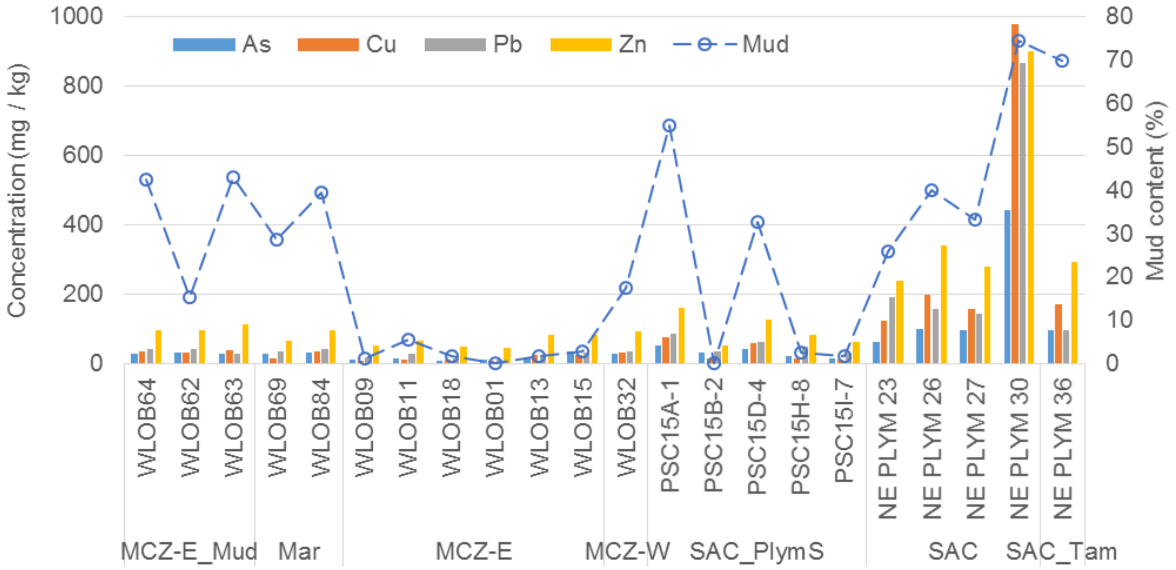


Figure 7. Concentration of trace metals regarded as primary indicators of presence of dredged material (Okada et al., 2009) in samples collected from different areas in 2015. Mud content (%) is also shown as dashed line.

The correlation analysis on the data collected from the Whitsand and Looe Bay area (station within and outside the MCZ) showed that sediment contamination generally decreased with distance from the disposal site along the likely direction of sediment transport by prevailing tidal currents (NW-SE) (Appendix 4). However, this decrease was significant for Pb only (Spearman's rank correlation $r = -0.83$, $P < 0.01$), whereas the pattern was not significant for the other trace metals regarded as primary indicators of presence of dredged material. The observed spatial pattern corresponded to a significant decrease in water depth and in mud content from the stations nearer the disposal site (within the deep mud habitat area within and just outside the MCZ boundary) to those farther inshore, into the MCZ area (Appendix 4). The highest concentrations of trace metals were recorded in the deep mud habitat (within and just outside the MCZ boundary), with contamination levels that corresponded to the lowest part of the range recorded in sediments from the disposal site in previous years (2001-2008; no data from the disposal site were available for 2015).

Hydrocarbons and chlorocarbons

Data on ten polycyclic aromatic hydrocarbon (PAH) compounds were available in 2015, including Naphthalene (N), Phenanthrene (P), Anthracene (A), Fluoranthene (Pl), Pyrene (Py), Benzo(a)anthracene (BaA), Chrysene + Triphenylene (Chrysene), Benzo(a)pyrene (BaP), Indeno(1,2,3-c,d)pyrene (I123-cdP), and Benzo(ghi)perylene (BghiP). Data on two chlorocarbon compounds were available, including Hexachlorobenzene (HCB) and Hexachlorobutadiene (HCBD).

All the muddy samples collected in 2015 had PAHs concentrations above OSPAR BAC level for all the PAH compounds that could be assessed. These samples included sediments from the deep mud habitat within the MCZ and just outside it, sediments from muddy areas of Plymouth Sound and all the sediment samples from the middle and upper part of the estuarine SAC (Table 10). Samples from MCZ-E generally showed the lowest PAHs concentrations (often below detection limit), with some exceptions. In fact, values above BAC were found for Fluoranthene, Pyrene, Benzo(a)anthracene, as well as Chrysene and Benzo(a)pyrene in two stations located within MCZ-E on slightly gravelly sand just to the north of the deep mud habitat as well as in sandy samples from the central-SW area of Plymouth Sound (Table 10). This latter result however, should be taken with caution as sediments in these samples had organic content below the minimum detection limit for assessment. Therefore the normalised contaminant value as used for comparison with BAC (half the value of the minimum detection limit for organic carbon was used for this normalisation) might have been overestimated, thus increasing the chance of having values above BAC. Chlorocarbons generally showed values below detection limit.

When assessing the likelihood of toxic effects on benthic organisms, all recorded PAHs concentrations were below ERL and below PEL, thus excluding a high likelihood for toxic effects. There was however a moderate likelihood of such effects (i.e. concentrations above ISQG) for all PAH compounds as assessed in the muddier stations sampled in Plymouth Sound and in the middle and upper part of the estuarine SAC, as well as for Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene and Benzo(a)pyrene from the muddy samples within the deep mud habitat in the MCZ, and from one of the muddy samples from the adjacent marine area (Table 11).

Table 10. PAH and chlorocarbon concentrations (µg/kg) in surficial sediments sampled in 2015 – Comparison with OSPAR background assessment concentration (see Table 5 for reference). Values above BAC (after normalisation to 2.5 % organic carbon, not shown here) are highlighted in yellow (*). Grey cells indicate contaminants for which no standard was available. Values preceded by < indicate concentrations below minimum detection level (where organic carbon was below detection level (MRV), 0.5*MRV was used for the normalisation).

Zone	Station	Mud	Org C	N	P	A	Fl	Py	BaA	Chrysene	BaP	I123-cdP	BghiP	HCB	HCBD
		%	%	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
MCZ-E_Mud	WLOB64	42.4	0.8	20.2*	74*	29.8	168*	160*	129*	109*	135*	82.7	89.1	<0.1	<0.1
	WLOB62	15.2	<0.2	<5	12.6	5.9	24.1	23.5	15.1	14.2	18.1	13.9	15.6	<0.1	<0.1
	WLOB63	43.1	0.9	23.2*	92.5*	35.6	212*	189*	156*	135*	167*	110.0	110.0	<0.1	<0.1
Mar	WLOB69	28.7	0.4	11.5*	49.7*	22.5	109*	96.4*	64.7*	66.5*	78.5*	52.9	57.7	<0.1	<0.1
	WLOB84	39.5	0.4	26.1*	55.5*	25.3	157*	148*	117*	100*	123*	76.4	80.7	<0.1	<0.1
MCZ-E	WLOB09	1.2	<0.2	<5	<5	<1	8.5	8.2	5.0	5.1	6.4	4.5	5.0	<0.1	<0.1
	WLOB11	5.6	<0.2	<5	18.9	7.6	58.8*	50.9*	34.6*	30.5*	36.5*	26.4	28.5	<0.1	<0.1
	WLOB18	1.7	<0.2	<5	<5	<1	1.9	1.8	1.2	<3	1.1	1.2	1.5	<0.1	<0.1
	WLOB01	0.0	<0.2	<5	<5	<1	4.0	4.2	2.6	<3	1.6	1.0	1.3	<0.1	<0.1
	WLOB13	1.8	<0.2	<5	11.4	4.4	16.2	15.3	10.4	10.9	8.6	6.8	7.1	<0.1	<0.1
	WLOB15	2.8	<0.2	<5	134*	40.6	88.2*	68.7*	22.2*	17.8	10.7	5.6	7.0	<0.1	<0.1
MCZ-W	WLOB32	17.4	0.2	<5	<5	1.9	18.8	17.7	14.8	12.3	14.9	10.8	11.5	<0.1	<0.1
SAC_PlymS	PSC15A-1	54.9	1.5	75*	271*	104.0	592*	586*	358*	375*	454*	331.0	349.0	3.7	<0.1
	PSC15B-2	0	<0.2	6.8	20.0	6.3	26.7	26.8*	16.9*	16.2	13.0	6.9	8.2	<0.1	<0.1
	PSC15D-4	32.6	1.5	90*	480*	167.0	886*	781*	507*	550*	585*	380.0	392.0	0.2	<0.1
	PSC15H-8	2.5	<0.20	5.0	17.6	10.0	65.9*	58.5*	41.7*	40.3*	36.3*	25.5	26.5	<0.1	<0.1
	PSC15I-7	1.8	<0.2	5.4	17.5	6.2	40*	35.4*	22.6*	23*	27.5	20.0	22.4	<0.1	<0.1
SAC	NE PLYM 23	25.9	3.8	98.6*	198*	66.7	308*	367*	205*	207*	235*	178.0	199.0	0.3	<0.1
	NE PLYM 26	40.1	2.5	82.9*	291*	231.0	679*	718*	426*	436*	485*	334.0	366.0	0.1	<0.1
	NE PLYM 27	33.1	2.1	49.1*	135*	46.5	286*	315*	187*	188*	211*	161.0	171.0	0.1	<0.1
	NE PLYM 30	74.5	1.9	54.3*	222*	101.0	467*	374*	284*	275*	267*	191.0	188.0	<0.1	<0.1
SAC_Tam	NE PLYM 36	69.9	3.1	51.7*	207*	72.3	498*	477*	323*	328*	378*	275.0	296.0	<0.1	<0.1

Overall, the total concentration of PAHs (as total sum of the measured compounds) showed a significant pattern in the broad scale distribution in sediments between areas (ANOSIM: Global R statistics = 0.326, P = 0.8 %). This was mainly due to the markedly lower concentrations recorded within the MCZ-E area compared to the other areas and in particular to MCZ-E_Mud, Mar and SAC (Figure 8). A marked variability was observed between sediment samples taken in the Plymouth Sound, with those showing the lowest contamination being taken from the central and SW part of the Sound, whereas those with the highest concentration were collected in the NE area of the Sound. These spatial patterns were most likely related with the distribution of mud sediments between areas and within Plymouth Sound, as also confirmed by the highly significant correlation between total PAHs and mud content (r = 0.84, P < 0.001).

Within the Whitsand and Looe Bay area, the total concentration of PAHs decreased with distance from the disposal site along the likely direction of sediment transport by prevailing tidal currents (NW-SE). However, this pattern was not significant (Appendix 4). The highest concentrations of total PAHs observed in 2015 were at the lowest end of the range recorded at the disposal site in previous years (2001-2008).

Table 11. PAH and chlorocarbon concentrations (µg/kg) in surficial sediments sampled in 2015 – Comparison with Canadian Interim Sediment Quality Guidelines (see Table 5 for reference). Values above ISQG but below PEL are highlighted in yellow (*). No values above PEL were measured. Grey cells indicate contaminants for which no standard was available. Values preceded by < indicate concentrations below minimum detection level.

Zone	**Station**	**Mud**	**Org C**	**N**	**P**	**A**	**Fl**	**Py**	**BaA**	**Chrysene**	**BaP**	**I123-cdP**	**BghiP**	**HCB**	**HCBD**
		%	**%**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**	**µg/kg**
MCZ-E_Mud	WLOB64	42.4	0.8	20.2	74.0	29.8	168*	160*	129*	109*	135*	82.7	89.1	<0.1	<0.1
	WLOB62	15.2	<0.2	<5	12.6	5.9	24.1	23.5	15.1	14.2	18.1	13.9	15.6	<0.1	<0.1
	WLOB63	43.1	0.9	23.2	92.5*	35.6	212*	189*	156*	135*	167*	110.0	110.0	<0.1	<0.1
Mar	WLOB69	28.7	0.4	11.5	49.7	22.5	109.0	96.4	64.7	66.5	78.5	52.9	57.7	<0.1	<0.1
	WLOB84	39.5	0.4	26.1	55.5	25.3	157*	148.0	117*	100.0	123*	76.4	80.7	<0.1	<0.1
MCZ-E	WLOB09	1.2	<0.2	<5	<5	<1	8.5	8.2	5.0	5.1	6.4	4.5	5.0	<0.1	<0.1
	WLOB11	5.6	<0.2	<5	18.9	7.6	58.8	50.9	34.6	30.5	36.5	26.4	28.5	<0.1	<0.1
	WLOB18	1.7	<0.2	<5	<5	<1	1.9	1.8	1.2	<3	1.1	1.2	1.5	<0.1	<0.1
	WLOB01	0.0	<0.2	<5	<5	<1	4.0	4.2	2.6	<3	1.6	1.0	1.3	<0.1	<0.1
	WLOB13	1.8	<0.2	<5	11.4	4.4	16.2	15.3	10.4	10.9	8.6	6.8	7.1	<0.1	<0.1
	WLOB15	2.8	<0.2	<5	134*	40.6	88.2	68.7	22.2	17.8	10.7	5.6	7.0	<0.1	<0.1
MCZ-W	WLOB32	17.4	0.2	<5	<5	1.9	18.8	17.7	14.8	12.3	14.9	10.8	11.5	<0.1	<0.1
SAC_PlymS	PSC15A-1	54.9	1.5	75*	271*	104.0	592*	586*	358*	375*	454*	331.0	349.0	3.7	<0.1
	PSC15B-2	0	<0.2	6.8	20.0	6.3	26.7	26.8	16.9	16.2	13.0	6.9	8.2	<0.1	<0.1
	PSC15D-4	32.6	1.5	90*	480*	167.0	886*	781*	507*	550*	585*	380.0	392.0	0.2	<0.1
	PSC15H-8	2.5	<0.20	5.0	17.6	10.0	65.9	58.5	41.7	40.3	36.3	25.5	26.5	<0.1	<0.1
	PSC15I-7	1.8	<0.2	5.4	17.5	6.2	40.0	35.4	22.6	23.0	27.5	20.0	22.4	<0.1	<0.1
SAC	NE PLYM 23	25.9	3.8	98.6*	198*	66.7	308*	367*	205*	207*	235*	178.0	199.0	0.3	<0.1
	NE PLYM 26	40.1	2.5	82.9*	291*	231.0	679*	718*	426*	436*	485*	334.0	366.0	0.1	<0.1
	NE PLYM 27	33.1	2.1	49.1*	135*	46.5	286*	315*	187*	188*	211*	161.0	171.0	0.1	<0.1
	NE PLYM 30	74.5	1.9	54.3*	222*	101.0	467*	374*	284*	275*	267*	191.0	188.0	<0.1	<0.1
SAC_Tam	NE PLYM 36	69.9	3.1	51.7*	207*	72.3	498*	477*	323*	328*	378*	275.0	296.0	<0.1	<0.1

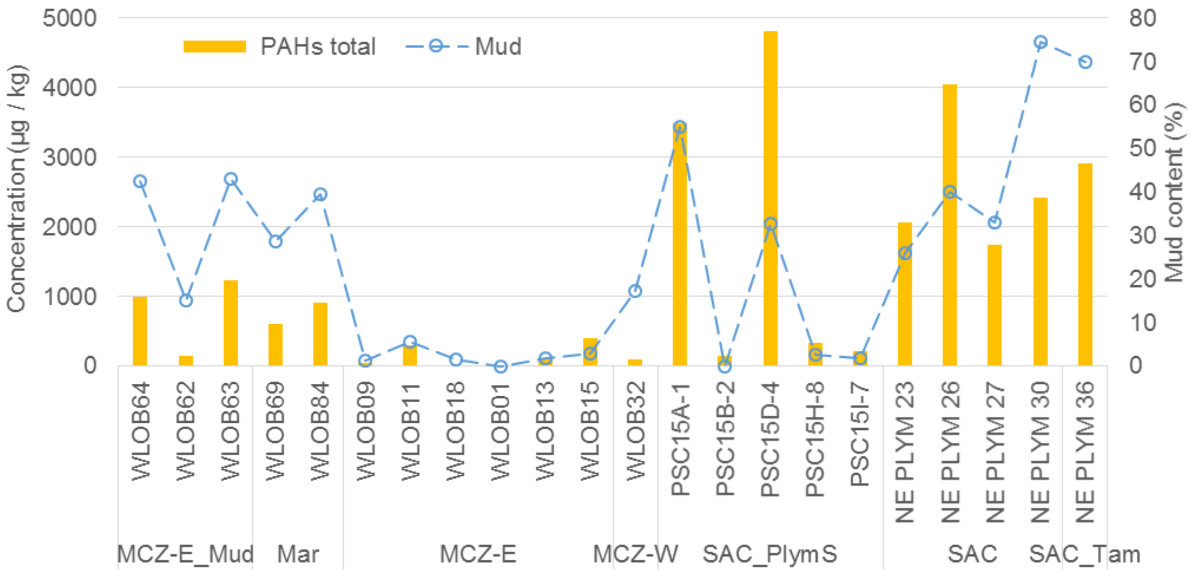


Figure 8. Concentration of PAHs (total sum) in samples collected from different areas in 2015. Mud content (%) is also shown as dashed line.

Organohalogens

Data on seven polychlorinated biphenyls (PCB) compounds were available in 2015, including the ICES7 CB congeners CB-028, 052, 101, 118, 153, 138, and 180. Data on six additional polybrominated diphenyl ether (PBDE) compounds were available, including BDE-028, 47, 99, 100, 153, and 154.

All PBDEs showed concentrations below detection limit as did all of the PCB compounds when measured in sediments from within the MCZ, excluding those from the deep mud habitat (Table 12). Muddy sediments from this latter habitat as distributed within the MCZ as well as in the adjacent marine area had concentrations above BAC level for most of the PCB compounds and a similar result was obtained for sediments from muddy areas of the Plymouth Sound and from the middle and upper parts of the estuarine SAC (Table 12).

The distribution of total PCBs concentrations between areas showed a pattern similar to that observed for PAHs (Figure 9). There was also a similarly significant positive correlation with the mud content in the sediments (r = 0.74, P < 0.001), which most likely drove this pattern. As a result, most of the sediments with lower mud content (<15.5 %) had PCBs concentrations below or close to detection limits (0.1 µg/kg), and these included all the samples from MCZ-E, the samples from the central and SW part of Plymouth Sound (PSC15B-2, PSC15H-8 and PSC15I-7), and the sample from the SE corner of the deep mud habitat area within the MCZ (WLOB32) which was classed as subtidal sand in 2015.

Table 12. Organohalogens concentrations (mg/kg) in surficial sediments sampled in 2015 – Comparison with OSPAR background assessment concentration (see Table 5 for reference). Values above BAC (after normalisation to 2.5 % organic carbon, not shown here) are highlighted in yellow (*). Grey cells indicate contaminants for which no standard was available. Values preceded by < indicate concentrations below minimum detection level (where organic carbon was below detection level (MRV), 0.5*MRV was used for the normalisation).

Zone	Station	Mud	Org C	CB#28	CB#52	CB#101	CB#118	CB#138	CB#153	CB#180	BDE#28	BDE#47	BDE#99	BDE#100	BDE#153	BDE#154
		%	%	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg
MCZ-E_Mud	WLOB64	42.4	0.8	<0.1	0.126*	0.273*	0.301*	0.271*	0.27*	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB62	15.2	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB63	43.1	0.9	<0.1	<0.1	0.21*	0.244*	0.233*	0.257*	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
Mar	WLOB69	28.7	0.4	<0.1	0.1	0.395*	0.639*	0.64*	0.429*	0.111*	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB84	39.5	0.4	<0.1	<0.1	0.219*	0.229*	0.296*	0.303*	0.118*	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
MCZ-E	WLOB09	1.2	<0.2	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB11	5.6	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB18	1.7	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB01	0.0	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB13	1.8	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	WLOB15	2.8	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
MCZ-W	WLOB32	17.4	0.2	<0.1	<0.1	<0.1	0.1	0.1	0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
SAC_PlymS	PSC15A-1	54.9	1.5	0.2	0.257*	0.758*	0.812*	0.896*	0.996*	0.441*	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	PSC15B-2	0	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	PSC15D-4	32.6	1.5	0.1	0.236*	0.648*	0.689*	0.624*	0.642*	0.246*	<0.02	<0.07	<0.05	<0.02	<0.02	0.021
	PSC15H-8	2.5	<0.20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	PSC15I-7	1.8	<0.2	<0.1	<0.1	0.1	0.193*	0.173*	0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
SAC	NE PLYM 23	25.9	3.8	0.2	0.252*	0.937*	1.19*	1.58*	1.31*	0.472*	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
	NE PLYM 26	40.1	2.5	0.2	1.63*	3.4*	3.07*	3.11*	2.38*	0.738*	<0.02	<0.07	0.082	<0.02	<0.02	<0.02
	NE PLYM 27	33.1	2.1	0.1	0.308*	1.01*	1.28*	1.49*	1.23*	0.412*	<0.02	<0.07	<0.05	<0.02	<0.02	0.0
	NE PLYM 30	74.5	1.9	<0.1	<0.1	0.1	0.1	0.1	0.1	<0.1	<0.02	<0.07	<0.05	<0.02	<0.02	<0.02
SAC_Tam	NE PLYM 36	69.9	3.1	0.2	0.259*	0.716*	0.797*	0.878*	0.831*	0.516*	<0.02	<0.07	0.064	<0.02	<0.02	0.021

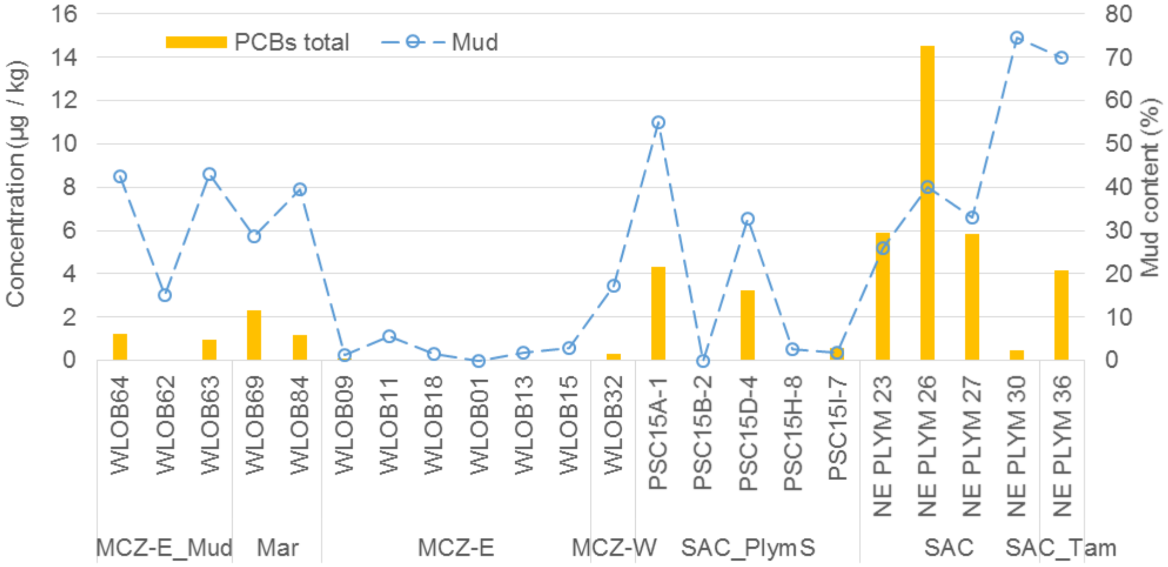


Figure 9. Concentration of PCBs (total sum) in samples collected from different areas in 2015. Mud content (%) is also shown as dashed line.

Within the Whitsand and Looe Bay area, the total concentration of PCBs decreased with distance from the disposal site along the likely direction of sediment transport by prevailing tidal currents (NW-SE) (Appendix 4). This decrease was significant (Spearman's rank correlation r = -0.75, P < 0.05) and it was mostly determined by the fact that in most samples collected within the MCZ area (NW of the deep mud habitat) PCB concentrations were below detection limits.

Within the Whitsand and Looe Bay area, the total concentration of PCBs decreased with distance from the disposal site along the likely direction of sediment transport by prevailing tidal currents (NW-SE) (Appendix 4). This decrease was significant (Spearman's rank correlation r = -0.75, P < 0.05) and it was mostly determined by the high frequency of records below detection limits in samples collected within the MCZ area (NW of the deep mud habitat) The highest concentrations of total PCBs observed in 2015 were at the very lowest end of the range recorded at the disposal site in previous years (2001-2008).

3.2.2 SPATIAL-TEMPORAL ANALYSIS

Trace metals

Data on trace metal contamination from muddy stations sampled within the deep mud habitat in the MCZ (MCZ-E_Mud) were available for 2001-2003, 2006-2009 in addition to 2015 and included Aluminium (Al), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper(Cu), Iron (Fe), Mercury (Hg), Lithium (Li), Manganese (Mn), Nickel (Ni), Lead (Pb), and Zinc (Zn).

When considering all trace metals, the multivariate analysis did not highlight a significant differentiation between years (ANOSIM[4]: Global R statistics = 0.177, P = 9 %). This was likely due to the wide variability observed for 2009 compared to other years, as well as to variable temporal patterns observed for different metals across years (Figure 10). In fact, while

---

[4] Only data between 2007 and 2015 were tested, as there was not sufficient sample replication (n<3) in previous years to conduct a valid test.

concentrations in 2015 were similar to previous years for most trace metals (As, Zn, Cd, Hg, Mn, Fe), a notable decrease in Cu, Pb and Ni was observed in 2015 compared to previous years, and to 2009 in particular, whereas Cr showed an apparent increase (Table 13, Figure 11 left panels). ANOSIM conducted on individual trace metals showed that only the decrease in Pb and Ni were significant (P < 5%, 2007 to 2015 only).

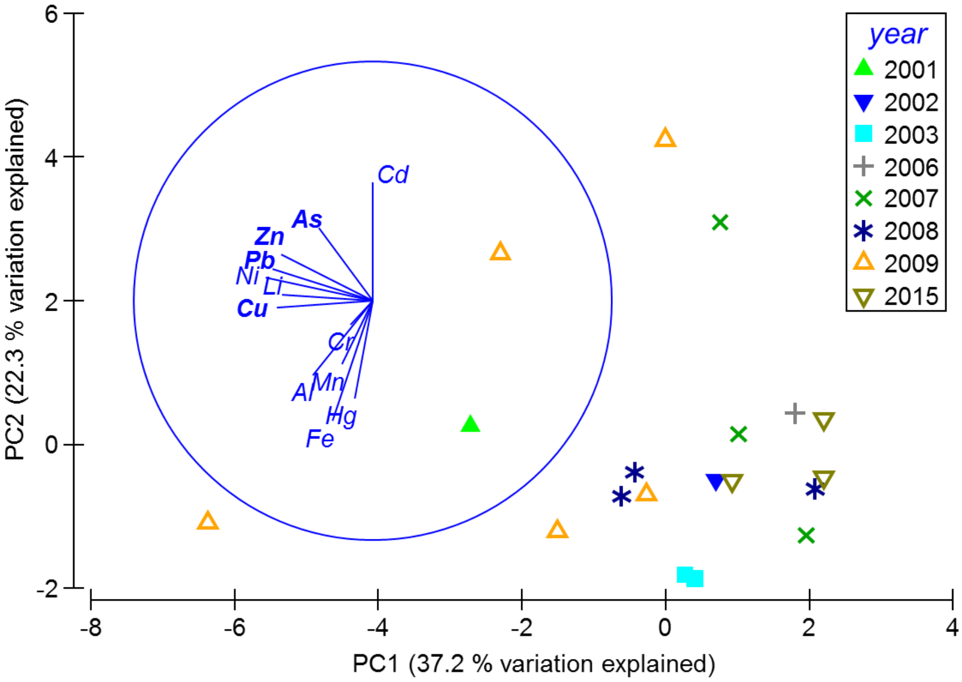


Figure 10. Ordination (principal component analysis, PCA) plot on trace metal concentrations in muddy sediment samples collected from the area MCZ-E_Mud between 2001 and 2015. Contaminants in bold are primary indicators of presence of dredge material (Okada et al., 2009).

Table 13. Mean concentration and range (min-max) of trace metals measured in muddy sediments from the area MCZ-E_Mud over the years (- is shown where only one sample was available).

Year	As mg/kg	Cu mg/kg	Zn mg/kg	Pb mg/kg	Cd mg/kg	Al mg/kg
2001	31 (-)	68 (-)	148 (-)	88 (-)	0.34 (-)	69942 (-)
2002	26 (-)	50 (-)	127 (-)	56 (-)	0.13 (-)	25834 (-)
2003	25 (24-26)	52 (51-53)	113 (106-119)	64 (63-64)	0.17 (0.15-0.18)	75723 (73724-77721)
2006	24 (-)	50 (-)	113 (-)	61 (-)	0.29 (-)	34348 (-)
2007	27 (24-31)	46 (43-51)	121 (108-135)	63 (55-71)	0.34 (0.27-0.37)	25566 (17365-31801)
2008	29 (25-34)	56 (40-72)	114 (92-134)	63 (55-74)	0.08 (0.08-0.08)	29278 (25880-35281)
2009	30 (27-33)	57 (46-74)	130 (107-152)	92 (70-123)	0.27 (0.08-0.59)	54546 (24809-89705)
2015	30 (29-31)	36 (33-40)	101 (95-112)	38 (30-42)	0.17 (0.12-0.25)	55200 (48800-59500)
Year	**Cr mg/kg**	**Hg mg/kg**	**Li mg/kg**	**Mn mg/kg**	**Ni mg/kg**	**Fe mg/kg**
2001	78 (-)	0.52 (-)	180 (-)	468 (-)	47 (-)	29643 (-)
2002	91 (-)	0.45 (-)	175 (-)	449 (-)	33 (-)	29131 (-)
2003	109 (94-124)	0.4 (0.35-0.45)	132 (121-143)	417 (384-450)	33 (32-33)	37872 (37811-37932)
2006	78 (-)	0.34 (-)	102 (-)	396 (-)	30 (-)	24898 (-)
2007	72 (60-82)	0.39 (0.35-0.44)	105 (89-113)	429 (276-519)	34 (27-38)	27586 (17542-34470)
2008	79 (64-93)	0.42 (0.31-0.5)	163 (151-172)	479 (457-511)	35 (33-36)	29240 (28014-31622)
2009	106 (85-132)	0.26 (0.01-0.51)	279 (237-417)	461 (436-518)	46 (39-59)	28382 (14690-39269)
2015	139 (91-223)	0.22 (0.11-0.33)	173 (157-204)	461 (424-533)	29 (28-29)	26200 (25500-26800)

Figure 11. Mean concentration of trace metals considered as primary indicators of presence of dredge material (Okada et al., 2009) during survey years: (A) Arsenic, As; (B) Copper, Cu; (C) Zinc, Zn; (D) Lead, Pb. Metal concentration refers to muddy samples (n) as collected from the deep mud habitat within the MCZ (left panels) and shown in the context of the concentrations in muddy samples from the current disposal site and within Plymouth Sound and Estuaries SAC areas (right panels). Whiskers show range of variation (min and max). Red dashed line indicates regional background levels (RBL).

Figure 9. Continued. (C) Zinc, Zn; (D) Lead, Pb.

Concentrations of trace metals regarded as primary indicators of presence of dredge material (As, Cu, Pb and Zn; Okada et al., 2009) were generally below regional background assessment concentrations within muddy sediments in MCZ-E_Mud, with the only exception for peak values recorded occasionally in 2009 (Figure 11 left panels). In the context of contamination levels in muddy sediments from the active disposal site (available for years 2001 to 2008) and from the SAC areas (available for years 2005, 2007 and 2015), the mean concentrations in the muddy sediments within MCZ-E_Mud were always lower than those recorded in these areas, with values that were often below the range of variability observed there. When all these areas were sampled in the same year (2007), a gradual decrease in the metal concentration was observed from the SAC areas to the disposal site to the deep mud habitat within the MCZ (Figure 11 right panels). Concentrations of As, Cu, Pb and Zn at the disposal site and in the SAC areas were almost always above regional background levels.

A significant positive correlation was detected between the concentration of lead (Pb) recorded in the muddy sediments within the deep mud habitat in the MCZ and the interannual variability in the disposal volumes at Rame Head South disposal site, particularly when this was calculated as cumulative volumes from dredging over the six months preceding the benthic surveys (for data between 2001 and 2009 only: $r = 0.60$, $P < 0.05$) and over the year of the survey (also including 2015: $r = 0.52$, $P < 0.05$). This result was mainly ascribed to the increase in disposal volumes (originating mainly from maintenance dredging) and Pb concentrations in 2001 and 2009 (Figure 12). This pattern was not confirmed, however, for trace metals in muddy sediments at the disposal site, as all correlations with disposal volumes were not significant ($P > 0.05$) for this area.

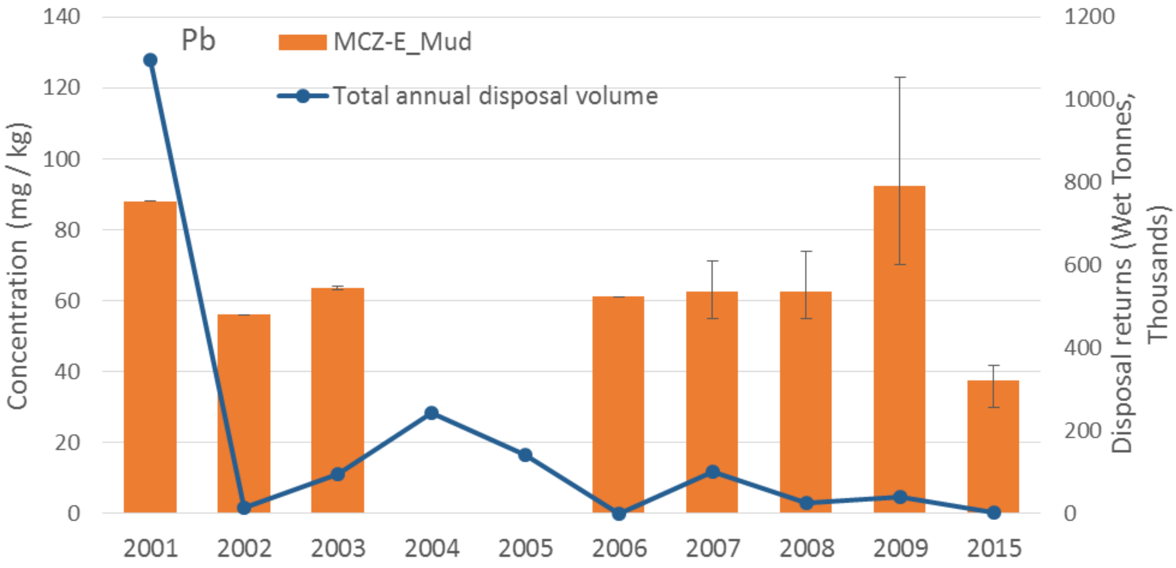


Figure 12. Mean concentration of Pb in muddy samples as collected from the deep mud habitat within the MCZ (orange bars; whiskers show range of variation, min - max), and changes in the disposal returns at Rame Head South disposal site (as annual cumulative dredged volumes).

PAHs

Data on PAH contamination from muddy stations sampled within the deep mud habitat in the MCZ (MCZ-E_Mud) were available for 2001 and 2003-2009 in addition to 2015 and included the following ten compounds: Naphthalene (N), Phenanthrene (P), Anthracene (A), Fluoranthene (Pl), Pyrene (Py), Benzo(a)anthracene (BaA), Chrysene + Triphenylene (Chrysene), Benzo(a)pyrene (BaP), Indeno(1,2,3-c,d)pyrene (I123-cdP), and Benzo(ghi)perylene (BghiP). The total hydrocarbon concentration (PAHs total) was calculated as the sum of these compounds.

The ordination analysis undertaken on all PAH compounds (including their sum) in muddy sediments within the MCZ-E_Mud area showed a main differentiation of 2008 samples due to higher PAHs concentrations compared to the other years, which in turn showed a higher similarity in PAHs concentrations (Figure 13, Figure 14 left panel). The statistical test confirmed this pattern by showing a significant differentiation in PAH contamination between 2008 and other years (ANOSIM[5]: Global R statistics = 0.350, P = 2.9 %), as ascribed in particular to higher concentrations of BaA, BaP, BghiP, Chrysene, I123-cdP and PAHs total in 2008 (Figure 13, Figure 14 left panel).

In the context of PAHs contamination as measured in muddy sediments from the active disposal site and from the Plymouth Sound and Estuaries SAC areas, the total PAHs concentration within deep mud habitat in the MCZ was generally lower than or within the range of variability as observed in these areas (Figure 14 right panel).

There were no significant positive correlations between PAHs concentrations (either as individual compounds or as total sum) measured in muddy sediments within the deep mud

---

[5] Only 2007, 2008 and 2015 were tested, as there was not sufficient sample replication (n<3) in other years to conduct a valid test.

habitat in the MCZ or within the current disposal site and the interannual variability (2001-2009) in the disposal volumes at Rame Head South disposal site.

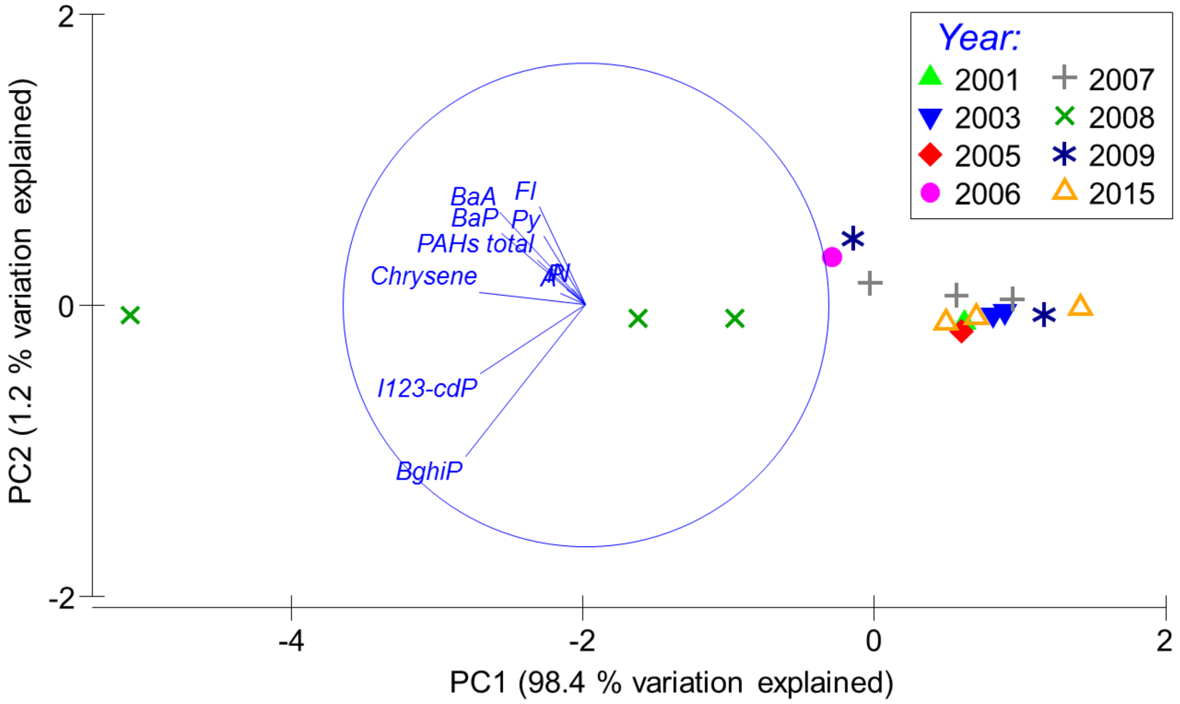


Figure 13. Ordination (principal component analysis, PCA) plot on concentrations of PAH compounds in muddy sediment samples collected from the area MCZ-E_Mud between 2001 and 2015.

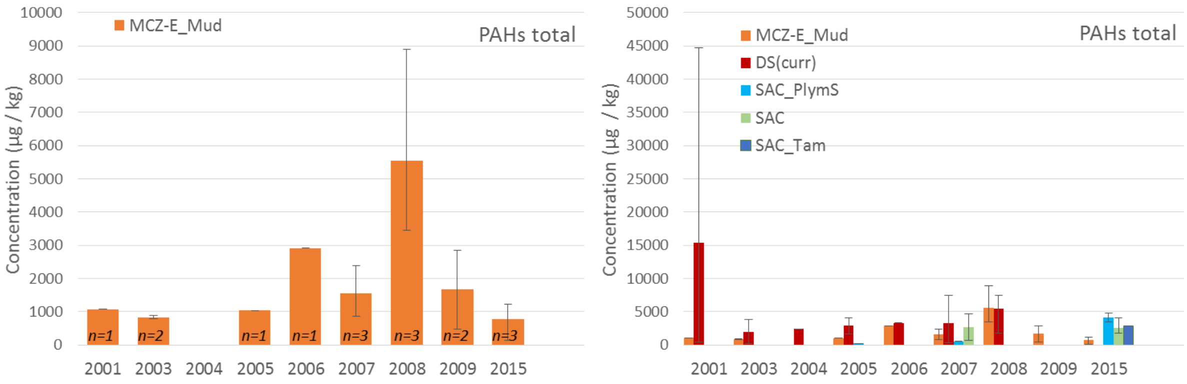


Figure 14. Mean concentration of PAHs (total sum of the ten compounds as specified in the text) during survey years. Concentration refers to muddy samples (n) as collected from the deep mud habitat within the MCZ (left panel) and shown in the context of the concentrations in muddy samples from the current disposal site and within Plymouth Sound and Estuaries SAC areas (right panel). Whiskers show range of variation (min and max).

PCBs

Data on PCB contamination from muddy stations sampled within the deep mud habitat in the MCZ (MCZ-E_Mud) were available for 2002, 2003 and 2006-2009 in addition to 2015 and included the following seven compounds: CB-028, 052, 101, 118, 153, 138 and 180. The total PCBs concentration (PCBs total) was calculated as the sum of these compounds.

The ordination analysis undertaken on all PCB compounds (including their sum) in muddy sediments within the MCZ-E_Mud area showed a differentiation of samples from 2006, 2007 and 2009 due to higher PCBs concentrations compared to the other years, although this was ascribed to individual samples within these years (Figure 15, Figure 16 left panel). The statistical test did not show a significant differentiation in PCB contamination between years (ANOSIM[6]: Global R statistics = 0.037, P = 70 %).

In the context of PCBs contamination as measured in muddy sediments from the active disposal site and from the Plymouth Sound and Estuaries SAC areas, the total PCBs concentration within deep mud habitat in the MCZ was generally lower than in these areas (Figure 16 Figure 14 right panel). Particularly higher values were recorded in muddy sediments from within the current disposal site, where also a marked variability was observed in years when replicate samples were available from this area.

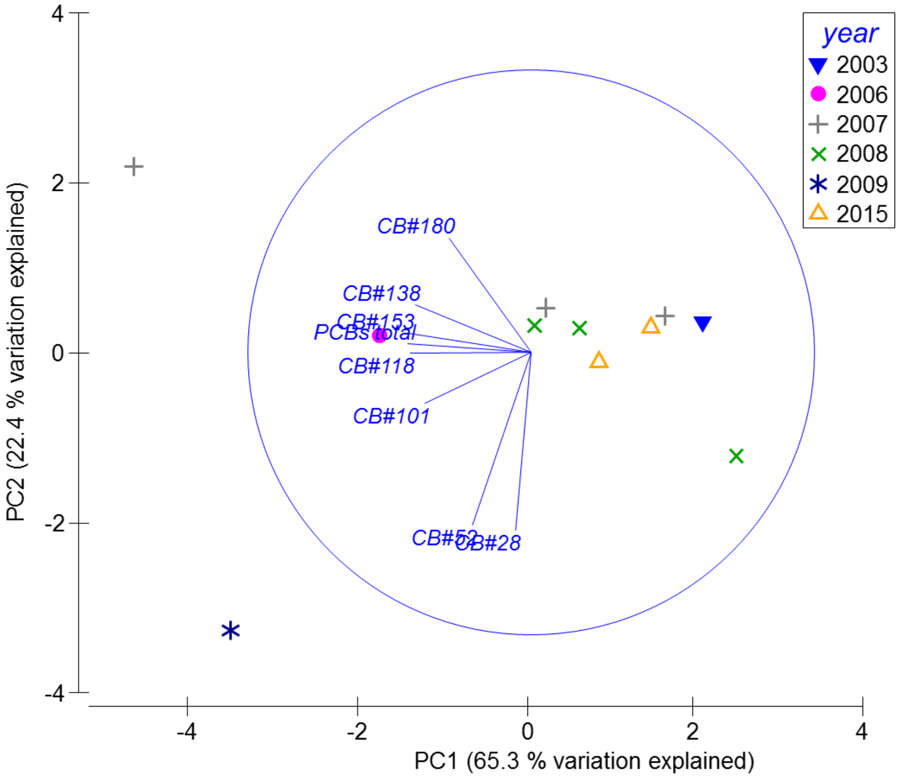


Figure 15. Ordination (principal component analysis, PCA) plot on concentrations of PCB compounds in muddy sediment samples collected from the area MCZ-E_Mud between 2003 and 2015.

---

[6] Only 2007 and 2008 were tested, as there was not sufficient sample replication (n<3) in other years to conduct a valid test.

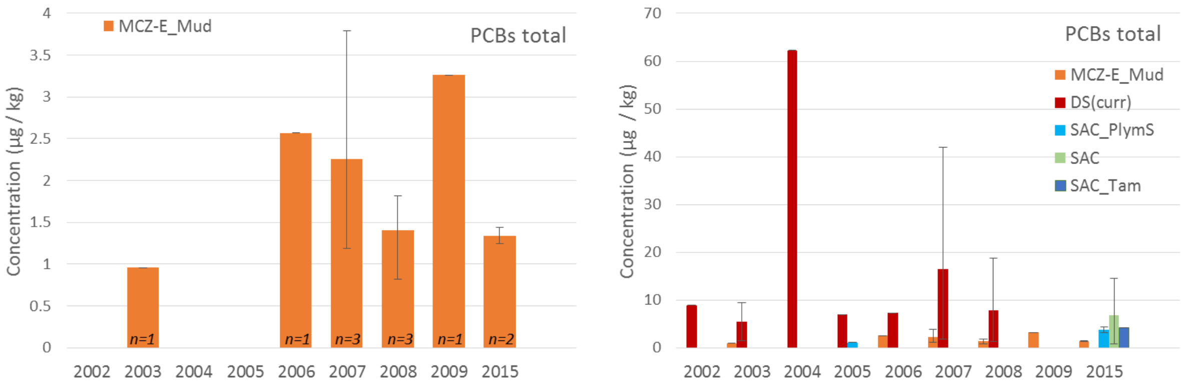


Figure 16. Mean concentration of PCBs (total sum of the seven compounds as specified in the text) during survey years. Concentration refers to muddy samples (n) as collected from the deep mud habitat within the MCZ (left panel) and shown in the context of the concentrations in muddy samples from the current disposal site and within Plymouth Sound and Estuaries SAC areas (right panel). Whiskers show range of variation (min and max).

There were no significant positive correlations between PAHs concentrations (either as individual compounds or as total sum) measured in muddy sediments within the deep mud habitat in the MCZ or within the current disposal site and the interannual variability (2001-2009) in the disposal volumes at Rame Head South disposal site.

3.3 Macrofauna

3.3.1 2015 DATA

Three main community types were identified from the 2015 WLOB (1 mm) dataset, which are determined by sediment type and are consistent with those described in Green & Godsell (2016). Sediments at Group 4 stations (Figure 17; Appendix 5) were predominantly subtidal muds, characterised by *Kurtiella* (*Mysella*) *bidentata* (Bivalvia), *Amphiura filiformis* (Ophiuroidea), *Melinna palmata* (Polychaeta), *Cylichna cylindacea* (Gastropoda), *Loimia medusa* (Polychaeta), *Diastylis laevis* (Cumacea), *Owenia* (Polychaeta) and *Scalibregma inflatum* (Polychaeta). Whilst there was some variation in community structure between 2013 (the mud habitat being denoted by group 10 and, to a lesser extent the mixed muddy sediments of group 9) and 2015, the top two characterising species (accounting for over 30 % of the similarity) remained the same and many of the species recorded in 2013 were also present in 2015 (Appendix 5). Group 2 stations (denoting muddy sediments in Plymouth Sound) were characterised by *M. palmata, Turritella communis* (Gastropoda) and *K. bidentata,* collectively accounting for 42 % of the similarity between samples. Other species present, also found in Whitsand Bay, included *A. filiformis*, *Owenia, Ampharete lindstroemi* (Polychaeta), *Cylichna cylindracea* (Gastropoda) and Nemertea (Appendix 5).

Groups 6 (Whistand Bay 2015) and 8 (Whitsand Bay 2013) contained stations with subtidal coarse or mixed sediments (Figure 17). In 2015, this community was characterised by the polychaetes *L. medusa, Mediomastus fragilis, Glycera lapidum (agg.), Sphaerosyllis bulbosa* and *Pisione remota* with Nemertea, nematodes, and *Echinocyamus pusillus* (Echinoidea). Stations in this group were generally located in the western part of the MCZ or in the marine area to the south of it. In 2013, *Pisione remota, Notomastus* and *G. lapidum* were the characterising species, accounting for 40 % of the similarity. In Plymouth Sound (2015, group

1), species composition was broadly similar to that in Whitsand Bay 2015 with *M. fragilis, N. cirrosa, E. pusillus, G. lapidum, P. remota, D. lupinus* and *P. fusca* being present in both areas.

Subtidal sands in Whitsand Bay (groups 5 and 7 for 2015 and 2013, respectively) were characterised by the polychaetes *Loimia medusa*, *Magelona johnstoni* and *M. filiformis, Nephtys cirrosa, Spiophanes bombyx* and *Chaetozone christiei,* the bivalves *Chamelea striatula* and *Dosinia lupinus,* Nemertea, the amphipod *Bathyporeia elegans, Phaxas pellucidus* (Bivalvia) and Amphiuridae. With the exception of *L. medusa,* these species were all present in the subtidal sands in Plymouth Sound (group 3) (Appendix 5).

Overall, there were no differences between the sand, mud or coarse sediment communities in Plymouth Sound and Whitsand Bay.

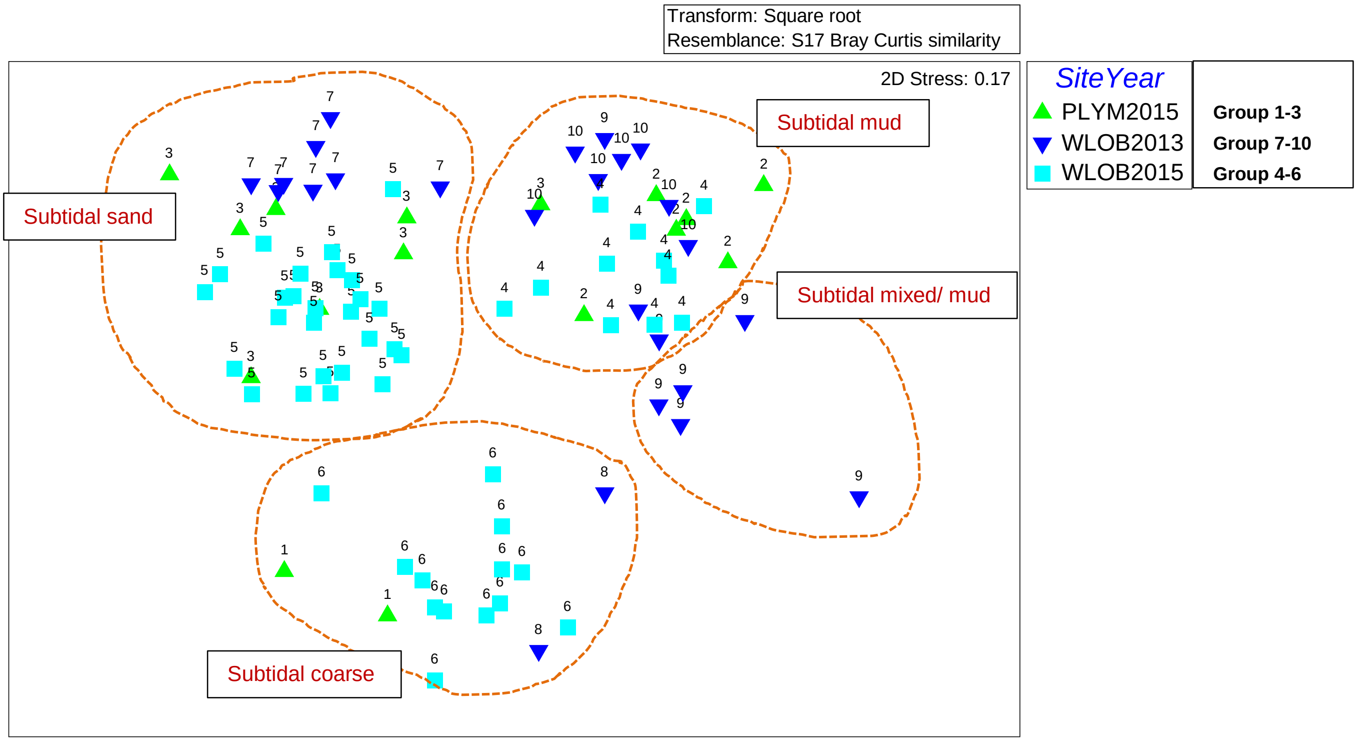


Figure 17. Ordination (non-metric multidimensional scaling, MDS) plot showing spatial variation in benthic community types for Plymouth Sound (PLYM 2015) and Whitsand Bay (WLOB 2013; 2015) (1 mm). Samples are labelled according to sediment type.

Comparison of the univariate community descriptors between the muddy habitats in Whitsand Bay (2015) and Plymouth Sound indicated no significant differences between areas for any of the parameters. The mean number of species was 39 in Plymouth Sound compared to 34 in Whitsand Bay, although the range was 22-48 and 25-50, for these areas, respectively, indicating a similar number of species in the mud habitats of the two areas (Table 14). This is supported by the 2013 data when the mean number of species was 36, with a range of 25-50. The mean number of individuals was higher in Plymouth Sound (92 individuals / 0.1 m^2) in both years with values of 62 and 63 individuals / 0.1 m^2 being recorded in Whitsand Bay in 2013 and 2015, respectively (Table 14). However, the range of values indicated little difference between the two areas, particularly in 2015 when the abundance ranged from 58 to 106 individuals / 0.1 m^2 in Plymouth Sound and 44 to 111 individuals / 0.1 m^2 in Whitsand Bay. There was no variation in diversity (H’) or evenness (J’) between areas.

Due to differences in sample collection method (Day vs Hamon grab), it is difficult to make valid comparisons between the mud habitats of the two areas but there are no apparent signs of stress within Whitsand Bay and the species composition between the two areas is broadly similar. This indicates that the deep mud habitat in Whitsand Bay (within and outside the MCZ) is in a similar condition to that in Plymouth Sound & Estuaries SAC.

Table 14. Mean and range (min-max) of total number of species (S), abundance (N, individuals per 0.1 m^2) and diversity (J' and H') in benthic communities sampled in 2015 and grouped as in Figure 17.

Group	S	N	J'	H'(log2)	S (range)	N (range)	J' (range)	H' (range)
2015 PLYM data 1 mm								
1 Subtidal coarse	26	40.6	1.0	4.5	23-29	34-47	0.95-0.97	4.4-4.6
2 Subtidal mud	39	92.4	0.9	4.7	22-48	58-106	0.87-0.91	3.9-5.1
3 Subtidal sand	25.13	40.9	1.0	4.3	7-36	12-60	0.9-0.99	2.7-5
2015 WLOB data 1 mm								
4 Subtidal mud	34.18	63.0	0.9	4.7	25-50	44-111	0.9-0.96	4.3-5.4
5 Subtidal sand	23.73	40.5	0.9	4.2	12-47	18-92	0.9-0.98	3.3-5.1
6 Subtidal coarse	40.15	85.0	0.9	4.8	14-62	26-138	0.9-0.97	3.4-5.5
2013 WLOB data 1 mm								
7 Subtidal sand	17.25	29.7	0.9	3.8	10-26	16-47	0.93-0.98	3.1-4.4
8 Subtidal coarse	34.5	51.0	1.0	4.9	22-47	35-67	0.97-0.98	4.3-5.4
9 Subtidal mixed/mud	30	45.3	1.0	4.6	13-47	20-70	0.9-0.98	3.3-5.4
10 Subtidal mud	36	61.8	0.9	4.9	25-50	46-92	0.92-0.98	4.4-5.2

3.3.2 SPATIAL-TEMPORAL ANALYSIS

The number of species (S) and total abundance (N) were variable between areas ($p < 0.01$ in both cases, based on $\log_{10}$ transformed data), with differences reflecting a depth gradient, to some extent. The mean number of species in the deep mud habitat within the MCZ (Mud biotope) and within the eastern MCZ (MCZ E) were 37 and 27, respectively (Figure 18A). Macrofaunal samples in these areas were collected at depths from 6 - 33.5 m, with more frequent values less than 23.5 m, compared to the marine area (MAR) where depth consistently exceeded 23.5 m and, regularly, 33.5 m. The number of species in this latter area was 53. Mean values of 43 and 49 were recorded for the current and past disposal areas, respectively. Abundance ranged from a mean of 95 individuals / 0.1 m^2 within the MCZ E to 227 and 524 individuals / 0.1 m^2 in the marine and past disposal areas, respectively (Figure 18B). In terms of both S and N, statistical comparison indicated a significant ($P < 0.05$) difference between MCZ E and all other areas, due to the lower benthic species numbers and abundance recorded in MCZ-E. No other differences were found and, in particular, the deep mud habitat within the MCZ was not significantly different from any other area. Shannon Wiener diversity (H') and Pielou's evenness (J') did not show significant differences between areas (Figure 18C and D).

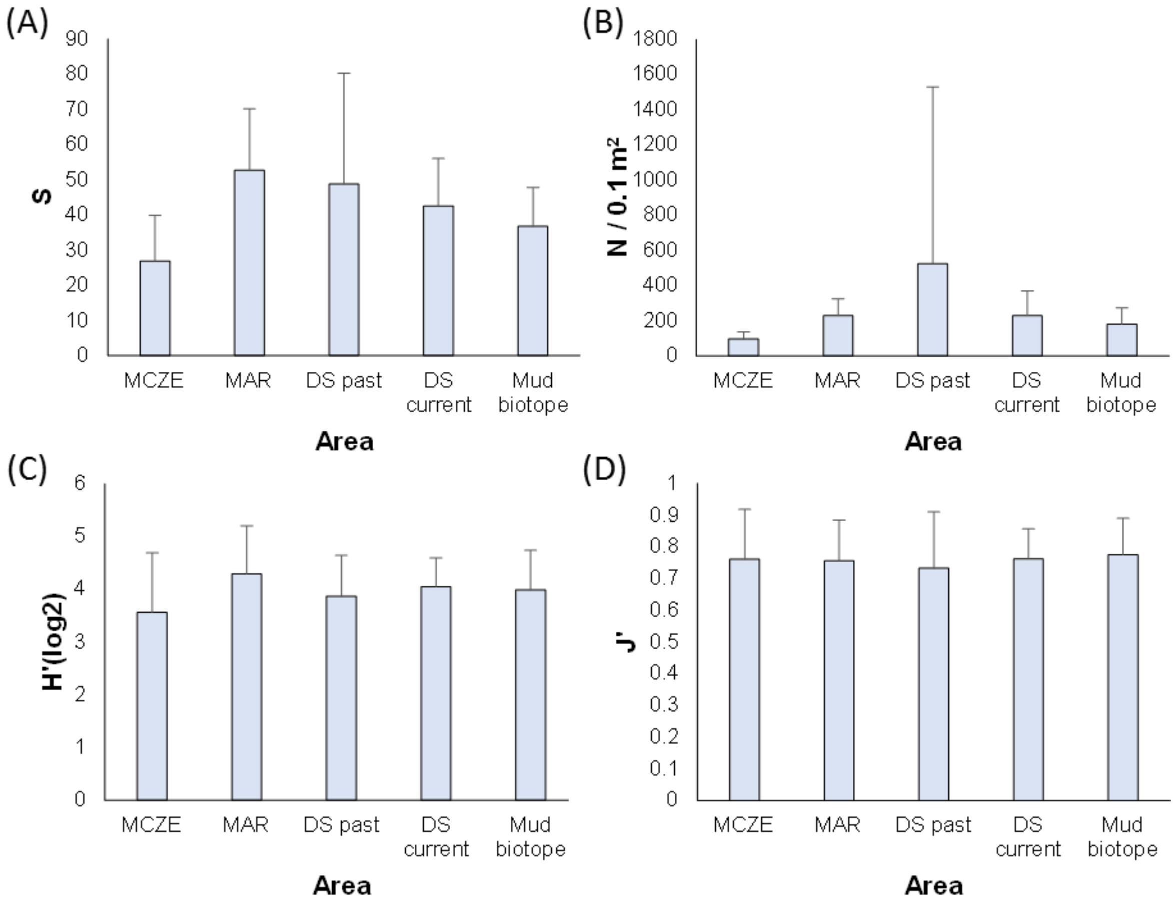


Figure 18. Variation in mean total number of species (A), abundance (B) and diversity (C and D) across areas (whiskers are standard deviation).

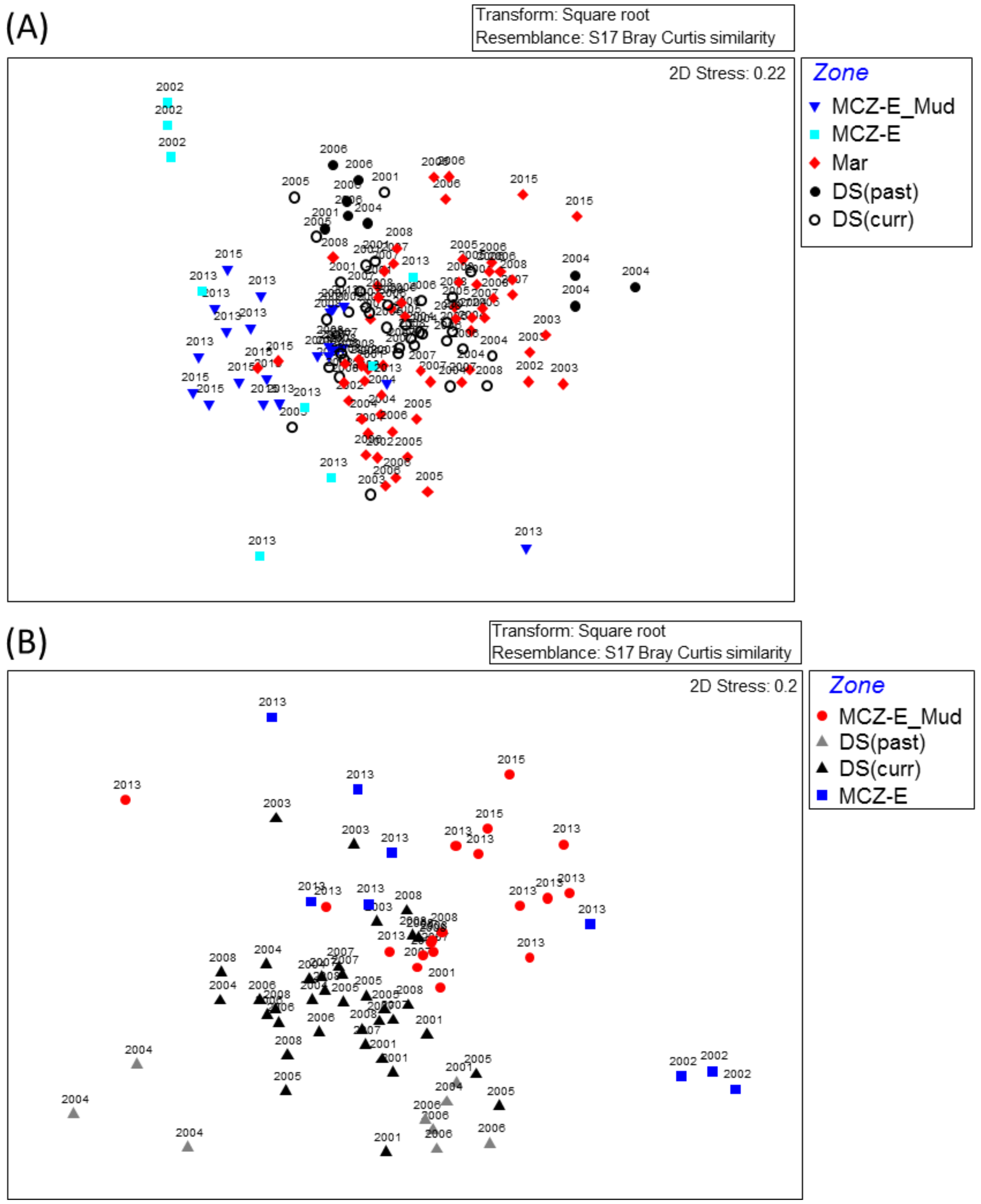


Figure 19. Ordination (non-metric multidimensional scaling, MDS) plot of benthic community structure (based on species abundance) in muddy sediment samples from the surveys undertaken between 2001 and 2015, as categorised by sampling zone: (A) ordination of samples from all zones in Whitsand and Looe Bay (East) and adjacent marine areas; (B) ordination of samples excluding zone Mar.

The community structure was highly variable with poor separation between groups (Figure 19A). This may be, in part, explained by the variation in sample location between years, the variation in sampling effort and purpose over time, the variation in the timing of sampling (2001-2009 data were collected in June (2001-2008) and July (2009), 2011 data in March, 2013 data in September-December, 2014-15 in June-July) and the arbitrary classification of the stations in relation to their inclusion within the MCZ (MCZ-E) or the marine area (Mar), a function of the arbitrary (in ecological terms) location of the MCZ boundary. Removal of the Mar group clarified the separation between the mud habitat and the MCZ and the two disposal groups to some degree (Figure 19B). Despite the variability, differences were found in benthic community structure between all groups (Global R statistics = 0.317, < 0.01), except for the past disposal site and the MCZ-E, and the current disposal site and the marine area to the south of the MCZ (MAR).

A SIMPER analysis was undertaken to identify species characterising the different areas and therefore responsible for the observed variability. There is high variability within the area groups, as indicated by the relatively low average similarity between samples within areas (ranging 19.9 to 34.4%; Table 15). This is most likely the result of the way the samples have been grouped, including multiple years, different sampling seasons, arbitrary classification within the MCZ, etc.

The collective species composition of samples within the deep mud habitat identified within the MCZ is consistent with the SS.SMU.CSaMu.AfilMysAnit biotope (*Amphiura filiformis, Kurtiella* (*Mysella*) *bidentata* and *Abra nitida* in circalittoral sandy mud). *A. filiformis* and *K. bidentata* were the dominant species, together with *Melinna palmata* (Table 15). Temporal analysis of samples within this group (for 2001, 2007, 2008, 2013 and 2015) indicates a degree of change over time with significant differences in community structure being found between 2007/2008 and 2015. This reflects a change in dominance by *Abra nitida, Phaxas pellucidus* and *Melinna palmata* to dominance by *A. filiformis* and *K. bidentata*, with these two species showing a gradual increase over time from 2001 onwards. The communities recorded in earlier years are characteristic of slightly sandier or coarser sediments and this change may therefore reflect slight changes in sediment composition as observed from PS data (in particular the slight increase in sand content and decrease in gravel content observed in MCZ-E_Mud over time; Table 7). Whilst there are no notable changes in the mud content of the sediment over time (31 – 35 % between 2007 and 2015, and 41 % in 2001; Table 7), the sediment characteristics have largely been derived from a single sample in most years. Where multiple replicates were analysed in 2013 and 2015, mud content ranged from 13 – 48 % and 15 – 43 %, respectively. Of note is the comparatively high gravel content in 2007 and 2008 (>10 %) compared to no gravel in 2015 (Table 7). Variability within the data (particularly 2013), sampling effort, timing and/or sampling technique should also be considered as potential influences on community structure. For example, a 0.1 m^2 Hamon grab has been used in all years except for 2015, when a 0.1 m^2 Day grab was used.

The comparison of the deep mud habitat within the MCZ with the current and past dredge disposal areas and other muddy sediments in the surrounding marine area indicates variation in species composition, but broad similarity in the overall community type. That is *Melinna palmata, Kurtiella bidentata, Amphiura filiformis, Scalibregma inflatum, Abra* species and, more so in coarser or deeper sediments, *Phaxas pellucidus* and *Lagis koreni* are generally the characterising species. All areas fall broadly within the general category of circalittoral sandy mud, with changes in species composition reflecting depth gradients and variation in sediment characteristics.

Table 15. Species characterising benthic assemblages (based on square root transformed data) in the different areas overall, with indication of their mean abundance (Av.A) and their cumulative contribution to the similarity (as %) between samples within an area., as resulting from SIMPER analysis.

MCZ-E_Mud **Average similarity: 32.37 %**			**Mar** **Average similarity: 27.93 %**		
Species	**Av.A**	**Cum.%**	**Species**	**Av.A**	**Cum.%**
Amphiura filiformis	3.81	11.04	*Scalibregma inflatum*	4.72	11.55
Kurtiella bidentata	3.68	19.37	*Lumbrineris aniara/cingulata*	3.28	17.07
Melinna palmata	2.73	25.98	Nemertea	1.69	22.04
Owenia	1.92	30.98	*Melinna palmata*	1.68	25.61
Scalibregma inflatum	1.69	35.5	*Polycirrus*	1.35	29.09
Cylichna cylindracea	1.53	39.64	*Phoronis*	1.5	32.54
Notomastus	1.13	43.13	*Owenia*	1.77	35.37
Ampharete lindstroemi agg.	1.17	46.41	*Notomastus*	1.23	38.06
Phoronis	1.8	49.68	*Cerianthus lloydii*	1.83	40.61
Prionospio multibranchiata	1.58	52.89	*Peresiella clymenoides*	1.19	43.06
Thyasira flexuosa	1.42	55.89	*Ampelisca tenuicornis*	1.2	45.47
Phaxas pellucidus	1.77	58.86	*Phaxas pellucidus*	1.28	47.67
Galathowenia oculata	1.1	61.02	*Magelona alleni*	0.98	49.82
Nephtys hombergii	0.95	63.16	*Mediomastus fragilis*	1.31	51.92
Magelona filiformis	1	65.06	*Ampharete lindstroemi agg.*	0.9	53.71
Trichobranchus roseus	1	66.82	*Magelona minuta*	1.1	55.39
Diastylis laevis	0.73	68.48	*Edwardsia claparedii*	0.89	57.04
Monticellina	1.01	70.1	*Trichobranchus roseus*	1.01	58.66
Nemertea	0.78	71.7	*Diplocirrus glaucus*	0.87	60.23
Ampelisca tenuicornis	0.88	73.14	*Nephtys kersivalensis*	0.91	61.76
Abra nitida	1.81	74.56	*Thyasira flexuosa*	0.98	63.19
Peresiella clymenoides	0.83	75.97	*Poecilochaetus serpens*	0.84	64.47
Magelona minuta	1	77.32	*Kurtiella bidentata*	1.08	65.74
Nephtys	0.67	78.39	*Abra alba*	0.81	66.97
Spiophanes bombyx	0.59	79.38	*Ampelisca spinipes*	0.85	68.18
Diplocirrus glaucus	0.7	80.35	*Glycera alba*	0.79	69.36
			Podarkeopsis capensis	0.63	70.3
			Abra nitida	1.12	71.23
			Praxillella affinis	0.63	72.15
			Lagis koreni	0.64	73.05
			Diastylis laevis	0.59	73.9
			Actiniaria	0.58	74.7
			Spiophanes kroyeri	0.67	75.49
			Chaetozone gibber	0.63	76.25
			Dipolydora coeca agg.	0.52	76.9
			Hydroides norvegica	0.86	77.54
			Galathowenia oculata	0.63	78.17
			Paguridae	0.52	78.79
			Terebellides	0.5	79.4
			Heteromastus filiformis	0.6	79.99
			Nephtys hombergii	0.5	80.54

Table 15. Continued

DS(past)
Average similarity: 27.20 %

Species	**Av.A**	**Cum.%**
Phaxas pellucidus	3.68	13.02
Cerianthus lloydii	2.61	24.93
Lumbrineris aniara/cingulata	2.25	32.73
Poecilochaetus serpens	1.31	37.45
Nephtys hombergii	1.26	41.45
Photis longicaudata	1.22	44.99
Dosinia	0.88	48.46
Spio decoratus	0.88	51.91
Ampelisca spinipes	1.18	55.27
Phoronis	1.17	58.6
Nemertea	1.2	61.73
Scalibregma inflatum	0.99	64.65
Urothoe elegans	0.74	67.2
Ampelisca tenuicornis	0.79	69.58
Polycirrus	1.25	71.7
Spiophanes bombyx	0.64	73.76
Lagis koreni	0.84	75.61
Nephtys kersivalensis	1.21	77.24
Amphiuridae	0.54	78.71
Dosinia lupinus	0.44	79.92
Abra alba	0.62	81.01

DS(curr)
Average similarity: 34.40 %

Species	**Av.A**	**Cum.%**
Melinna palmata	4.33	11.39
Scalibregma inflatum	3.57	20.93
Phaxas pellucidus	3.6	29.82
Lumbrineris aniara/cingulata	3.39	37.98
Cerianthus lloydii	3.33	45.22
Ampharete lindstroemi agg.	1.3	48.43
Nemertea	1.45	51.52
Owenia	1.59	54.39
Mediomastus fragilis	1.47	57.12
Kurtiella bidentata	1.75	59.52
Ampelisca tenuicornis	1.19	61.55
Glycera alba	0.93	63.45
Nephtys kersivalensis	0.9	65.27
Chaetozone gibber	0.97	67.05
Phoronis	1.02	68.82
Notomastus	0.86	70.56
Amphiura filiformis	1.32	72.26
Nephtys hombergii	0.81	73.74
Polycirrus	0.83	75.21
Magelona alleni	0.9	76.67
Lagis koreni	0.81	78.09
Edwardsia claparedii	0.84	79.37
Abra alba	1.07	80.44

MCZ-E %
Average similarity: 19.87

Species	**Av.A**	**Cum.%**
Nemertea	1.48	13.4
Amphiura filiformis	2.22	22.27
Magelona filiformis	1.7	29.73
Magelona johnstoni	1.83	36.33
Melinna palmata	1.71	42.66
Owenia	0.79	48.13
Ampharete lindstroemi agg.	1.15	52.59
Ampelisca tenuicornis	1.09	56.34
Chamelea striatula	0.76	60.08
Chaetozone christiei	1.02	63.74
Spiophanes bombyx	0.76	66.58
Monticellina	0.96	69.26
Notomastus	0.71	71.24
Phoronis	0.82	73.15
Urothoe poseidonis	0.64	75.03
Nephtys kersivalensis	0.63	76.83
Bathyporeia elegans	0.46	78.26
Lumbrineris aniara/cingulata	0.7	79.62
Kurtiella bidentata	1.2	80.9

4. DISCUSSION

4.1 Condition of the deep mud habitat within Whitsand and Looe Bay MCZ

The analysis of 2015 data showed results that are broadly consistent with previous assessments of the Whitsand and Looe Bay MCZ and surrounding areas, with particular regard to the deep mud habitat occurring within the MCZ.

The deep mud habitat is located at the SE margin of the MCZ, at depth >30 m (down to 43 m as recorded in 2015). Sediments are significantly muddier (mostly slightly gravelly muddy sands with 35-43 % mud and almost no gravel content) than in the rest of the MCZ where sedimentary habitats are dominated by subtidal sandy substrata (with > 90 % sand and < 6 % mud), being mostly slightly gravelly sands located at relatively shallow depth (down to 25 m approximately). Sediment data (as integrated between all survey years) also show the presence of a transition zone around the deep mud habitat area (particularly W-NW of it) within the MCZ where subtidal mixed sediment substrata are found.

The distribution of the deep mud habitat appears to extend outside the MCZ boundary, with similar sediment characteristics being also recorded in sampling stations located approximately 300 m south of the MCZ boundary and at similar depth as in the deep mud habitat within the MCZ. No sample data were available to characterise a gradient distance from the deep mud habitat, so its extent outside the MCZ boundary cannot be assessed with any certainty. As far as regards the area within the MCZ, there appear to be a broad consistency in the distribution of the muddy sediment over the years with the biotope area as mapped in Defra (2015). However, the sampling of the area was not designed to assess extent of this habitat (e.g. a regular sampling grid with replicate sampling over the years would be more suited to this aim), and therefore detailed assessment of interannual changes in its extent and spatial distribution cannot be undertaken based on the sample data. There is an indication of a possible contraction of the mud habitat extent in the SE corner of the deep mud biotope between 2013 and 2015, but this is based on observations from a single station and therefore cannot constitute proof of a trend and further targeted sampling would be required to ascertain this pattern. Furthermore, although the substratum in this part of the deep mud habitat has a lower mud content and is therefore characterised as subtidal sand habitat based on particle size data (station WLOB62 in 2015), the macrofaunal community still reflects characteristics closer to those of subtidal mud biotope (due to abundance of Ophiuroidea species) (Green and Godsell, 2016).

When integrating 2015 results with previous surveys providing a wider spatial coverage, the deep mud habitat (within the MCZ and just outside the MCZ boundary) shows some similarities with the Rame Head disposal site, due to the similarity in depth conditions (between 20 and 37 m) and in the higher mud content compared to the rest of the MCZ and surrounding marine area. However, gravel content is notably higher (24 % on average) in the disposal site compared to the deep mud habitat (where gravel content is almost negligible), albeit with a marked spatial variability (between <1 % and 65 %), and most of the seabed at the disposal site is characterised as subtidal mixed sediment habitat. The higher gravel content in the disposal site is likely to be associated with the dispersal processes acting in the area, whereby finer sediments are remobilised and transported away during and after disposal. Coarser mixed sediments (with gravel between 64 and 75 %) are also present relatively SE of the disposal site, with also a minor mud content (14 %) being recorded at the deepest station sampled in this area in 2015 (WLOB77, 31.6 m depth). The presence of mud in this area might be related to the predominant residual sediment transport in a SE direction away from the disposal site (Cefas, 2005, 2007), although it is noted that the mud content from a nearby deep station as sampled in previous years (G28 in SLAB5 surveys) was much higher (23-58 %) compared to 2015.

The analysis of the finer sediment fractions measured in the muddy sediments within the MCZ in 2015 has revealed a consistency over time (particularly in comparison with 2013) and higher similarity with the muddy sediments sampled in the surrounding marine area (as due to stations from the deep mud habitat outside the MCZ, as described above) and within Plymouth Sound. In turn, a significant differentiation was present with the muddy sediments from the middle and upper estuarine areas within the Plymouth Sound and Estuaries SAC. This is mainly due to the predominance of finer mud components in the estuarine sediments compared to the Sound and marine sediments, as it would be expected given the different nature and hydrodynamic conditions of the two areas.

Sediments collected from the deep mud habitat within the MCZ in 2015 showed contamination levels that are largely consistent with those recorded in previous years, although interannual fluctuations exist and 2015 levels are generally placed towards the lowest end of this variability range. Particularly notable (and significant) is the decrease in lead and nickel in 2015 compared to previous years. Trace metals in the sediments from the deep mud habitat within the MCZ are mostly below regional background levels in 2015, confirming previous assessments (Cefas, 2015). In turn, concentrations of most PAH and PCB compounds as recorded in the deep mud habitat within the MCZ in 2015 were above OSPAR BACs, similarly to what observed in previous years and in the muddy sediments from the surrounding marine area, the disposal site and the Plymouth Sound and Estuaries SAC area.

The comparison of contaminant concentrations with available standards also highlighted a moderate likelihood of toxicity to bottom dwelling organisms for sediments within the deep mud habitat in the MCZ, this being related in particular with As, Cr, Cu, Hg, Pb, and PAHs contamination. However, a similar result (particularly for trace metals) was obtained also for the less contaminated sediments within the rest of the MCZ. It is of note that there are natural high background levels of metals in the local area due to regional mineralogical characteristics and historic mining activities (Mazik & Elliott, 2011; Money et al., 2011), and it is likely that the local benthic fauna is adapted to such levels. This possible adaptation is not taken into account by the generic sediment guidelines given for marine sediments, and therefore the potential toxicity of the sediments for the fauna living in them could be overestimated.

When in the context of contamination levels measured in surrounding areas, the deep mud habitat shows contaminants concentrations generally higher than in the rest of the MCZ, but lower than in the current disposal site, with the highest values recorded for the Plymouth Sound and Estuaries SAC areas. This spatial pattern reflects the distribution of mud across the MCZ area (also in relation to depth) and is due to the higher affinity (i.e. binding capacity) of the finer (silt/clay) components for trace metals and organic contaminants (ICES, 2009). In fact, smaller differences between areas occurred when only muddy sediments were considered (hence reducing the effect of mud content distribution across areas).

Particularly notable is the higher concentration of trace metals, PAHs and PCBs observed in 2015 in the SAC areas, particularly from the middle and upper part of the Tamar estuary. This is a spatial pattern that reflects the presence of finer muddy fractions, as indicated by the sediment particle size analysis, and agrees with previous observations in the Tamar estuary (Bryan & Langston, 1992; Woodhead et al., 1999; Money et al., 2011). The observed sediment contamination in this area is almost always above background levels and the potential for toxicity issues has been highlighted by comparison with Canadian sediment quality guidelines (CCME, 2001). It is noted these latter standards were formulated for sediments in marine conditions and therefore higher uncertainty is associated with their use for the assessment of estuarine sediments. However, high levels of stress associated with metal and PAH pollution have been measured in mussels from the Tamar estuary, with animals from the upper part of this estuary being most affected (Shaw et al., 2011).

When compared to the current disposal site, the lower contamination levels measured in the muddy sediments from the deep mud habitat in 2015 agrees with previous observations of a decrease in contamination along a distance gradient from the disposal site (Okada et al., 2009). Although this difference may not be the result of a change in affinity of the sediments (as the two areas appeared to have similar mud content), it may be the result of the combination of different processes, including the dispersal from the disposal site and the mixing with natural sediments, as well as chemical reactions that might affect the transfer of metals from sediment to water column during and after disposal, as previously hypothesised (Okada et al., 2009).

The macrofaunal community structure in the deep mud habitat of Whitsand and Looe Bay MCZ is consistent with that of circalittoral sandy muds (biotope SS.SMu.CSaMu.AfilMysAnit), as described in JNCC (2015). The characterising species in this muddy area (when samples from all years were considered) include *Amphiura filiformis*, *Melinna palmata*, *Kurtiella* (*Mysella*) *bidentata* and *Abra nitida*, with *Phaxus pellucidus* and *Lagis koreni* increasing in mixed sediments of the disposal area. In 2015, the abundance of *Loimia medusa* increased throughout the survey area which may reflect the observed increase in sand content of the sediment. Overall species composition did not differ between the dredge disposal site (characterised my mixed muddy sediments) and the mud habitat although relative abundances were different with *P. pellucidus, Scalibregma inflatum, L. koreni* and *Lumbrineris* species being more common*.* *M. palmata* was the dominant species within the disposal site. These patterns are consistent with those documented in Cefas (2005) and Bolam et al. (2011). Whilst this would be expected given that all three studies include components of the same data set, the different approaches to the analysis but the consistency of the outputs provides confidence in the findings. Furthermore, the species composition and univariate indicators of diversity for the deep mud habitat in Whitsand Bay were similar to those of the muddy sediments in Plymouth Sound.

It is of note that the species in the deep mud habitat within the MCZ, those within the dredge disposal site and those within the surrounding muddy sediments are tolerant of periodic increases in suspended solids and sediment deposition (De Bastos, 2016). They are generally typical of habitats which are subject to frequent disturbance. For example, the polychaete *M. palmata* occurs in shallow mud, muddy sand and mixed sediments (Grehan, 1991; Dauvin et al., 2007) and shows high resistance to physical disturbance (including natural physical disturbance), most classes of chemical contamination, nutrients, organic enrichment and sediment deposition (Rostron et al., 1986; De Bastos, 2016). *L. koreni* has also been described as tolerant to disturbance related to dredge disposal (Whomersley et al., 2008). Sources of physical disturbance in this area may be both natural and anthropogenic. Natural sources of disturbance include exposure to waves and tidal currents, which may disturb and redistribute fine sediments, and the natural pattern of sediment transport out of Plymouth Sound (Siddorn et al., 2003; Okada et al., 2009; Elliott & Mazik, 2011), whilst possible anthropogenic disturbance relates to dredge disposal (see additional discussion on mud origin below). Regardless of the origin, the community in the deep mud habitat within the MCZ cannot be considered impoverished. The number of species, abundance and diversity (particularly evenness) are not strikingly different from the surrounding area and dominance by 1 or few species (indicative of stress) is not observed. Variation in community structure reflects variation in depth (with the marine area to the south of the MCZ being the most diverse) and sediment type. Furthermore, the mud habitats in Whitsand and Looe Bay MCZ and Plymouth Sound are broadly similar, despite differences in the sample processing techniques.

4.2 Origin of the deep mud habitat within Whitsand and Looe Bay MCZ

The vicinity of the deep mud habitat located in the Whitsand and Looe Bay MCZ to Rame Head disposal site has led to concerns that there might be anthropogenic causes to the presence of the mud habitat in the MCZ, considering the different nature of the sandy substratum covering most of the MCZ area.

The Rame Head disposal site has been operating for over 100 years, with only its southern part (Rame Head South, PL031) currently being used. The disposal site has received on average 104,000 tonnes of dredge material per year, 5.9 M tonnes of maintenance and capital material combined since 1982 (Cefas, 2017). Maintenance dredging from the Plymouth Sound and Tamar estuary area is the main (approx. 60 %) and most frequent source of material dumped at Rame Head disposal site, with the predominant origin being the naval dockyard (Devonport) in the middle section of the Plymouth Sound and Estuaries SAC and additional points of origin being the authorities of Cattewater Harbour commissioners, Sutton Harbour Company and Associated British Ports (ABP) Millbay Dock, and marinas such as the Plymouth Yacht Haven, Yacht Haven Quay and Queen Anne's Battery (Black & Veatch Ltd, 2010). Capital dredging has also contributed to source material (2.5 M wet tonnes since 1982) destined to Rame Head disposal site, with more recent significant peak in dredge volumes associated with the Remote Ammunitioning Facility Tamar (RAFT) Naval Base development in 2000/2001 and the 2004 Millbay Dock development (Black & Veatch Ltd, 2010). Typically, disposal is undertaken during the winter months, with the location, depth, tidal circumstance and seasonal timing restricted in the FEPA license, to ensure that the material is either quickly dispersed by local currents or rapidly deposited (Mazik & Elliott, 2011). The material deposited at the disposal site consists mainly of clay and silt of modal particle size around 40 µm (Okada et al., 2009).

Rame Head South, like the majority of disposal sites located along the English and Welsh coast, is a dispersive disposal site located in a hydrologically dynamic area (Mazik & Elliott, 2011; Cefas, 2015). It is therefore expected that dredged material is dispersed during or after deposition and transported away from the site by currents and wave action. Prevailing tidal current in the area is along a NW-SE direction, with predominant residual movement of disposed material having been reported along a SE direction away from the disposal site (Cefas, 2005, 2007, 2015). Recent hydrodynamic modelling of the area by Uncles et al. (2015) and by Cefas (2016b; in relation to a potential selection of a new disposal site further SW off Rame Head) have confirmed the existence of an eddy on the eastern shore of Whitsand Bay, near Rame Head, with a clockwise flow during ebb tide, and with currents also flowing from Plymouth Sound around Rame Head to the eastern part of Whitsand Bay (Figure 20). This eddy described, is likely to influence the settlement of fine particles, particularly as there are slow tidal currents in the area. The tidal currents within the bay are < 0.25 m s^{-1} (< 0.15 m s^{-1} for an average tide; Uncles et al., 2015), i.e. lower than the threshold velocity for transport of sediment particles of around 40 µm diameter (25 cm s^{-1}; Hjulstrom, 1935), and therefore are likely to influence the settlement of fine particles in the area. Considering the above hydrodynamic evidence, the hypothesis of a transport of fine (mud) sediment from the disposal site into the MCZ is considered valid.

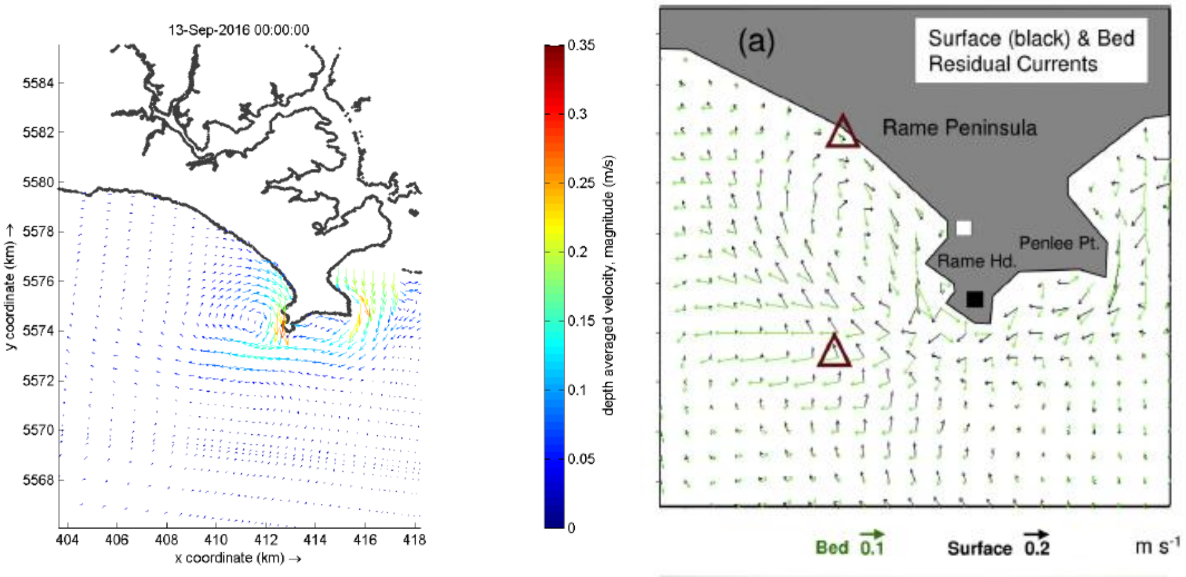


Figure 20. Modelled tidal velocities showing an eddy at the eastern side of Rame Head. Source: Left panel- Cefas (2016); Right panel- Uncles et al. (2015).

The 2015 data were analysed in the context of previous survey data by taking into account the above transport hypothesis as well as the fine nature of the dredge dispersed sediment, by focusing the analysis on fine (mud) fractions only (sediment particle size analysis) or on muddy or mud sediments only (sediment particle size, contaminant and macrofaunal analysis). This approach is likely to increase the chances of identifying sample similarities that can be related to a signal from dredge material (Okada et al., 2009). The resulting spatial patterns, as described in the previous section, have highlighted similarities in depth and broad sediment characteristics, and in consequent sediment contamination and macrofaunal community, between the deep mud habitat within the MCZ and the disposal site, with differences, likely agreeing with a dispersal hypothesis. For example, despite the similarity in mud content, coarser material (due to a higher gravel and lower sand content) characterised the disposal site compared to the deep mud habitat in the MCZ, in agreement with the findings of Murray (2002). Similarly, changes in finer sediment characteristics and contamination were previously detected on a distance gradient along the main NW-SE direction from the disposal site, and these might be related with the transport and deposition of dispersed material from the disposal site as well as with chemical reactions occurring during and after disposal (e.g. leading to exchanges of metals between sediments and the water column) (Okada et al., 2009). These authors suggested a possible influence of the disposal site on particle size and metal concentrations in sediments around 6 km of disposal site (Okada et al., 2009). Macrofaunal data, as analysed in the present study, also confirmed the presence of species that are adapted to disturbed conditions in the mud habitat.

Although the above spatial patterns may suggest a possible connectivity between the disposal site and the deep mud habitat in the MCZ, these alone are not enough to prove the anthropogenic origin of the mud in the MCZ. Considering the hydrodynamic conditions described above, and the similarities observed in the data, the influence of possible natural sediment transport and sources cannot be ignored. Modelling studies have highlighted that a proportion of sediment transported out of the Tamar and Plymouth Sound is likely to be transported into Whitsand Bay, where the low currents would favour fine sediment deposition (Siddorn et al., 2003; Uncles et al., 2015; Cefas, 2016). Furthermore, the deep mud habitat within the MCZ shares broadly similar sediment and faunal characteristics with the Plymouth Sound and estuaries SAC areas, but with significant gradients (e.g. coarser mud and lower contamination with increasing distance from the upper/middle parts of the estuarine SAC) that could also be related to a transport hypothesis from the SAC area to Whitsand Bay. It is of note that the dredge material dumped at the Rame Head disposal site also originates from the Plymouth Sound and Tamar estuary areas, and therefore a common signature would be expected in sediments from the deep mud habitat in the MCZ and in the Rame Head disposal site, even in the absence of any connection between these two sites, i.e. with only natural transport of sediments from the Plymouth Sound and estuaries SAC areas.

A number of historic studies make reference to “Rame Mud”. While Crawford (1937) seems to refer to Rame mud as to a shallower area of 20 m depth, possibly SE of Rame Head, other sources indicate Rame mud as a muddy patch which lies to the south of the disposal site, at a depth of approximately 50 m (Mare, 1942; Holme, 1953;[7]). The exact location or the origin of this mud habitat are not known (a disused disposal site exists to the south of Rame Head) but if natural, the presence of this habitat indicates the potential for naturally occurring muddy sediments in this area. Furthermore, this muddy area could also be an additional source of mud for the deep mud habitat in the MCZ, although there is higher uncertainty on this link, given the uncertainty on the location and nature of the Rame mud habitat.

An additional line of evidence was explored by analysing temporal correlation between disposal volumes at the disposal site and sediment characteristics and contamination at the disposal site and at the deep mud habitat in the MCZ. This analysis was undertaken to test the hypothesis that a signal of increase in sediment mud content and contamination would occur when higher volumes of dredge material were dumped at the disposal site and that consistent positive relationships would occur for both sites under the assumption of a source-sink link between them. Such a relationship and consistency between the two sites was not detected, hence the link between disposal site and mud in the MCZ could not be proved (although it cannot be excluded). It is of note that, in some cases, negative correlations between contamination and disposal volumes were observed, and, although they cannot be explained, these highlight the variability and uncertainty of the obtained results.

Overall, it is expected that the deep mud habitat occurring within the MCZ originates from multiple sources, which may include the disposal site (Table 16). However, the relative contribution of sediment from each source can be neither quantified nor separated and, therefore, the disposal site cannot justifiably be identified as the only source. Furthermore, the benthic communities within the muddy habitat are similar to those in the muddy areas of Plymouth Sound. They are typical of the habitat and cannot be considered impoverished.

---

[7] See also http://www.westernchannelobservatory.org.uk/benthic_survey.php

Table 16. Summary of lines of evidence on potential sources of sediment.

Evidence in support of the disposal site as a potential source	Evidence against disposal site as a potential source	Conclusion	Confidence in Disposal site as a source
Mud habitat adjacent to disposal site	No direct evidence There are no data to confirm the pre-disposal existence of the mud habitat	Disposal site is a potential source	Low when all factors are considered holistically
Similar sediment characteristics in mud habitat and disposal site	Similar sediment type to Plymouth Sound, the source of the dredged material.	Multiple potential sources	Low, the contribution of sediment from Plymouth Sound, the disposal site and any other source can neither be quantified nor separated.
Prevailing current patterns put the mud habitat in the path of sediment dispersed from the disposal site	Prevailing currents carry sediment from Plymouth Sound in a NW-SE direction. This results in transportation of sediments from Plymouth Sound and the estuaries feeding into it and, possibly from the disposal site.	Multiple potential sources	Low, the contribution of sediment from Plymouth Sound, the disposal site and any other source can neither be quantified nor separated.
Disposal site is 'dispersive'	It is accepted that material moves off the disposal site, and in the direction of the mud habitat. However, this cannot be separated from Plymouth Sound as a source of sediment to the deep mud habitat	Multiple potential sources	Low, the contribution of sediment from Plymouth Sound, the disposal site and any other source can neither be quantified nor separated.
Contaminants present in the mud habitat at elevated concentrations compared to the surrounding area. Concentrations in the disposal site were lower than in the mud habitat, reflecting the higher gravel content of that site.	Highest concentrations were recorded form Plymouth Sound and the estuaries	Multiple potential sources	None. Contaminant concentrations were strongly linked to particle size. The source of the fine sediments cannot be established.
There are similarities between the benthic communities in the disposal site and the mud habitat	There are also similarities with the benthic communities in the muddy sediments in Plymouth Sound	Multiple potential sources	None. The benthic communities are typical of the habitat in all three locations. None are considered impoverished

4.3 Conclusions

The data collated from 2015 and previous surveys do not allow to establish the origin of the deep mud habitat occurring within the Whitsand and Looe Bay MCZ. There is uncertainty associated with the data themselves. In addition, the available survey design and the type of data do not allow to test a source-sink hypothesis.

The sampling programmes undertaken over the years were not designed to assess the deep mud habitat in the study area and specifically the potential relationship with existing disposal site and surrounding areas. As such, there is variable spatial coverage and sampling effort over the years and this affects the confidence on results. For example, only one station was sampled in the deep mud habitat within the MCZ in SLAB5 surveys, and therefore there is high uncertainty associated with using these stations as representative of the mud area as a whole.

Ideally, a before-after-control-impact (BACI) design would be needed to test a possible effect of the Rame Head disposal site on the presence and characteristics of the mud habitat in the MCZ. However, no historic evidence could be found referring to the existence of the deep mud habitat in Whitsand Bay before the Rame Head disposal site became operational (i.e. more than 100 years ago), nor data from a control site in the area (i.e. deep mud habitat in similar hydrological conditions and natural influences but outside the possible influence of the disposal site) were available. In the absence of such data, the lines of evidence gathered over the years on sediment characteristics, contamination and faunal communities can only be regarded as circumstantial in the search for an understanding of the origin of the mud habitat in the Whitsand and Looe Bay MCZ.

As a result, it is likely that the fine sediments in the Rame Head disposal site and in the deeper area of the MCZ have a common origin. However, the evidence available does not allow to establish the degree to which the mud habitat in the MCZ originates directly from the disposal site or is the result of natural processes (e.g. transport from Plymouth Sound and Tamar estuaries area). Alternative approaches (e.g. use of tracers that allow to characterise and differentiate sediments from natural sources vs. disposal site) would be more suited for future assessments, as suggested in Cefas (2015).

Irrespectively of its origin, the results suggest that the deep mud habitat has been present in the MCZ throughout the duration of the survey work undertaken since 2001 by Cefas and the EA/Natural England. Minor changes have been observed in the sediment characteristics, contamination and infaunal communities, generally associated with natural interannual variability rather than with existing trends, thus suggesting a relative stability in the condition of this habitat. Although the habitat characteristics significantly differ from the rest of the MCZ due to depth and nature of the substratum, there are not striking differences from the surrounding areas where muddy sediments also occur. Furthermore, the deep mud habitat in the MCZ shows a well-established macrofaunal community which is typical of the substratum and hydrodynamic conditions in the area and which doesn’t show signs of stress.

5. REFERENCES

ARNOLD, K. & GODSELL, N. 2016. Whitsand and Looe Bay MCZ 2013 Survey Report. . Report of the Environment Agency to Cefas. Project Code: C5784A. Final report (version 3.0), July 2016.

BLACK & VEATCH LTD. 2010. Baseline document for maintenance dredging in Plymouth Sound and Estuaries European Marine Site. Report to Debut Services (SW) Ltd and Defence Estates, 147pp.

BLOTT, S.J. & PYE, K. 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, 26, 1237-1248.

BOLAM, S.G., BARRY, J., BOLAM, T., MASON, C., RUMNEY, H.S., THAIN, J.E. & LAW, R.J. 2011. Impacts of maintenance dredged material disposal on microbenthic structure and secondary productivity. *Marine Pollution Bulletin*, 62, 2230-2245.

BOLAM, S.G., BOLAM, T., RUMNEY, H., BARBER, J., MASON, C., MCILWAINE, P., CALLAWAY, A., MEADOWS, B., PETTAFOR, A. & ARCHER, S. 2015. Dredged Material Disposal Site Monitoring Around the Coast of England: Results of Sampling (2014). A report from Cefas to the MMO. Cefas contract report: SLAB5. May 2015.

BRYAN, G.W. & LANGSTON, W.J. 1992. Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environmental Pollution*, 76, 89-131.

CANADIAN COUNCIL OF MINISTERS OF THE ENVIRONMENT. 2001. Canadian sediment quality guidelines for the protection of aquatic life: Summary tables. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. URL: http://www.elaw.org/system/files/sediment_summary_table.pdf [Accessed January 2017].

CEFAS. 2005. Environmental impacts resulting from disposal of dredged material at the Rame Head disposal site, S.W. England: An analysis of existing data and implications for environmental management. A CEFAS Multi-disciplinary Project Team. Work performed under CEFAS Contract BA004. Version 2nd, June 2005.

CEFAS. 2005. Rame Head: Furthering our understanding of the ecological consequences of dredged material disposal activities. Report ME1116 to Defra. Cefas, Lowestoft, UK, 19pp.

CEFAS. 2011. Regional trace metal baselines for determining trace metal enrichment at disposal site assessment in England and Wales. Final report for project ME5403 Module 10, Cefas, Lowestoft, UK.

CEFAS. 2015. Rame Head Marine Conservation Zone (MCZ) subtidal mud review report. Published by the MMO, October 2015. URL: https://www.gov.uk/government/news/outcome-of-review-on-whitsand-and-looe-bay-mcz-sub-tidal-mud [Accessed January 2017].

CEFAS. 2016. BERAUD, C. Modelling of dredged material disposal at proposed disposal site off Plymouth (draft for steering group) C7041, 33 pp, October 2016.

CEFAS. 2017. RANDALL, K. Plymouth dredged material disposal site selection-characterisation report C7041, 172 pp, February 2017. URL: https://www.gov.uk/government/publications/plymouth-dredged-material-disposal-site-selection-phase-1 [Accessed March 2017]

CLARKE K.R. & WARWICK, R.M. 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E: Plymouth.

CRAWFORD, G.I. 1937. Notes on the distribution of burrowing isopoda and amphipoda in various soils on the sea bottom near Plymouth. *Journal of the Marine Biological Association UK*, 21(2), 631-643.

DAUVIN, J-C., RUELLET, T., THEIBAUT, E., GENTIL, F., DESROY, N., JANSON, A-L., DUHAMEL, S., JOURDE, J. & SIMON, S. 2007. The presence of *Melinna palmata* (Annelida: Polychaeta) and *Ensis directus* (Mollusca: Bivalvia) related to sedimentary changes in the Bay of Seine (English Channel, France). *Cahiers de Biologie Marine,* 48, 391-401.

DE-BASTOS, E.S.R. 2016. *Melinna palmata* with *Magelona* spp. and *Thyasira* spp. in infralittoral sandy mud. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. URL: http://www.marlin.ac.uk/habitat/detail/1104 [Accessed August 2016].

DEFRA. 2015. Whitsand and Looe Bay MCZ Summary Site Report. Contract Reference: MB0120. Report Number: 24, Version 3. March 2015.

ELLIOTT, M. & MAZIK, K. 2011. Rame Head Environmental Impact study: Review of Evidence. Report of the Institute of Estuarine and Coastal Studies, University of Hull to the Marine Management Organisation. Report No. YBB168-F-2011, February 2011.

GREEN, B. & GODSELL, N. 2016. Whitsand and Looe Bay MCZ Baseline Survey Report. Report of the Environment Agency to Natural England. Project Code: RP02821. Final report (version 3.0), January 2016.

GREHAN, A.J. 1991. Demography and reproductive biology of *Melinna palmata* (Ampharetidae: Polychaeta) in inner Galway Bay on the west coast of Ireland. *Mar. Biol.,* 109, 459-467.

HOLME, N.A. 1953. The biomass of the bottom fauna in the English Channel off Plymouth. *Journal of the Marine Biological Association of the United Kingdom*, 32(1), 1-49.

JNCC. 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03 [Online]. URL: www.jncc.defra.gov.uk/MarineHabitatClassification [Accessed February 2017]

HJULSTROM, F. 1935. Studies on the morphological activity of rivers as illustrated by the River Fyris. *Bulletin of the Geological Institute of Uppsala* 25, 221–527.

ICES. 2009. Report of the Work Group on Marine Sediments in Relation to Pollution (WGMS, 2009). URL: http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2009/Special%20Requests/OSPAR%20JAMP%20guidance%20%20normalisation%20of%20contaminant%20concentrations%20in%20sediment.pdf [Accessed February 2017].

LONG, E.R., FIELD, L.J. & MACDONALD, D.D. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environmental Toxicology and Chemistry*, 17(4), 714–727.

MARE, M.F. 1942. A study of a marine benthic community with special reference to the micro-organisms. *Journal of the Marine Biological Association of the United Kingdom*, 25(3), 517-554.

MONEY, C., BRAUNGARDT, C.B., JHA, A.N., WORSFOLD, P.J. & ACHTERBERG, E.P. 2011. Metal speciation and toxicity of Tamar estuary water to larvae of the Pacific oyster *Crassostrea gigas*. *Marine Environmental Research*, 72, 3-12.

MURRAY, I. 2002. Impact of dredged spoil on grain size distributions in Whitsand Bay, Cornwall. Unpublished BSc thesis, University of Plymouth, 157pp.

OKADA, T., LARCOMBE, P. & MASON, C. 2009. Estimating the spatial distribution of dredged material disposed of at sea using particle-size distributions and metal concentrations. *Marine Pollution Bulletin*, 58, 1164-1177.

OSPAR Commission. 2008. Co-ordinated Environmental Monitoring Programme – Assessment manual for contaminants in sediment and biota ISBN 978-1-906840-20-4, Publication Number No. 379/2008.

ROSTRON, D.M., LITTLE, D.I. & HOWELLS, S.E. 1986. A study of the sediments and communities in Milford Haven, Wales. *Oil & Chemical Pollution*, 3, 131-166.

SHAW, J.P., DONDERO, F., MOORE, M.N., NEGRI, A., DAGNINO, A., READMAN, J.W., LOWE, D.R., FRICKERS, P.E., BEESLEY, A., THAIN, J.E. & VIARENGO, A. 2011. Integration of biochemical, histochemical and toxicogenomic indices for the assessment of health status of mussels from the Tamar Estuary, UK. *Marine Environmental Research*, 72, 13-24.

SIDDORN, J.R., ALLEN, J.I. & UNCLES, R.J. 2003. Heat, salt and tracer transport in the Plymouth Sound coastal region: a 3D modelling study. *Journal of the Marine Biological Association UK*, 83, 4074/1-10.

UNCLES, R.J., STEPHENS, J.A., HARRIS, C., 2015. Physical processes in a coupled bay-estuary coastal system: Whitsand Bay and Plymouth Sound. *Progress in Oceanography*, 137, 360-384.

WHOMERSLEY, P., WARE, S., REES, H.L., MASON, C., BOLAM, T., HUXHAM, M. & BATES, H. 2008. Biological indicators of disturbance at a dredged-material disposal site in Liverpool Bay, UK: an assessment using time-series data. *ICES Journal of Marine Science,* 65(8), 1414-1420.

WOODHEAD, R.J., LAW, R.J. & MATTHIESSEN, P. 1999. Polycyclic aromatic hydrocarbons (PAH) in surface sediments around England and Wales, and their possible biological significance. *Marine Pollution Bulletin*, 38, 773-790.

APPENDICES

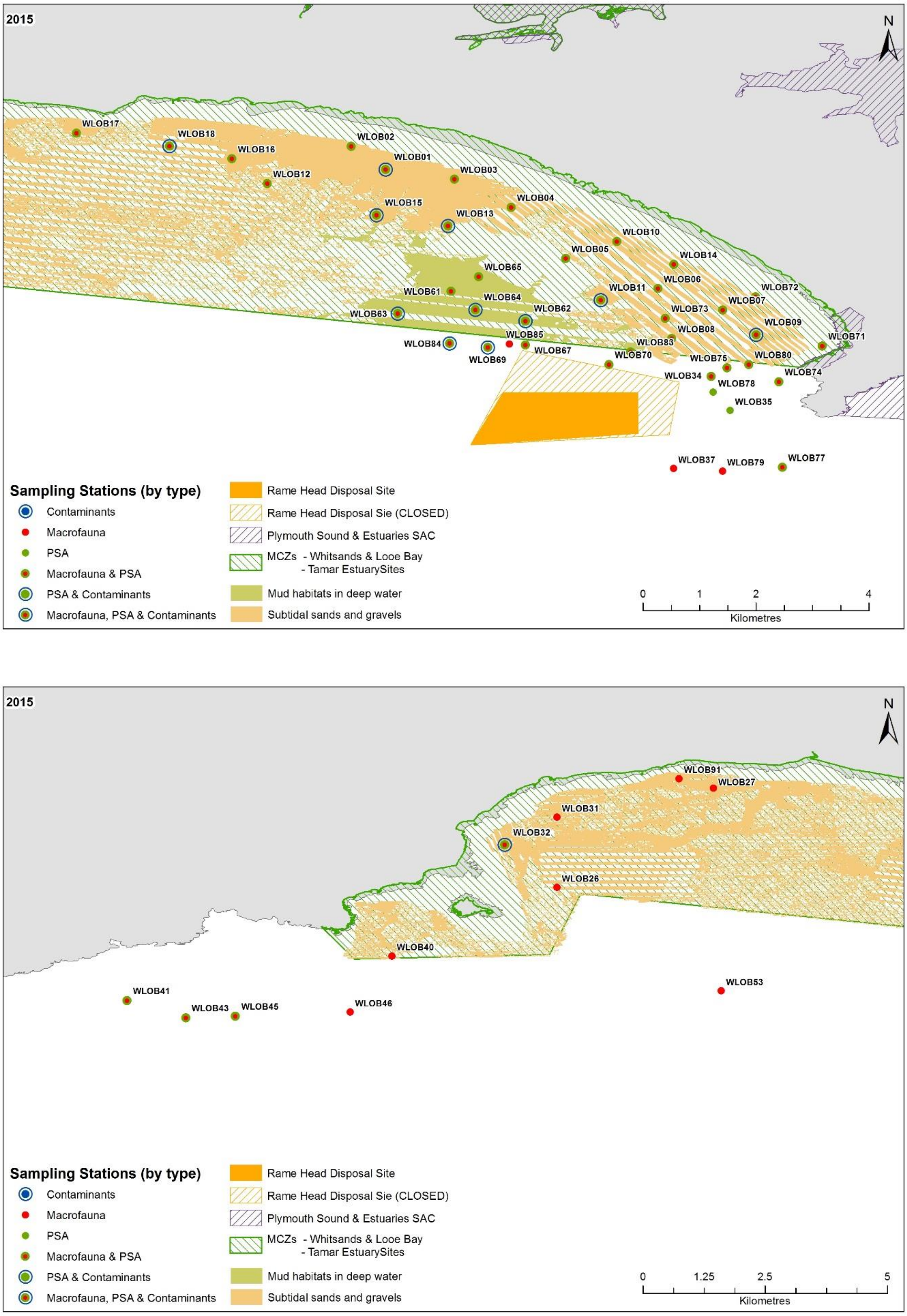
Appendix 1. Data collated by survey year and zone.

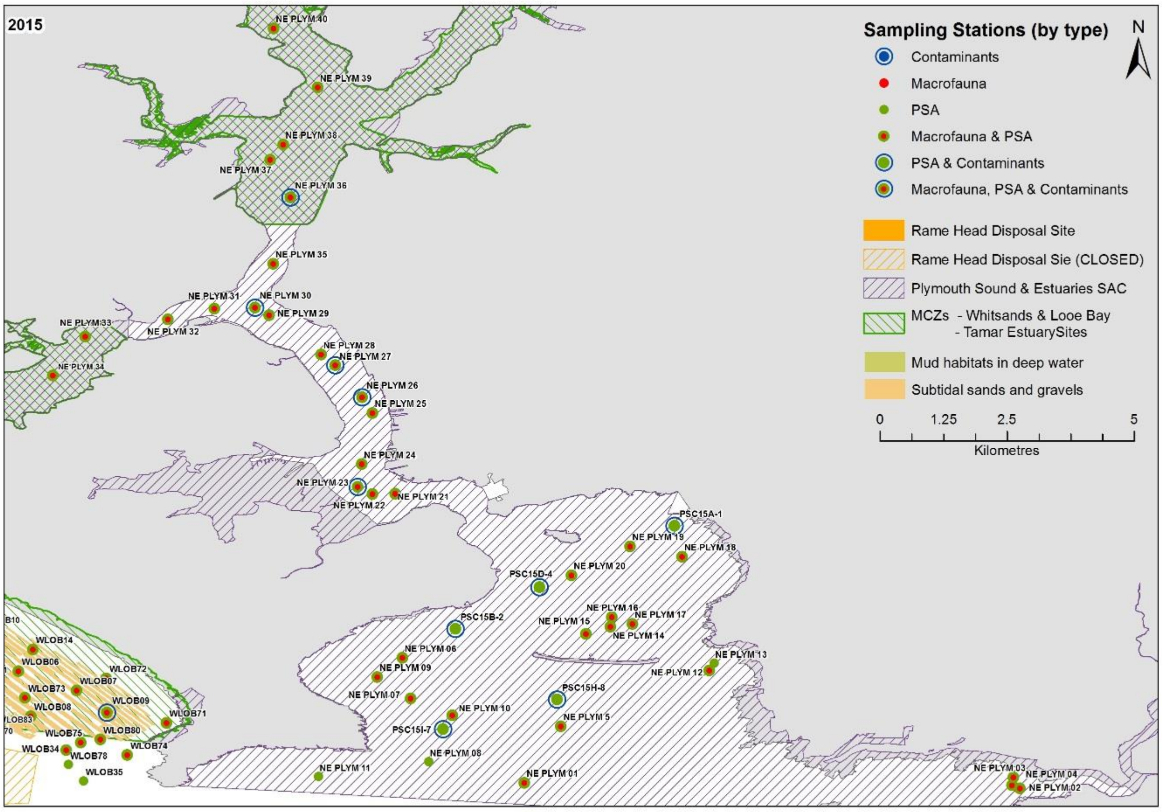
Table A1.1. Number of sample data available for different survey components by survey year and zone.

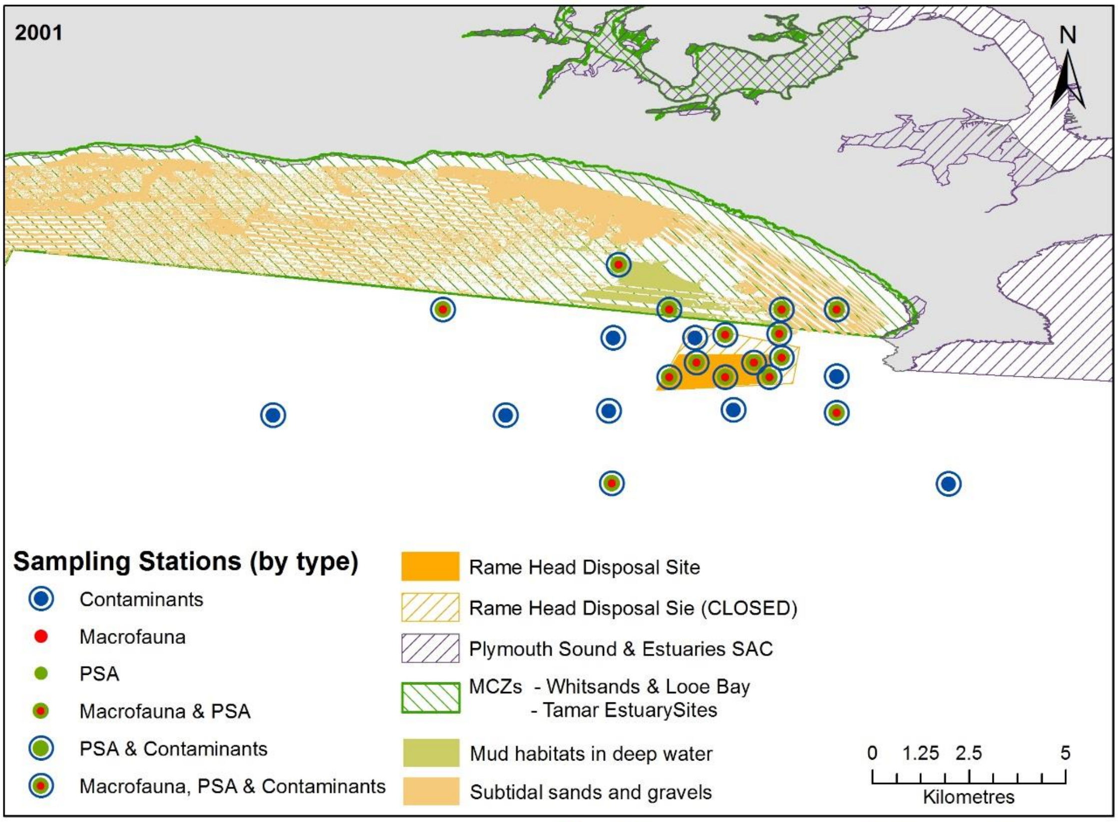
Zone	Data	Sampling year													
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2013	2014	2015	Total
MCZ-E_Mud	Macrofauna	2						1	1	1		10	*	5	20
	Sediment particle size	2	1	2			1	3	3	5		10	3	5	35
	Contaminants	2	1	2		1	1	3	3	6			*	3	22
MCZ-E	Macrofauna	2	1	1	1	1	3	2	2	2		24	*	21	60
	Sediment particle size	2	1	8	1	11	4	10	5	6		24	5	21	98
	Contaminants	2	1	10	1	12	4	10	5	6			*	6	57
MCZ-W	Macrofauna											2		6	8
	Sediment particle size							1				2		1	4
	Contaminants							1						1	2
DS(current)	Macrofauna	5	2	2	1	2	1	3	4						20
	Sediment particle size	5	3	3	1	2	1	4	5						24
	Contaminants	5	3	3	1	3	1	4	5						25
DS(past)	Macrofauna	2	1		1		2						*		6
	Sediment particle size	2	1	1	1		2						1		8
	Contaminants	3	1	1	1		2						*		8
DS(offsh)	Macrofauna							1	1	1			*		3
	Sediment particle size							1	1	1			1		4
	Contaminants							1	1	1			*		3
Mar	Macrofauna	4	4	3	3	4	5	4	4	4			*	13	48
	Sediment particle size	4	5	7	3	4	6	7	6	19			6	12	79
	Contaminants	11	5	7	3	5	6	7	6	19			*	2	71
Mar-W	Macrofauna													5	5
	Sediment particle size							1						3	4
	Contaminants							1							1
SAC_PlymS	Macrofauna										35			14	49
	Sediment particle size					5		1			29			22	57
	Contaminants					5		1						5	11
SAC	Macrofauna										18			16	34
	Sediment particle size							3			17			16	36
	Contaminants							3						4	7
SAC_Tam	Macrofauna										5			7	12
	Sediment particle size										5			7	12
	Contaminants													1	1
Total	Macrofauna	15	8	6	6	7	11	11	12	8	58	36		87	265
	Sediment particle size	15	11	21	6	22	14	31	20	31	51	36	16	87	361
	Contaminants	23	11	23	6	26	14	31	20	32				22	208

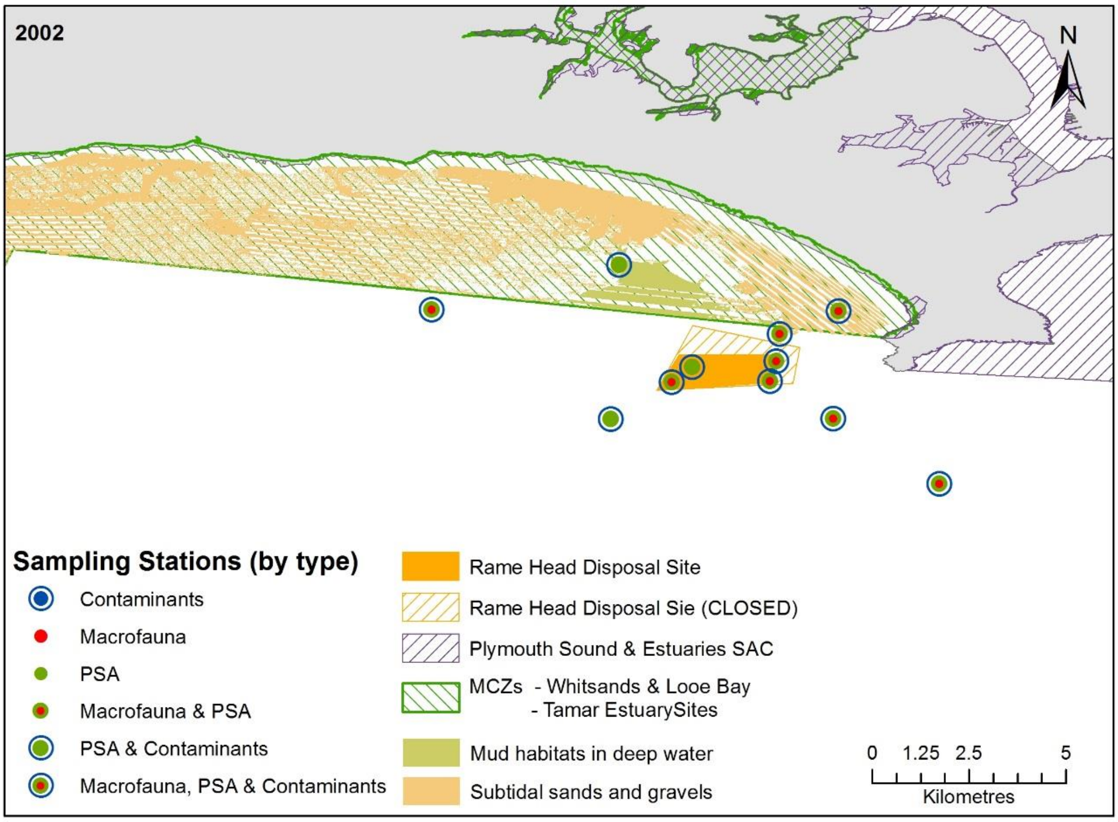
* Samples were collected but data could not be obtained.

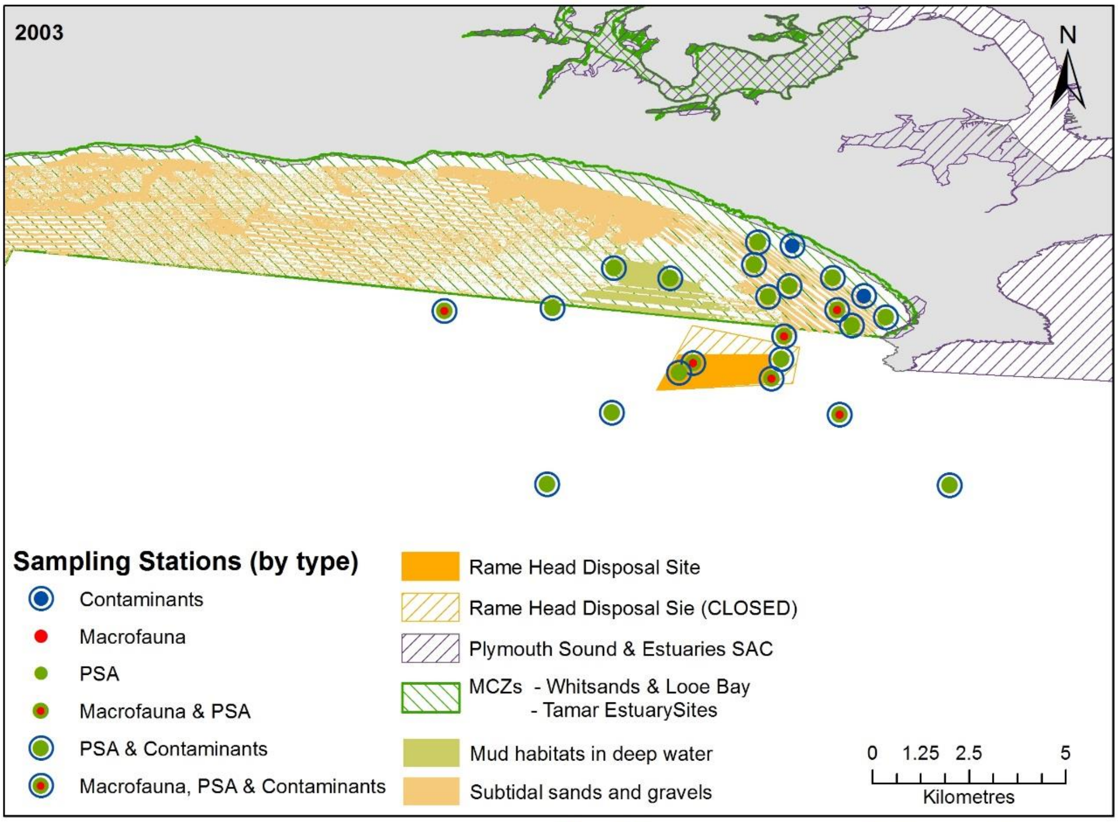
Figure A1.1. Sample locations with survey component in analysed datasets by year.

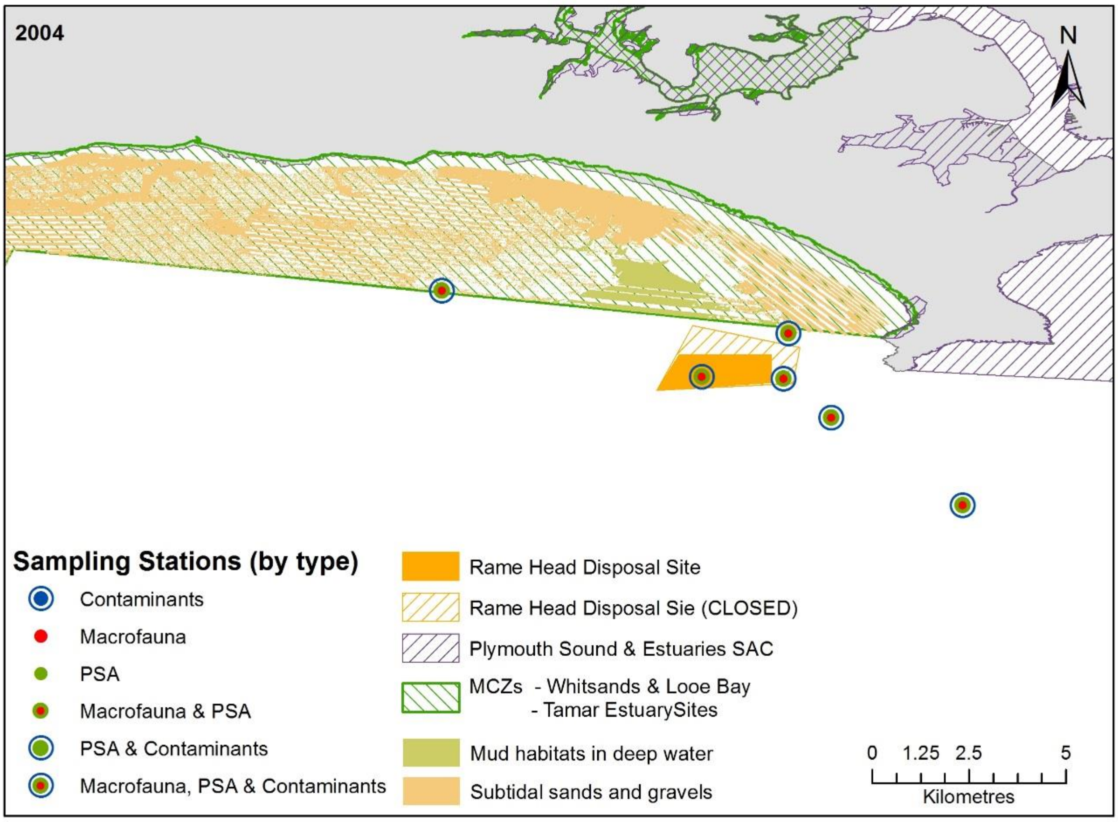


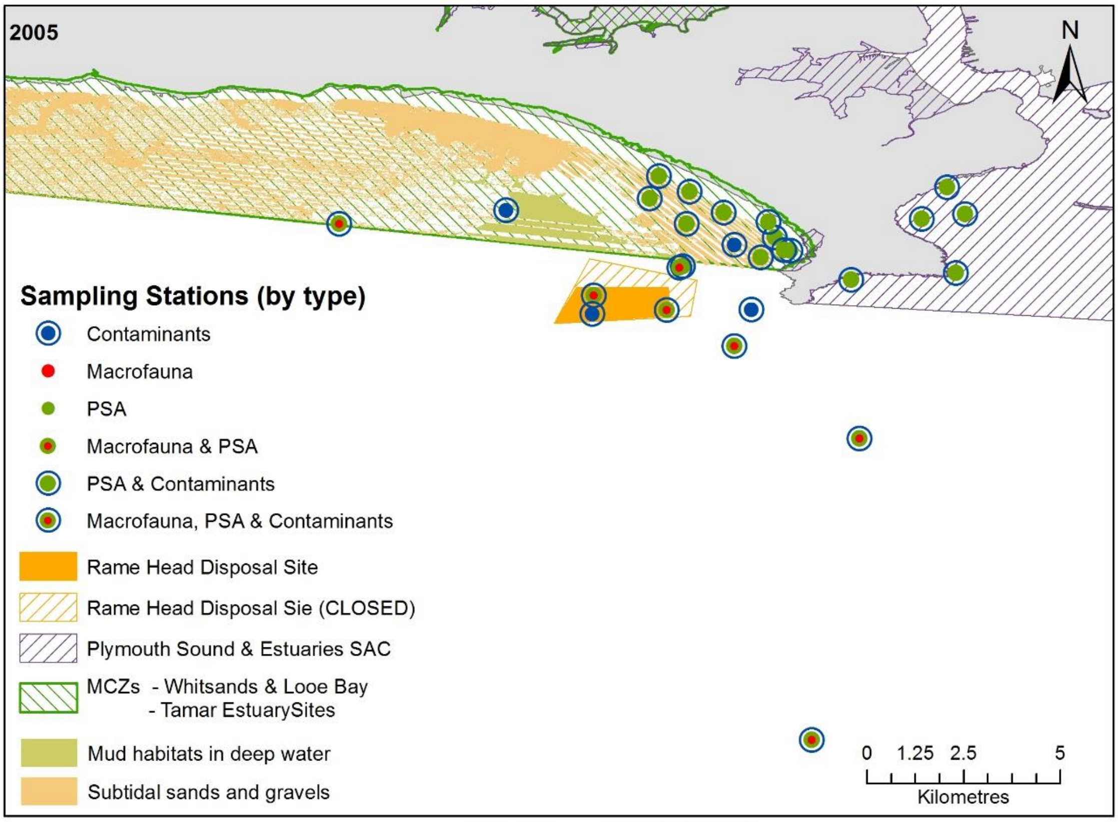

2015
Sampling Stations (by type)
N
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0
1.25
2.5
5
Kilometres
NE PLYM 40
NE PLYM 39
NE PLYM 38
NE PLYM 37
NE PLYM 36
NE PLYM 35
NE PLYM 31
NE PLYM 30
NE PLYM 29
NE PLYM 33
NE PLYM 32
NE PLYM 34
NE PLYM 28
NE PLYM 27
NE PLYM 26
NE PLYM 25
NE PLYM 24
NE PLYM 23
NE PLYM 22
NE PLYM 21
PSC15A-1
NE PLYM 19
NE PLYM 18
NE PLYM 20
PSC15D-4
NE PLYM 16
NE PLYM 17
NE PLYM 15
NE PLYM 14
PSC15B-2
NE PLYM 06
NE PLYM 09
NE PLYM 13
NE PLYM 12
NE PLYM 07
PSC15H-8
NE PLYM 10
NE PLYM 5
PSC15I-7
NE PLYM 08
NE PLYM 11
NE PLYM 01
NE PLYM 03
NE PLYM 04
NE PLYM 02
B10
WLOB14
WLOB06
WLOB72
WLOB07
WLOB73
WLOB09
WLOB08
WLOB71
WLOB83
70
WLOB75
WLOB80
WLOB34
WLOB78
WLOB74
WLOB35

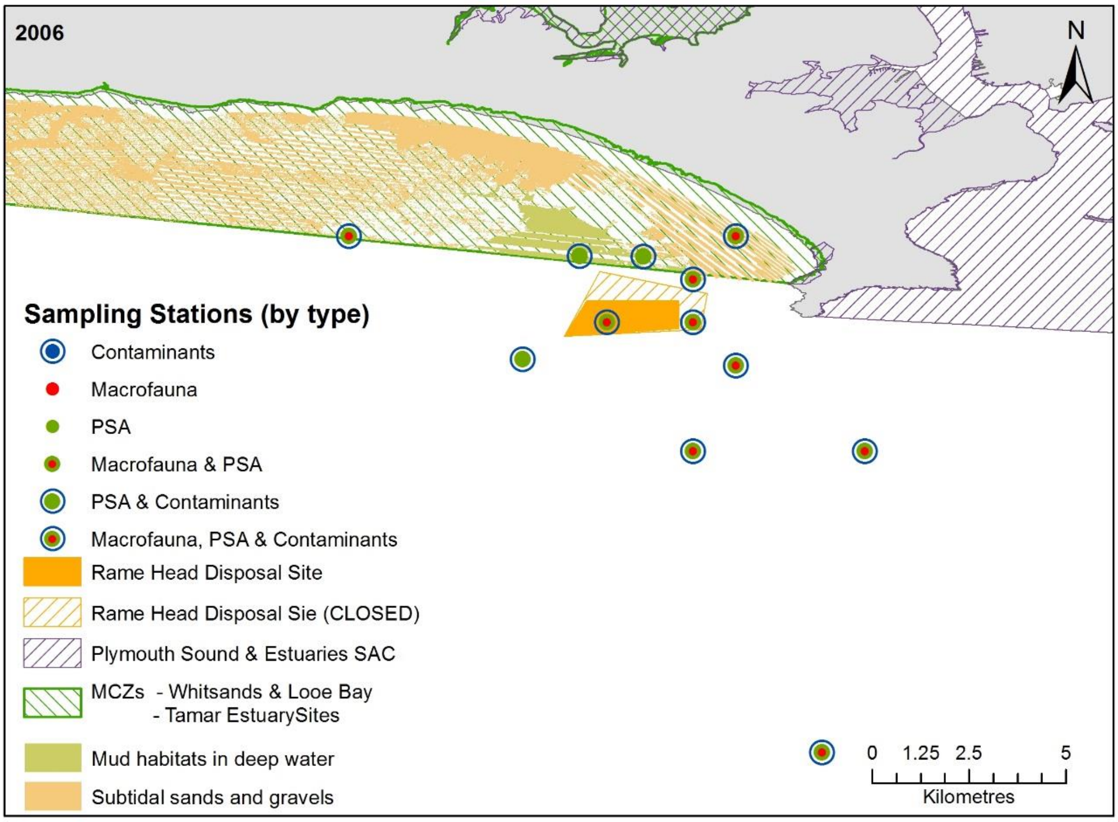

2001
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

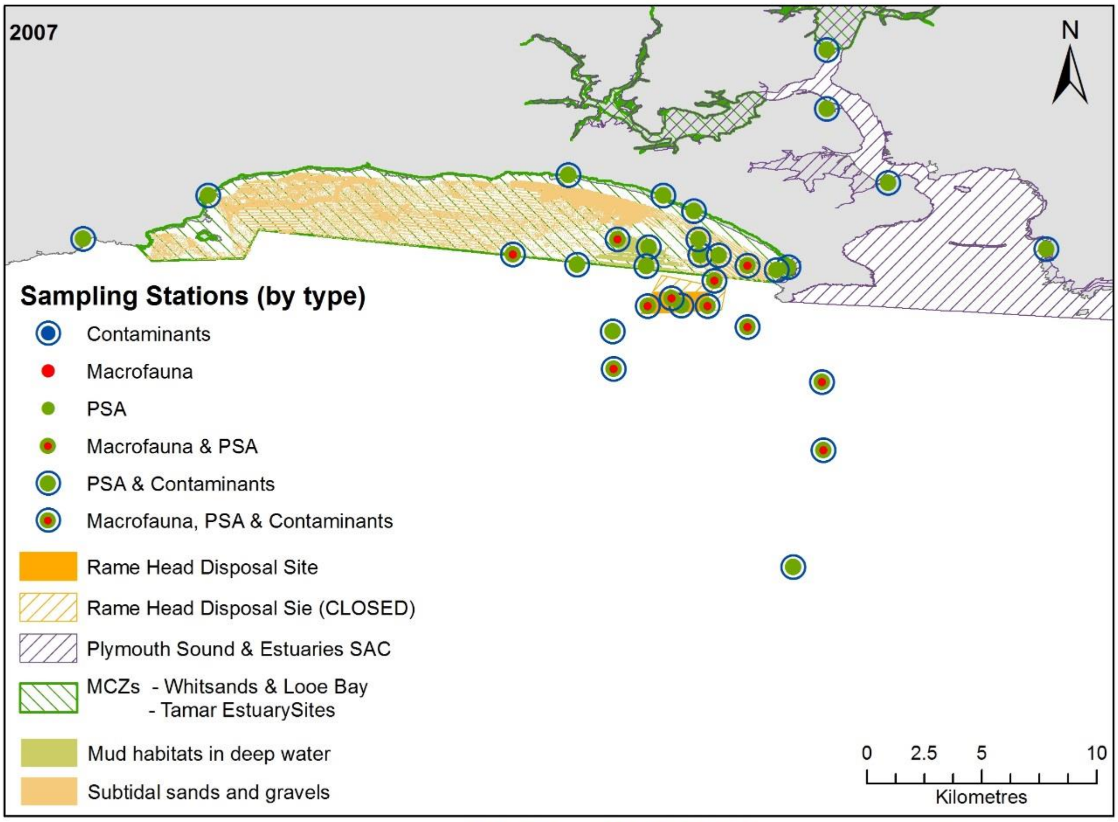

2002
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

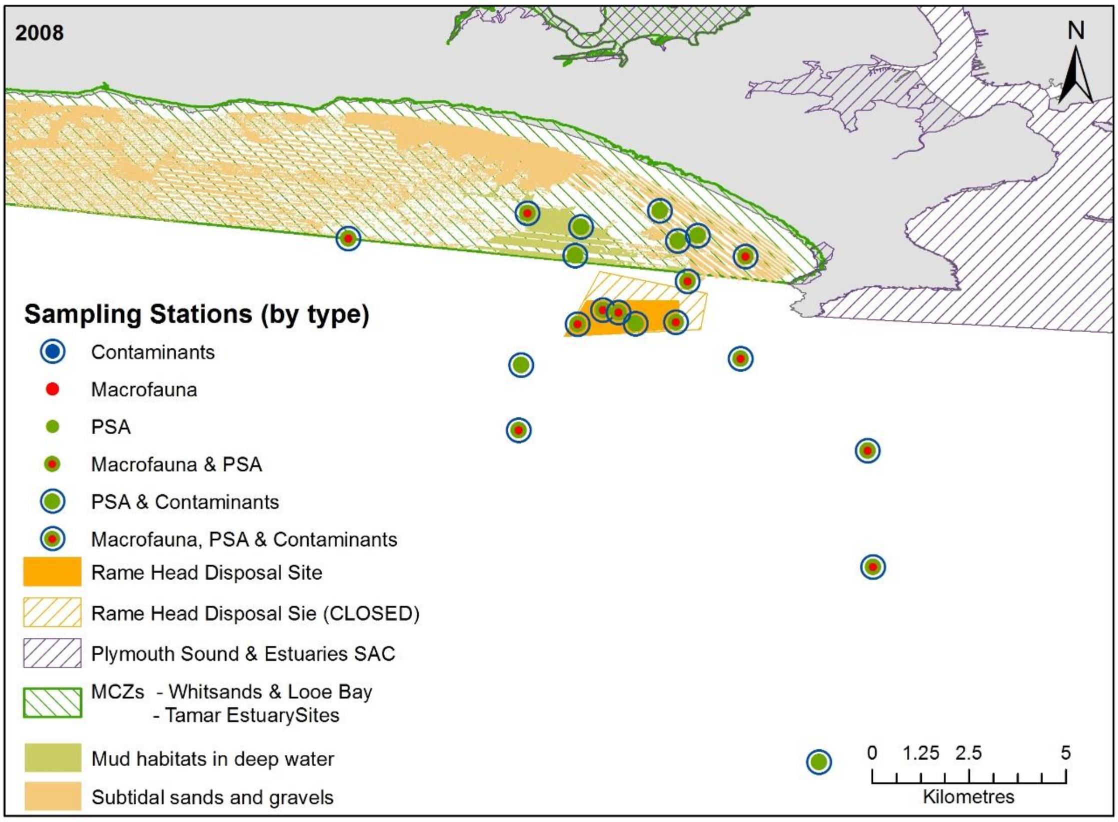

2003
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

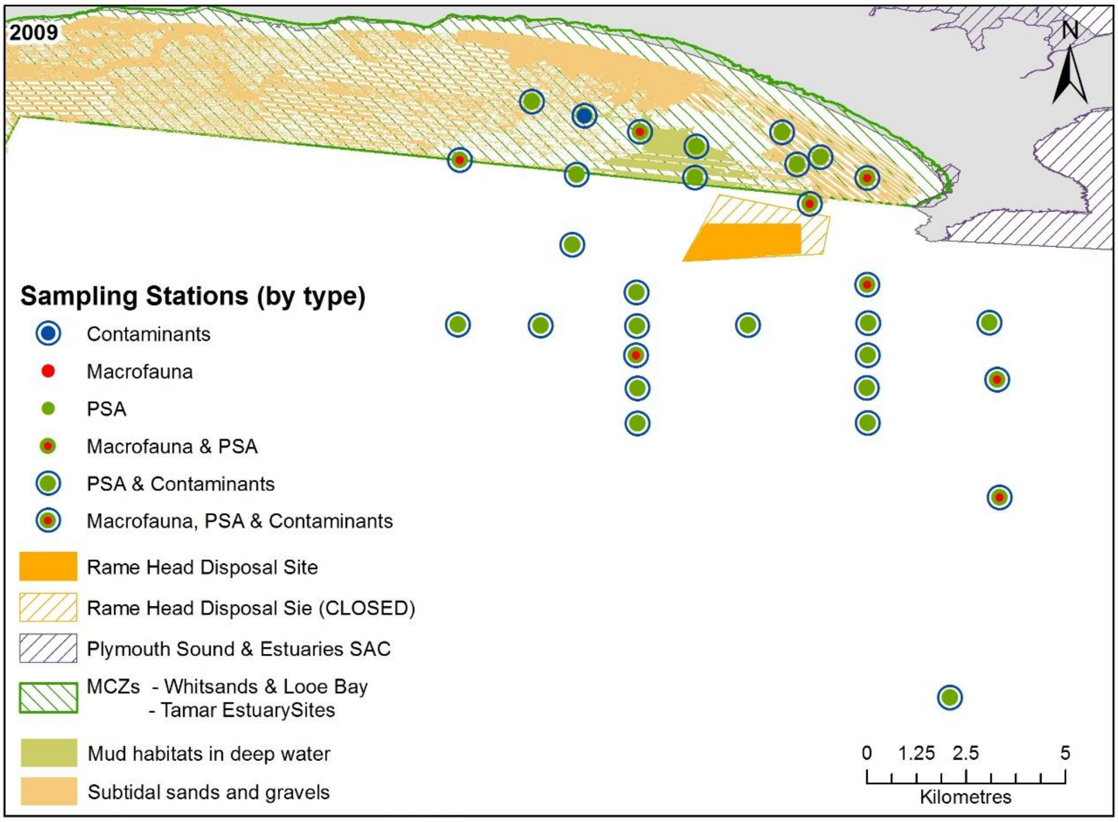

2004
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

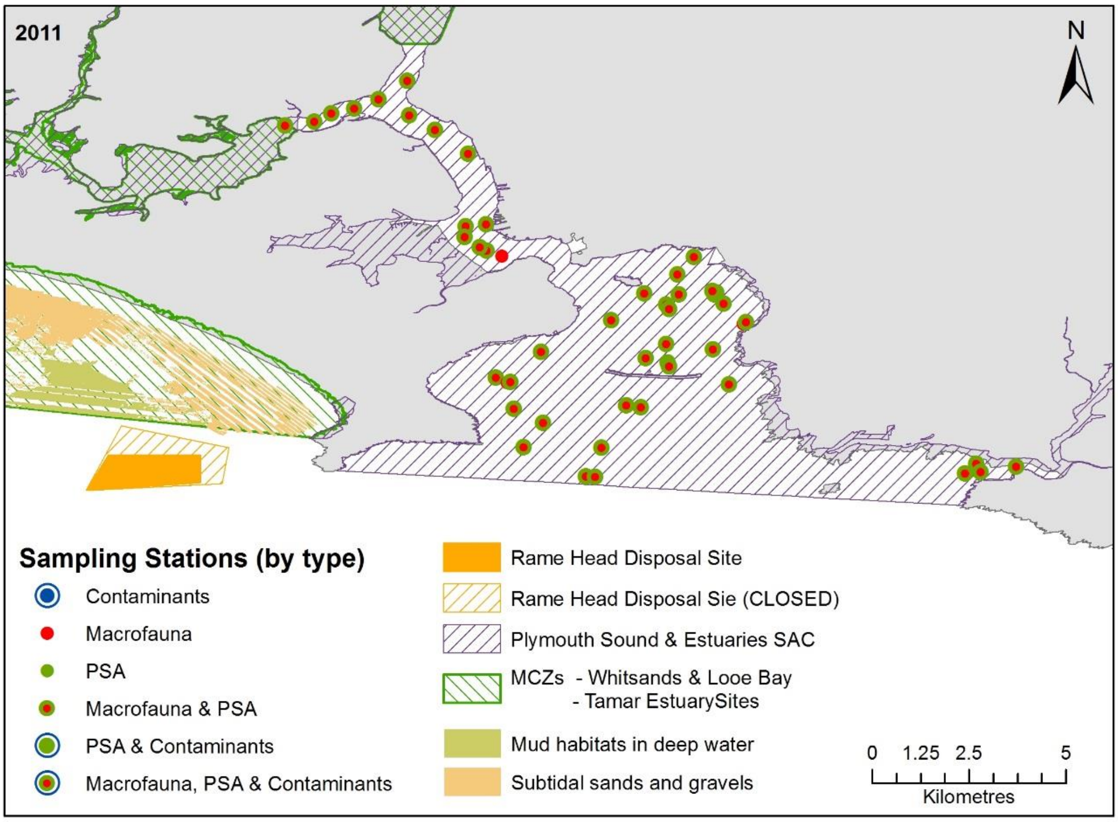

2005
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

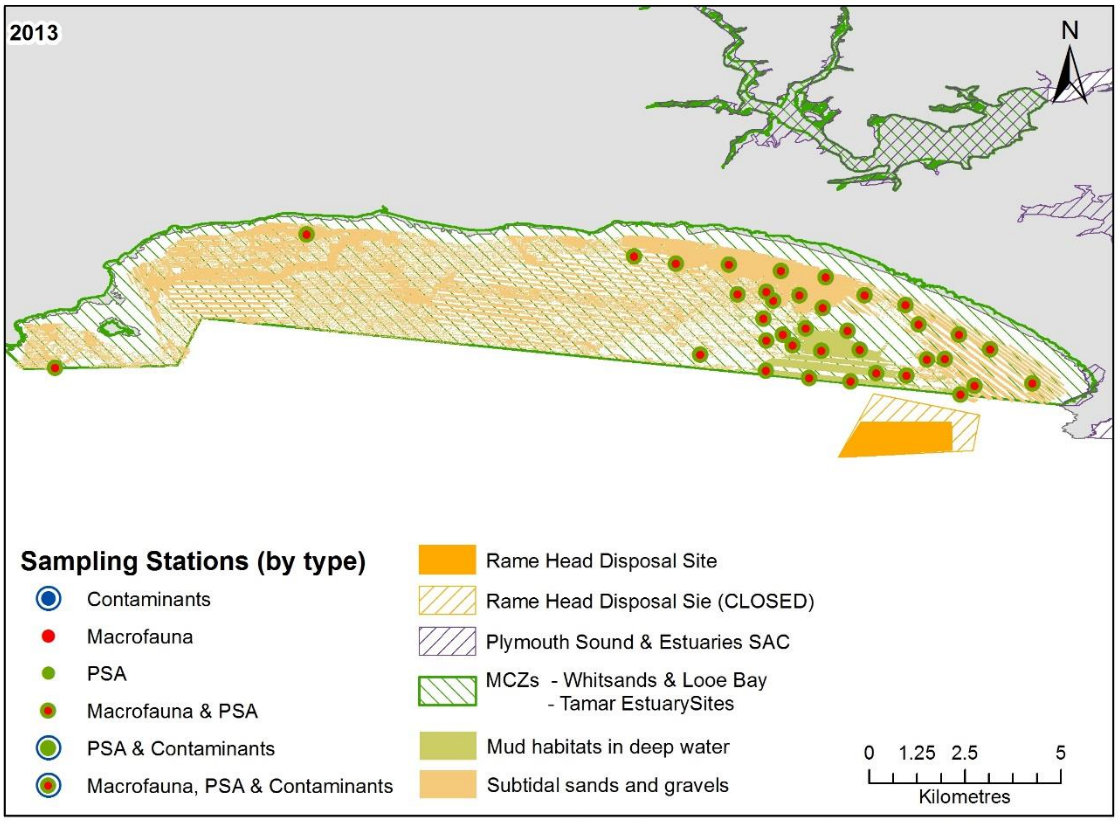

2006
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

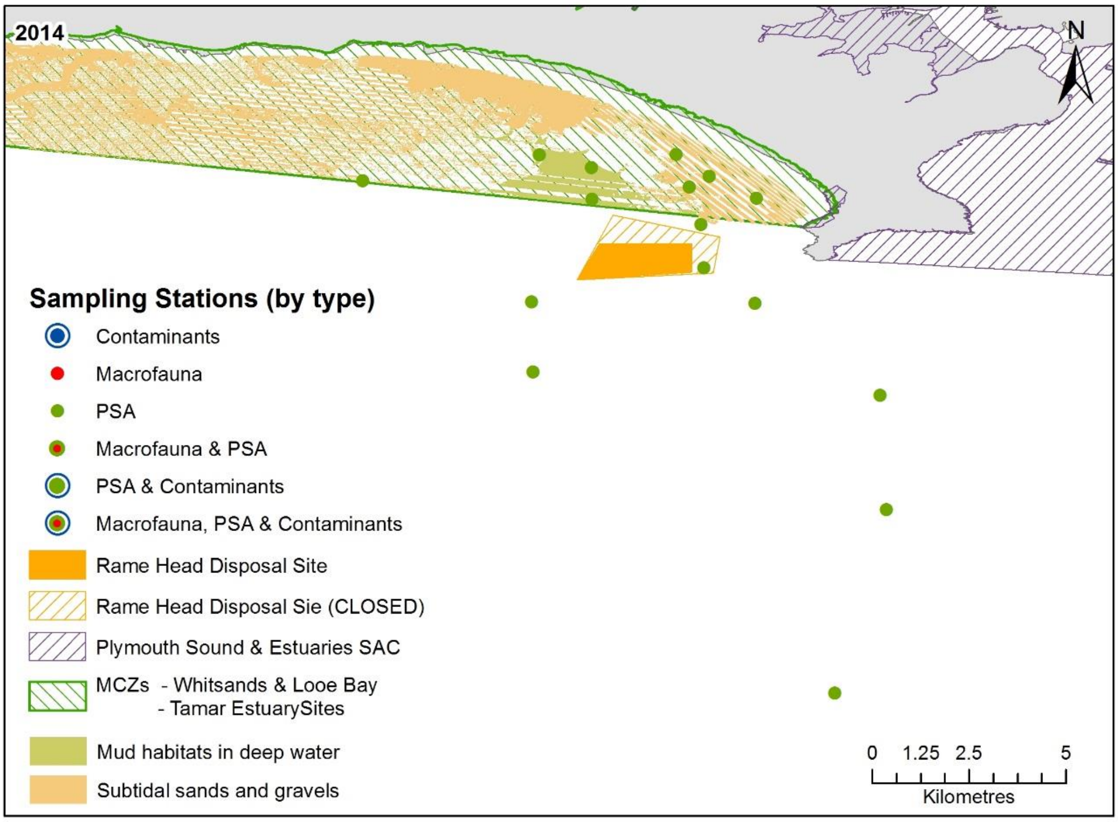

2007
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 2.5 5 10
Kilometres


2008
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres


2009
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres


2011
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres


2013
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres


2014
N
Sampling Stations (by type)
Contaminants
Macrofauna
PSA
Macrofauna & PSA
PSA & Contaminants
Macrofauna, PSA & Contaminants
Rame Head Disposal Site
Rame Head Disposal Sie (CLOSED)
Plymouth Sound & Estuaries SAC
MCZs - Whitsands & Looe Bay
- Tamar EstuarySites
Mud habitats in deep water
Subtidal sands and gravels
0 1.25 2.5 5
Kilometres

Appendix 2. PSA data comparability - Methodological and spatial consistency across surveys.

			PSA in support of biology						**PSA in support of contaminants**			
			Day/Hamon grab						**Day grab**		**Shipek/Handheld grab (surface sediments)**	
			Sample wet seived at 1 mm		**Sample wet seived at 0.5 mm**		**Sample wet seived at 63 µm**		**Sample wet seived at 63 µm**		**Sample wet seived at 63 µm**	
year	Survey	Data provider/owner	**No. stations**	**Spatial coverage**	**No. stations**	**Spatial coverage**	**No. stations**	**Spatial coverage**	**No. stations**	**Spatial coverage**	**No. stations**	**Spatial coverage**
2001	RH	Cefas / MMO					14	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)	2 {+12*}	WLOB MCZ (East - Mud biotope) Adjacent Marine area (no disposal site) {WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)}		
2002	RH	Cefas / MMO			6	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)	1	Disposal site			11	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)
2003	RH	Cefas / MMO			6	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)					21	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)
2004	RH	Cefas / MMO					6	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)			1 {+5*}	Marine area only (no MCZ or disposal site) {WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)}
2005	RH	Cefas / MMO			7	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)					22	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site) Plym/SAC
2006	RH	Cefas / MMO			11	WLOB MCZ (East only, no Mud biotope) Adjacent Marine area (incl. disposal site)					14	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)
2007	RH	Cefas / MMO					11	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)			31	WLOB MCZ (East, incl. Mud biotope + West) Adjacent Marine area (incl. disposal site) Plym/SAC
2008	RH	Cefas / MMO					12	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)			20	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (incl. disposal site)
2009	RH	Cefas / MMO					8	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (no disposal site)			32	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (no disposal site)
2011	Plym	EA / NE	45	Plym/SAC only	6	Plym/SAC only						
2013	WLOB	Cefas / DEFRA	36	WLOB MCZ only (East, incl. Mud biotope+								
2014	RH	Cefas / MMO									16	WLOB MCZ (East only, incl. Mud biotope) Adjacent Marine area (no disposal site)
2015	WLOB / Plym	EA / NE	82	WLOB MCZ only (East, incl. Mud biotope+ West) adjacent Marine area (no disposal site) Plym/SAC					{+5*}	{Plym/SAC only}		
Grand Total			163		36		52		2 (+17)		168 (+5)	

(*) No particle size distribution data available, only bulk components (gravel/sand/mud %) or mud%

An Excel version of the table above is provided as an attached file.

Appendix 3. PSA summary data for 2015 samples from Whitsand and Looe Bay MCZ benthic survey (RP02821).

Excel versions of the tables below are provided as an attached file.

Table A3.1. Sediment sample summary - Descriptive.

Station	Zone	SAMPLE TYPE	TEXTURAL GROUP	SEDIMENT NAME	Folk & Ward method			
					MEAN	SORTING	SKEWNESS	KURTOSIS
WLOB01	MCZ-E	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB02	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB03	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB04	MCZ-E	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB05	MCZ-E	Unimodal, Poorly Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Poorly Sorted	Coarse Skewed	Leptokurtic
WLOB06	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB07	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB08	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB09	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Medium Gravelly Fine Sand	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB10	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB11	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB12	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Medium Gravelly Fine Sand	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB13	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB14	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB15	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB16	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB17	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB18	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Fine Gravelly Fine Sand	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB32	MCZ-W	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Very Fine Gravelly Very Coarse Silty Very Fine Sand	Very Fine Sand	Poorly Sorted	Symmetrical	Very Leptokurtic
WLOB34	Marine	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB35	Marine	Polymodal, Poorly Sorted	Sandy Gravel	Sandy Medium Gravel	Fine Gravel	Poorly Sorted	Symmetrical	Platykurtic
WLOB41	Marine-W	Unimodal, Poorly Sorted	Gravelly Sand	Very Fine Gravelly Very Coarse Sand	Very Coarse Sand	Poorly Sorted	Fine Skewed	Very Leptokurtic
WLOB43	Marine-W	Unimodal, Poorly Sorted	Muddy Sandy Gravel	Medium Silty Sandy Very Fine Gravel	Very Fine Gravel	Poorly Sorted	Fine Skewed	Extremely Leptokurtic
WLOB45	Marine-W	Unimodal, Poorly Sorted	Muddy Sandy Gravel	Medium Silty Sandy Very Fine Gravel	Very Fine Gravel	Poorly Sorted	Fine Skewed	Very Leptokurtic
WLOB61	MCZ-E_Mud	Bimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Very Fine Gravelly Very Coarse Silty Very Fine Sand	Very Coarse Silt	Poorly Sorted	Very Fine Skewed	Leptokurtic
WLOB62	MCZ-E_Mud	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Fine Gravelly Very Coarse Silty Very Fine Sand	Very Fine Sand	Poorly Sorted	Symmetrical	Very Leptokurtic
WLOB63	MCZ-E_Mud	Bimodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Fine Gravelly Very Coarse Silty Very Fine Sand	Very Coarse Silt	Very Poorly Sorted	Very Fine Skewed	Leptokurtic
WLOB64	MCZ-E_Mud	Bimodal, Poorly Sorted	Muddy Sand	Very Coarse Silty Very Fine Sand	Very Coarse Silt	Poorly Sorted	Very Fine Skewed	Leptokurtic
WLOB65	MCZ-E_Mud	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Fine Gravelly Very Coarse Silty Very Fine Sand	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
WLOB67	Marine	Bimodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Very Fine Gravelly Very Coarse Silty Very Fine Sand	Very Coarse Silt	Very Poorly Sorted	Fine Skewed	Mesokurtic
WLOB69	Marine	Polymodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand	Slightly Very Fine Gravelly Very Coarse Silty Fine Sand	Very Fine Sand	Very Poorly Sorted	Fine Skewed	Mesokurtic
WLOB70	Marine	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Sorted	Symmetrical	Platykurtic
WLOB71	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB72	MCZ-E	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB73	MCZ-E	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Fine Sand	Moderately Well Sorted	Symmetrical	Mesokurtic
WLOB74	Marine	Unimodal, Moderately Sorted	Gravelly Sand	Very Fine Gravelly Very Coarse Sand	Coarse Sand	Moderately Sorted	Symmetrical	Leptokurtic
WLOB75	Marine	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Medium Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB77	Marine	Trimodal, Very Poorly Sorted	Muddy Sandy Gravel	Very Coarse Silty Sandy Coarse Gravel	Very Fine Gravel	Very Poorly Sorted	Very Fine Skewed	Platykurtic
WLOB78	Marine	Trimodal, Poorly Sorted	Sandy Gravel	Sandy Medium Gravel	Very Fine Gravel	Poorly Sorted	Symmetrical	Platykurtic
WLOB80	Marine	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	Medium Sand	Moderately Sorted	Symmetrical	Mesokurtic
WLOB83	Marine	Unimodal, Poorly Sorted	Slightly Gravelly Sand	Slightly Medium Gravelly Fine Sand	Fine Sand	Poorly Sorted	Symmetrical	Leptokurtic
WLOB84	Marine	Bimodal, Poorly Sorted	Muddy Sand	Very Coarse Silty Very Fine Sand	Very Coarse Silt	Poorly Sorted	Very Fine Skewed	Leptokurtic

Table A3.2. Sediment sample summary - particle size distribution characteristics and statistics (based on Folk & Ward method).

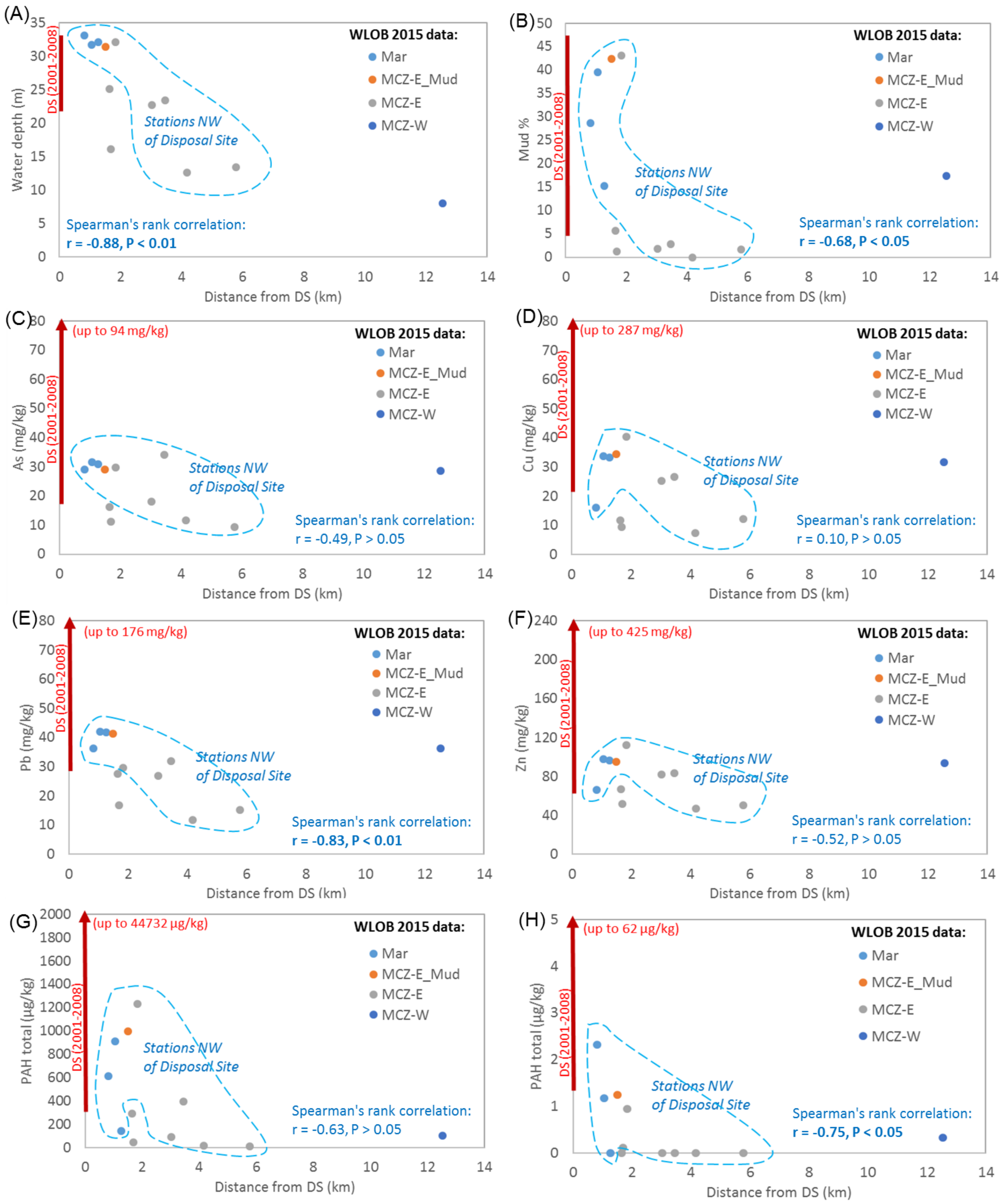
Station	Zone	MODE 1 µm	MODE 2 µm	MODE 3 µm	MEDIAN µm	MEAN µm	SORTING µm	SKEWNESS	KURTOSIS	MEAN phi	SORTING phi	SKEWNESS	KURTOSIS
WLOB01	MCZ-E	215			260.75	262.66	1.58	0.03	0.99	1.93	0.66	-0.03	0.99
WLOB02	MCZ-E	303			282.80	287.98	1.68	0.07	0.97	1.80	0.74	-0.07	0.97
WLOB03	MCZ-E	303			307.16	307.84	1.61	0.01	0.96	1.70	0.69	-0.01	0.96
WLOB04	MCZ-E	303			287.38	289.70	1.61	0.02	0.96	1.79	0.68	-0.02	0.96
WLOB05	MCZ-E	215			203.79	224.01	2.10	0.29	1.25	2.16	1.07	-0.29	1.25
WLOB06	MCZ-E	215			249.30	251.95	1.73	0.03	1.03	1.99	0.79	-0.03	1.03
WLOB07	MCZ-E	215			231.85	234.47	1.66	0.04	1.00	2.09	0.73	-0.04	1.00
WLOB08	MCZ-E	215			220.19	222.74	1.83	0.04	1.04	2.17	0.87	-0.04	1.04
WLOB09	MCZ-E	215			208.02	208.54	1.61	0.02	0.98	2.26	0.69	-0.02	0.98
WLOB10	MCZ-E	303			313.61	317.26	1.70	0.03	0.98	1.66	0.77	-0.03	0.98
WLOB11	MCZ-E	215			187.53	185.65	1.98	-0.03	0.98	2.43	0.98	0.03	0.98
WLOB12	MCZ-E	215			220.63	220.25	1.60	0.01	1.02	2.18	0.68	-0.01	1.02
WLOB13	MCZ-E	215			248.88	249.40	1.65	0.00	1.10	2.00	0.72	0.00	1.10
WLOB14	MCZ-E	303			282.56	282.80	1.73	0.00	0.97	1.82	0.79	0.00	0.97
WLOB15	MCZ-E	215			219.24	218.25	1.71	-0.01	1.02	2.20	0.78	0.01	1.02
WLOB16	MCZ-E	215			203.75	204.55	1.59	0.03	0.97	2.29	0.67	-0.03	0.97
WLOB17	MCZ-E	215			198.31	202.12	1.65	0.10	1.02	2.31	0.72	-0.10	1.02
WLOB18	MCZ-E	215			185.19	184.65	1.60	0.02	1.01	2.44	0.68	-0.02	1.01
WLOB32	MCZ-W	108			118.62	118.03	2.47	-0.07	1.64	3.08	1.30	0.07	1.64
WLOB34	Marine	215			264.59	271.21	1.78	0.10	1.03	1.88	0.84	-0.10	1.03
WLOB35	Marine	26950	1700	9600	5144.59	5126.04	3.21	-0.04	0.77	-2.36	1.68	0.04	0.77
WLOB41	Marine-W	1200			1276.60	1224.76	2.00	-0.28	2.29	-0.29	1.00	0.28	2.29
WLOB43	Marine-W	2400			2195.34	2233.32	2.89	-0.28	3.18	-1.16	1.53	0.28	3.18
WLOB45	Marine-W	2400			2146.51	2153.65	2.59	-0.21	2.32	-1.11	1.37	0.21	2.32
WLOB61	MCZ-E_Mud	108	9		82.26	59.00	3.75	-0.36	1.47	4.08	1.91	0.36	1.47
WLOB62	MCZ-E_Mud	108			116.52	118.71	2.32	-0.06	1.74	3.07	1.22	0.06	1.74
WLOB63	MCZ-E_Mud	108	9		73.81	51.06	4.16	-0.33	1.25	4.29	2.06	0.33	1.25
WLOB64	MCZ-E_Mud	108	9		73.80	52.15	3.62	-0.41	1.32	4.26	1.86	0.41	1.32
WLOB65	MCZ-E_Mud	108			88.55	67.33	3.86	-0.30	1.64	3.89	1.95	0.30	1.64
WLOB67	Marine	108	9		82.18	59.39	5.28	-0.27	1.04	4.07	2.40	0.27	1.04
WLOB69	Marine	108	605	19	134.56	103.57	5.39	-0.26	1.07	3.27	2.43	0.26	1.07
WLOB70	Marine	428			428.27	419.62	1.76	-0.08	0.89	1.25	0.82	0.08	0.89
WLOB71	MCZ-E	215			217.30	217.80	1.66	0.02	0.96	2.20	0.73	-0.02	0.96
WLOB72	MCZ-E	215			236.01	238.95	1.69	0.05	1.01	2.07	0.76	-0.05	1.01
WLOB73	MCZ-E	215			244.61	244.73	1.62	-0.01	1.04	2.03	0.70	0.01	1.04
WLOB74	Marine	1200			1014.80	992.61	1.92	-0.07	1.16	0.01	0.94	0.07	1.16
WLOB75	Marine	215			269.15	272.69	1.76	0.04	0.98	1.87	0.82	-0.04	0.98
WLOB77	Marine	26950	9600	1700	9151.87	2779.00	15.56	-0.64	0.87	-1.47	3.96	0.64	0.87
WLOB78	Marine	1700	13600	6800	3477.29	3760.43	3.16	0.02	0.80	-1.91	1.66	-0.02	0.80
WLOB80	Marine	215			252.92	259.28	1.72	0.09	1.05	1.95	0.78	-0.09	1.05
WLOB83	Marine	215			205.51	215.40	2.26	0.03	1.17	2.21	1.18	-0.03	1.17
WLOB84	Marine	108	9		78.96	59.17	3.57	-0.35	1.40	4.08	1.84	0.35	1.40

Table A3.3. Sediment sample summary - Broadscale habitat and sediment fractions content (%).

Station	Zone	UKSeaMap	Eunis Level 3	% GRAVEL	% SAND	% MUD	% V COARSE GRAVEL:	% COARSE GRAVEL:	% MEDIUM GRAVEL:	% FINE GRAVEL:	% V FINE GRAVEL:	% V COARSE SAND:	% COARSE SAND:	% MEDIUM SAND:	% FINE SAND:	% V FINE SAND:	% V COARSE SILT:	% COARSE SILT:	% MEDIUM SILT:	% FINE SILT:	% V FINE SILT:	% CLAY:
WLOB01	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0	100%	0	0	0	0	0	0	0	7.0%	46.4%	42.3%	4.3%	0	0	0	0	0	0
WLOB02	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.0%	0.2%	1.0%	13.3%	44.6%	37.0%	3.9%	0	0	0	0	0	0
WLOB03	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0	0.1%	0.3%	14.9%	51.4%	31.6%	1.8%	0	0	0	0	0	0
WLOB04	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0	100%	0	0	0	0	0	0	0	11.6%	49.6%	35.6%	3.2%	0	0	0	0	0	0
WLOB05	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	3%	96%	1%	0	0	0.4%	0.9%	1.5%	3.4%	8.5%	21.3%	45.4%	17.4%	0.1%	0.3%	0.4%	0.3%	0.0%	0
WLOB06	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0%	0	0	0	0.0%	0.0%	0.2%	9.9%	39.7%	41.4%	8.5%	0.1%	0.2%	0.0%	0	0	0
WLOB07	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.0%	0.1%	0.2%	6.2%	37.3%	47.2%	9.0%	0	0	0	0	0	0
WLOB08	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	97%	2%	0	0	0	0.1%	0.1%	0.7%	7.8%	32.3%	43.0%	13.8%	0.5%	0.7%	0.5%	0.6%	0.1%	0
WLOB09	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	99%	1%	0	0	0.1%	0.0%	0.1%	0.2%	3.0%	30.6%	52.5%	12.3%	0.0%	0.5%	0.4%	0.3%	0.0%	0
WLOB10	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.0%	0.4%	1.3%	17.2%	47.8%	30.3%	3.0%	0	0	0	0	0	0
WLOB11	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	94%	6%	0	0	0	0.1%	0.2%	0.5%	5.8%	26.7%	38.0%	23.2%	3.3%	0.6%	0.7%	0.6%	0.4%	0.0%
WLOB12	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	2%	97%	2%	0	0	0.8%	0.4%	0.6%	0.9%	2.2%	33.8%	51.6%	8.1%	0.1%	0.7%	0.4%	0.4%	0.0%	0
WLOB13	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	98%	2%	0	0	0	0.1%	0.3%	0.9%	5.6%	42.7%	43.1%	5.4%	0.7%	0.4%	0.2%	0.4%	0.0%	0
WLOB14	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	99%	1%	0	0	0	0	0.1%	0.4%	14.4%	43.7%	35.3%	5.5%	0.3%	0.3%	0.0%	0	0	0
WLOB15	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	97%	3%	0	0	0	0.0%	0.1%	0.4%	5.2%	33.8%	46.0%	11.6%	0.9%	0.8%	0.4%	0.6%	0.2%	0
WLOB16	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0	0.0%	0.2%	2.3%	29.4%	54.0%	14.0%	0	0	0	0	0	0
WLOB17	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0%	0	0	0	0	0.0%	0.3%	5.0%	25.4%	53.4%	15.9%	0.0%	0	0	0	0	0
WLOB18	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	98%	2%	0	0	0	0.0%	0.0%	0.2%	1.6%	22.7%	55.4%	18.4%	0.1%	0.5%	0.5%	0.5%	0.1%	0
WLOB32	MCZ-W	Sand & muddy sand	A5.2 Subtidal Sand	2%	81%	17%	0	0	0.2%	0.5%	1.1%	1.3%	2.4%	8.3%	32.8%	36.0%	9.7%	2.5%	2.0%	1.7%	1.2%	0.3%
WLOB34	Marine	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0.0%	0.1%	0.3%	1.6%	12.9%	38.9%	39.6%	6.6%	0	0	0	0	0	0
WLOB35	Marine	Coarse sediment	A5.1 Subtidal Coarse Sediment	74%	24%	1%	0	19.0%	20.0%	17.4%	18.1%	18.8%	3.9%	0.8%	0.3%	0.3%	0.3%	0.4%	0.4%	0.3%	0.1%	0.1%
WLOB41	Marine-W	Coarse sediment	A5.1 Subtidal Coarse Sediment	15%	82%	4%	0	0	0.1%	1.7%	13.2%	62.4%	12.4%	3.9%	1.8%	0.9%	0.8%	0.9%	0.9%	0.6%	0.3%	0.0%
WLOB43	Marine-W	Mixed sediment	A5.4 Subtidal Mixed Sediment	58%	37%	6%	0	0	3.0%	9.8%	44.8%	36.4%	0.0%	0.0%	0.1%	0.2%	0.6%	1.4%	1.7%	1.2%	0.5%	0.2%
WLOB45	Marine-W	Mixed sediment	A5.4 Subtidal Mixed Sediment	55%	40%	5%	0	0	4.1%	10.3%	40.8%	36.4%	3.0%	0.1%	0.2%	0.4%	0.6%	1.2%	1.4%	1.0%	0.4%	0.2%
WLOB61	MCZ-E_Mud	Mud & sandy mud	A5.3 Subtidal Mud	0%	62%	38%	0	0	0	0.0%	0.0%	0.3%	3.6%	4.1%	19.8%	34.6%	15.1%	5.8%	6.1%	5.6%	3.3%	1.6%
WLOB62	MCZ-E_Mud	Sand & muddy sand	A5.2 Subtidal Sand	1%	84%	15%	0	0	0.1%	0.5%	0.3%	0.6%	3.5%	7.0%	33.0%	39.9%	8.4%	1.7%	2.1%	1.7%	1.1%	0.2%
WLOB63	MCZ-E_Mud	Mud & sandy mud	A5.3 Subtidal Mud	0%	57%	43%	0	0	0	0.1%	0.0%	0.5%	3.7%	4.0%	17.2%	31.4%	16.0%	7.3%	7.2%	6.7%	3.9%	2.1%
WLOB64	MCZ-E_Mud	Mud & sandy mud	A5.3 Subtidal Mud	0	58%	42%	0	0	0	0	0	0	2.1%	3.1%	18.0%	34.4%	17.5%	6.7%	6.3%	6.0%	3.8%	1.9%
WLOB65	MCZ-E_Mud	Mud & sandy mud	A5.3 Subtidal Mud	0%	65%	35%	0	0	0	0.1%	0.1%	0.6%	4.6%	5.7%	20.4%	33.8%	14.3%	5.2%	5.3%	5.1%	3.3%	1.6%
WLOB67	Marine	Mud & sandy mud	A5.3 Subtidal Mud	0%	58%	42%	0	0	0	0.0%	0.1%	0.3%	7.0%	10.5%	17.7%	22.5%	12.9%	7.7%	7.1%	7.0%	4.6%	2.8%
WLOB69	Marine	Mud & sandy mud	A5.3 Subtidal Mud	0%	71%	29%	0	0	0	0.0%	0.2%	1.3%	15.9%	14.2%	20.9%	19.0%	6.7%	6.0%	6.1%	5.5%	3.1%	1.4%
WLOB70	Marine	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.1%	0.2%	2.5%	37.1%	41.2%	17.4%	1.5%	0	0	0	0	0	0
WLOB71	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0%	0	0	0	0	0.1%	0.3%	4.9%	33.4%	48.0%	13.2%	0.1%	0	0	0	0	0
WLOB72	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0	0.0%	0.3%	7.4%	37.8%	45.1%	9.4%	0	0	0	0	0	0
WLOB73	MCZ-E	Sand & muddy sand	A5.2 Subtidal Sand	0%	99%	1%	0	0	0	0.1%	0.1%	0.6%	4.9%	42.4%	44.5%	6.5%	0.5%	0.2%	0	0	0	0
WLOB74	Marine	Coarse sediment	A5.1 Subtidal Coarse Sediment	12%	88%	0	0	0	0.2%	2.2%	9.4%	39.3%	35.7%	9.2%	3.2%	0.8%	0	0	0	0	0	0
WLOB75	Marine	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.0%	0.0%	0.5%	14.1%	40.2%	38.1%	7.0%	0	0	0	0	0	0
WLOB77	Marine	Mixed sediment	A5.4 Subtidal Mixed Sediment	65%	21%	14%	8.6%	35.5%	7.8%	5.7%	6.9%	7.8%	2.2%	2.0%	4.1%	5.3%	3.1%	2.8%	3.0%	2.8%	1.6%	0.8%
WLOB78	Marine	Coarse sediment	A5.1 Subtidal Coarse Sediment	66%	32%	2%	0	9.4%	19.4%	17.8%	19.3%	22.8%	6.7%	1.6%	0.4%	0.5%	0.4%	0.5%	0.5%	0.4%	0.2%	0.1%
WLOB80	Marine	Sand & muddy sand	A5.2 Subtidal Sand	0%	100%	0	0	0	0	0.0%	0.1%	0.9%	10.3%	39.4%	42.7%	6.5%	0	0	0	0	0	0
WLOB83	Marine	Sand & muddy sand	A5.2 Subtidal Sand	1%	93%	6%	0	0	0.8%	0.1%	0.3%	1.2%	12.2%	24.4%	37.5%	17.9%	1.3%	1.4%	1.1%	1.2%	0.8%	0.0%
WLOB84	Marine	Mud & sandy mud	A5.3 Subtidal Mud	0	61%	39%	0	0	0	0	0	0	2.9%	4.5%	19.4%	33.8%	16.9%	6.5%	5.8%	5.4%	3.3%	1.6%

Appendix 4. Change in (A) water depth, (B) mud content, (C) Arsenic, (D) Copper, (E) Lead, (F) Zinc, (G) total polycyclic aromatic hydrocarbons, and (H) total polychlorinated biphenyls (zero PAH values denote concentrations below detection limit) with distance from the Rame Head disposal site as measured in 2015 in sediments from the Whitsand and Looe Bay area.

Point data are coloured according to zone. The dashed blue line encircles stations located along the main direction of tidal transport in the area, with results of the correlation analysis being shown for this spatial gradient (significant results in bold). The value range observed in the disposal site is given for reference (red line at distance 0). This refers to data collected between 2001-2008 data (the disposal site was not sampled in following years), therefore the comparability with 2015 data is limited.



Appendix 5. Detailed SIMPER outputs showing species composition (average abundance and percentage contribution to the similarity between sites within each group) of benthic communities sampled in 2015.

PLYMOUTH
Group 1 **Subtidal coarse**
Average similarity: 26.70

Species	**Av.A**	**Cum.%**
Mediomastus fragilis	2.32	18.47
Nephtys cirrosa	1.71	31.53
Echinocyamus pusillus	2.21	44.59
Glycera lapidum agg.	2	53.83
Pisione remota	1	63.06
Dosinia lupinus	1	72.3
Psamathe fusca	2.16	81.53
Pontocrates arcticus	1.21	90.77

WLOB 2013
Group 8 **Subtidal coarse**
Average similarity: 33.03

Species	**Av.A**	**Cum.%**
Pisione remota	2.98	15.7
Notomastus	2.44	28.96
Glycera lapidum agg.	1.98	39.24
Nematoda	1.83	47.63
Nemertea	1.41	56.02
Goniadella gracilis	1.57	64.41
Amphiuridae	1	70.34
Pista mediterranea	1.91	76.27
Psamathe fusca	1.5	82.2
Branchiostoma lanceolatum	1.5	88.14
Clausinella fasciata	1.21	94.07

WLOB 2015
Group 6 **Subtidal coarse/ mixed**
Average similarity: 34.55

Species	**Av.A**	**Cum.%**
Loimia medusa	7.91	16.77
Mediomastus fragilis	5.35	27.47
Glycera lapidum agg.	3.1	33.94
Echinocyamus pusillus	1.81	38.4
Nematoda	3.78	42.78
Sphaerosyllis bulbosa	3.36	46.74
Nemertea	1.69	50.53
Pisione remota	2.39	53.81
Lumbrineris aniara/cingulata	1.86	57.07
Polygordius	2.87	60.12
Protodorvillea kefersteini	1.88	63.16
Pista mediterranea	1.94	66.05
Pisidia longicornis	1.27	68.82
Eulalia mustela	1.45	71.41
Syllis garciai	1.82	73.95
Polynoidae	1.54	76.4
Polycirrus	1.16	78.77
Aonides paucibranchiata	1.98	80.49
Enchytraeidae	1.44	82
Psamathe fusca	1.08	83.22
Notomastus	0.88	84.34
Ampelisca	0.83	85.35
Ampelisca spinipes	1.02	86.29
Eumida	0.69	87.22
Nephtys cirrosa	0.78	88.07
Dosinia lupinus	0.73	88.91
Laonice bahusiensis	0.89	89.65
Caulleriella bioculata	0.66	90.21

Plymouth **Group 2 Subtidal mud/mixed** **Average similarity: 50.56**		
Species	**Av.A**	**Cum.%**
Melinna palmata	14.81	28.13
Turritella communis	5.46	36.09
Kurtiella bidentata	4.39	42.12
Chaetozone gibber	4.38	47.07
Thyasira flexuosa	2.69	51.62
Phoronis	2.36	55.34
Sternaspis scutata	3.62	58.99
Magelona alleni	2.49	62.62
Nephtys incisa	2.81	65.92
Amphiura filiformis	2.33	69.01
Owenia	2.17	71.56
Euclymene oerstedi	3.9	73.94
Ampharete lindstroemi agg.	1.28	76.17
Praxillella affinis	2.24	78.34
Corbula gibba	2.09	80.47
Cerebratulus	1.28	82.39
Notomastus	1.4	84.2
Nemertea	1.19	85.51
Cylichna cylindracea	1.29	86.77
Edwardsiidae	1.14	87.99
Nucula nitidosa	1.34	89.14
Pholoe baltica	1.03	90.15

WLOB 2015 **Group 4** **Average similarity: 37.56**	**Subtidal mud**	
Species	**Av.A**	**Cum.%**
Kurtiella bidentata	6.56	18.06
Amphiura filiformis	5.63	35.63
Melinna palmata	3.27	43.76
Cylichna cylindracea	2.31	50.51
Loimia medusa	3.21	54.76
Diastylis laevis	1.24	58.48
Owenia	1.51	62.02
Scalibregma inflatum	1.93	65.06
Nephtys	1.28	67.28
Nephtys hombergii	0.8	69.28
Phaxas pellucidus	0.88	71.17
Ampharete lindstroemi agg.	0.89	72.87
Notomastus	0.99	74.44
Magelona minuta	0.99	75.89
TURBELLARIA	0.69	77.26
Edwardsiidae	0.75	78.56
Nemertea	1	79.83
Pholoe baltica	1.13	81.09
Diplocirrus glaucus	0.86	82.27
Leptosynapta bergensis	0.7	83.41
Eudorella truncatula	0.56	84.19
Polynoidae	0.53	84.96
Oxydromus flexuosus	0.56	85.68
Eumida	0.64	86.39
Echinocardium cordatum	0.53	87.04
Lucinoma borealis	0.4	87.61
Hippomedon denticulatus	0.54	88.15
Oestergrenia digitata	0.43	88.66
Acanthocardia juveniles	0.36	89.16
Trichobranchus roseus	0.36	89.64
Tubulanus polymorphus	0.5	90.11

WLOB 2013		
Group 10	**Subtidal mud**	
Average similarity: 38.98		
Species	**Av.A**	**Cum.%**
Amphiura filiformis	5.3	17.31
Kurtiella bidentata	5.48	31.42
Thyasira flexuosa	1.94	37.31
Leptosynapta inhaerens	2.01	41.88
Magelona filiformis	1.76	46.29
Prionospio multibranchiata	2.01	50.52
Ampharete lindstroemi agg.	1.2	54.03
Owenia	1.2	57.27
Phoronis	1.09	60.35
Cylichna cylindracea	1.24	62.7
Nemertea	0.96	64.86
Spiophanes bombyx	1.06	66.98
Scalibregma inflatum	0.84	68.66
Harpinia antennaria	0.88	70.23
Nucula nitidosa	0.85	71.67
Ampelisca tenuicornis	1.02	73.11
Goniada maculata	0.74	74.47
Galathowenia oculata	0.9	75.8
Diastylis laevis	0.74	77.12
Pectinaria (Amphictene) auricoma	0.78	78.4
Echinocardium cordatum	0.63	79.68
Pholoe baltica	0.87	80.96
Podarkeopsis capensis	0.74	82.21
Monticellina	0.92	83.41
Ceratia proxima	0.85	84.57
Tellimya ferruginosa	0.68	85.7
Oxydromus flexuosus	0.63	86.78
Notomastus	0.57	87.83
Melinna (juv)	0.63	88.86
Edwardsiidae	0.74	89.87
Abra alba	0.99	90.79

WLOB 2013		
Group 9	**Subtidal mud/mixed**	
Average similarity: 30.82		
Species	**Av.A**	**Cum.%**
Ampharete lindstroemi agg.	2.07	12.22
Notomastus	1.57	22.04
Melinna palmata	1.91	29.55
Scalibregma inflatum	1.56	35.92
Ampelisca tenuicornis	1.63	42.17
Lumbrineris aniara/cingulata	1.31	47.63
Amphiura filiformis	1.69	51.9
Nemertea	1.18	56
Monticellina	1.36	59.99
Mediomastus fragilis	1.6	63.33
Phoronis	1.15	66.29
Podarkeopsis capensis	0.87	69.09
Nephtys	0.82	71.86
Owenia	0.89	74.6
Melinna (juv)	0.84	76.84
Nephtys kersivalensis	0.87	78.62
Magelona filiformis	0.64	80.37
Prionospio multibranchiata	0.78	82.11
Oxydromus flexuosus	0.72	83.72
Lysidice unicornis	0.59	85.09
Ampelisca spinipes	0.59	86.33
Terebellides	0.55	87.49
Goniada maculata	0.78	88.6
Phaxas pellucidus	0.59	89.51
Trichobranchus roseus	0.5	90.31

Plymouth
Group 3 **Subtidal sand**
Average similarity: 25.82

Species	**Av.A**	**Cum.%**
Magelona johnstoni	3.89	24.09
Magelona filiformis	1.81	32.25
Mactra stultorum	1.36	40.3
Nemertea	1.02	47.24
Phaxas pellucidus	1.59	53.29
Loimia medusa	1.41	58.43
Scoloplos (Scoloplos) armiger	1	61.99
Glycera tridactyla	0.9	65.25
Nephtys cirrosa	0.85	68.44
Chamelea striatula	1.04	71.24
Spiophanes bombyx	0.77	73.98
Chaetozone christiei	0.98	76.3
Acrocnida brachiata	0.8	78.34
Sthenelais limicola	0.99	80.36
Nephtys hombergii	0.73	82.28
Magelona alleni	0.55	84.03
Iphinoe trispinosa	0.5	85.36
Corbula gibba	1.05	86.67
Abra alba	0.48	87.81
Nephtys assimilis	0.58	88.81
Hippomedon denticulatus	0.43	89.76
Corystes cassivelaunus	0.5	90.69

WLOB 2013
Group 7 **Subtidal sand**
Average similarity: 47.44

Species	**Av.A**	**Cum.%**
Amphiuridae	3.38	18.01
Magelona filiformis	3.37	35.51
Magelona johnstoni	2.94	50.8
Bathyporeia guilliamsoniana	2.35	62.13
Spiophanes bombyx	2.21	73.39
Nephtys cirrosa	1.32	79.23
Chaetozone christiei	1.27	83.71
Phaxas pellucidus	1.03	86.91
Nemertea	1.13	90.1

WLOB 2015
Group 5 **Subtidal sand**
Average similarity: 35.46

Species	**Av.A**	**Cum.%**
Loimia medusa	5.37	22.01
Magelona johnstoni	2.82	32.69
Chamelea striatula	1.85	41.59
Nephtys cirrosa	1.38	48.66
Nemertea	1.38	54.05
Chaetozone christiei	1.65	59.32
Magelona filiformis	1.16	63.41
Bathyporeia elegans	1	67.2
Dosinia lupinus	1.03	70.5
Glycera tridactyla	0.89	73.54
Spiophanes bombyx	0.84	76.33
Mactra stultorum	1.02	79
Owenia	0.61	80.86
Amphiuridae	0.74	82.19
Phaxas pellucidus	0.82	83.36
Sigalion mathildae	0.66	84.53
Spio decoratus	0.68	85.7
Corbula gibba	0.63	86.54
Fabulina fabula	0.53	87.38
Pisidia longicornis	0.36	88.14
Sthenelais limicola	0.57	88.9
Synchelidium maculatum	0.39	89.63
Hippomedon denticulatus	0.4	90.24

Natural England is here to secure a healthy natural environment for people to enjoy, where wildlife is protected and England's traditional landscapes are safeguarded for future generations.

Natural England publications are available as accessible pdfs from www.gov.uk/natural-england.

Should an alternative format of this publication be required, please contact our enquiries line for more information: 0300 060 3900 or email enquiries@naturalengland.org.uk.

ISBN 978-1-78354-749-4

Catalogue code: NECR357