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Dredged Material Disposal Site Monitoring Round the Coast of England: Results of Sampling (2016-17)

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Executive Summary

- This report presents the scientific findings of, and implications for subsequent monitoring based on the results from, dredged material disposal site monitoring conducted under a Cefas/Marine Management Organisation Service Level Agreement (SLA 1.3) project (C6794 hereafter) round the coast of England during 2016-17.
- The main aims of this report are: to aid the dissemination of the monitoring results; to assess whether observed changes resulting from dredged material disposal are in line with predictions; to compare the results with those of previous years (where possible); and, to facilitate our improved understanding of the impacts of dredged material disposal at both a site-specific and a national (i.e. non site-specific) level.
- Targeted monitoring was conducted at four disposal sites during 2016, at Souter Point (northeast coast), Dover (southeast coast), Rame Head South and Lantic Bay (southwest coast). Additionally, LiDAR, single beam acoustic and aerial photographic data for Boston 7, a shallow site in The Wash (east coast), were acquired to address the issue of shoaling pertaining to that site.
- Parameters monitored varied between sites (governed by site-specific issues) but included sediment particle size, sediment organic carbon and contaminants (e.g., polycyclic aromatic hydrocarbons or PAHs, organohalogens (e.g., pesticides, flame retardants) and trace metals) concentrations and macrofaunal assemblages.
- Variations (both spatially and temporally) in the concentrations of the various contaminant types were site-specific, and, in general, indicated that concentrations remain temporally stable or show a slight decline.
- For the sites where biological assemblages were sampled, the results reveal that disposal sites harbour assemblages that are either at least as rich as those outside the disposal site, or ones which, at worst, represent an altered community structure, depending on the site.
- The implications of the findings for each site are discussed with respect to the need for subsequent monitoring under C6794. However, these data do not represent the sole basis of such final decisions regarding monitoring; in addition, up-to-date intelligence regarding potential changes to the disposal regime and/or concerns raised from stakeholders are all embraced within the selection process for disposal site monitoring under this project.

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1. Introduction

1.1 Regulation of disposal activity in England

Disposal of waste at sea is strictly regulated through the licensing requirements of the Marine and Coastal Access Act 2009 (MCAA). The MCAA provides the principal statutory means by which the UK complies with EU law, such as the Water Framework Directive (WFD, 2000/60/EC), the Habitats and Species Directive (92/43/EEC), the Wild Birds Directive (79/409/EEC) and international obligations such as under the OSPAR Convention and the London Protocol, in relation to disposals at sea.

Pursuant to the OSPAR Convention and the London Protocol, only certain wastes or other matter are permitted for disposal at sea. During the 1980s and 1990s, the UK phased out sea disposal of most types of waste, including industrial waste and sewage sludge. Since then, dredged material from ports and harbours, and a small amount of fish waste, has been the only type of material routinely licensed for disposal at sea.

The Marine Management Organisation (MMO) regulates, and is responsible for, licensing activities in the marine area around England including the disposal of dredged material at sea. The MMO assesses the suitability of dredged material for disposal at sea in line with the OSPAR Guidelines for the management of dredged material (OSPAR, 2014). These guidelines provide generic guidance on determining the conditions under which dredged material may (or may not) be deposited at sea and involve the consideration of alternative uses, disposal sites and the suitability of the dredged material for aquatic disposal including the presence and levels of contaminants in the material, along with perceived impacts on any nearby sites of conservation value.

One of the roles of Cefas is to provide scientific advice to the MMO on the suitability of the material for sea disposal at the application stage and, once a licence is granted, to provide technical advice on any monitoring undertaken as a result of licence conditions. Advice on the licensing of dredged material disposal at sea is provided by Cefas' Sustainable Environment and Advice for Licensing (SEAL) team, work conducted under C6794 helps underpin the scientific rationale for such advice (see Section 1.3).

1.2 Disposal sites around England

There are approximately 155 open sites designated for dredged material disposal round the coast of England, not all of which are used in any one year. While the majority of these are located along the coast of the mainland, generally within a few miles of a major port or estuary entrance, a significant number are positioned within estuaries (e.g., Humber) or on intertidal mudflats as part of beneficial use schemes (Bolam et al., 2006).

In total, approximately 40 Mt (wet weight) are annually disposed to coastal sites around England. Individual quantities licensed may range from a few hundred to several million tonnes, and the nature

may vary from soft silts to stiff clay, boulders or even crushed rock according to origin, although the majority consists of finer material (Bolam et al., 2006).

1.3 Overview of Cefas / MMO MoU contract C6794 'Monitoring of dredged material disposal sites'

The dredged material disposal site monitoring project C6794, funded by the MMO, falls under a service level agreement (or SLA) between the MMO and Cefas. Operationally, this project represents a continuation of the disposal site monitoring programme SLAB5 which was a component of a former SLA between Defra and Cefas; this SLA formerly ceased at the end of March, 2015. C6794 was initiated on 1st April 2015, and, thus, while the project and work planned under this project is termed here under C6794, any reference to its predecessor project is inevitable (i.e. to its survey work, reports or other scientific outputs), and will continue to be referenced as SLAB5.

In summary, C6794 provides field evaluations ('baseline' monitoring and 'trouble-shooting' surveys) at dredged material disposal sites around the coast of England. A major component of the project is, therefore, the commissioning of sea-going surveys at targeted disposal sites. Such field evaluations under C6794 are designed to ensure that:

- environmental conditions at newly designated sites are suitable for the commencement of disposal activities;
- predictions for established sites concerning limitations of effects continue to be met; and,
- disposal operations conform with licence conditions.

The outcomes of such surveys contribute, either directly or indirectly, to the licensing/enforcement process by ensuring that any evidence of unacceptable changes or practices is rapidly communicated and acted upon by the MMO. As such, there are inherently strong links and ongoing discussions between the approaches and findings of this project with the work carried out by Cefas' SEAL team and case licensing officers within the MMO. The scientific outcomes of the work undertaken within C6794 are circulated to the Cefas SEAL team and the MMO *via* a number of routes including peer-reviewed publications (including both activity-specific and site-specific findings), reports, direct discussions and internal and external presentations. The production of this report, within which a summary of the annual findings is presented (Section 2), forms an important element of such scientific communication. The current report, which presents the findings of work undertaken during 2016-17, is the eighth in the series; the previous ones are accessible *via* the Defra website (https://www.gov.uk/government/publications?departments%5B%5D=centre-for-environment-fisheries-and-aquaculture-science). It is not the purpose of this report to present a detailed appraisal of the processes giving rise to impacts at a particular site (see Section 1.5) but to encapsulate the essence of the impacts associated with this activity in its entirety around the coast of England.

1.4 Sites monitored

To aid with determining which disposal sites should be selected for sampling in any one year, Cefas has derived a tier-based approach that classifies a number of possible issues or environmental concerns that may be associated with dredged material disposal into a risk-based framework (Bolam et al., 2009; Birchenough et al., 2010). The issues that pertain to a particular disposal site, and where these lie within the tiering system (i.e., their perceived environmental risk) depict where that site lies within the tiered system. This ultimately determines whether that site is considered for sampling during a particular year. It is intended that this approach increases the transparency of the decision-making process regarding disposal site selection for C6794 monitoring, i.e., it establishes a model for site-specific decisions regarding sampling.

A tiered survey design and site assessment system, therefore, facilitates the prioritisation of dredged material disposal sites in terms of the need for, and the scale of, monitoring required at each site. In practice, this method will provide a scientifically valid rationale for the assessment of risks associated with relinquished, current and proposed disposal sites to the surrounding environment and amenities.

The disposal sites targeted for Cefas monitoring during 2016-17 are listed in Table 1.1. These sites were identified following consultation between Cefas' SEAL team, Cefas scientists in a number of key disciplines (e.g., benthic ecology, sediment contaminants), together with a significant involvement from the MMO.

Table 1.1. Dredged material disposal sites targeted for monitoring under C6794 during 2016-17.

Disposal site	Geographical location off English coast	Code
Souter Point	Northeast	TY081
Boston 7	East	HU170
Dover	Southeast	DV010
Rame Head South	Southwest	PL031
Lantic Bay	Southwest	PL060

1.5 Aims and structure of this report

This report does not aim to present a critique of the processes leading to observed changes at dredged material disposal sites around the coast of England. Such appraisals are conducted *via* other reporting routes, either *via* discussions with Cefas' SEAL team, presentations and subsequent publications at national and international conferences, and *via* papers in peer-reviewed journals (e.g. Bolam and Whomersley, 2005; Bolam et al., 2006; Birchenough et al., 2006; Bolam, 2014; Bolam et al., 2014a; Rumney et al., 2015; Bolam et al., 2016a). The aims of this report are:

- To present the results of sampling undertaken during 2016-17 under C6794, thereby aiding the dissemination of the findings under this project;
- To indicate whether the results obtained are in line with those expected for each disposal site, or whether subsequent investigations should be conducted;
- Where possible, to compare the 2016-17 results with those of previous years to provide a temporal assessment (see Bolam et al., 2009; 2011a; 2012a; 2012b; 2014b; 2015a; 2015b; and 2016b for reports of previous years' monitoring);
- To facilitate our improved understanding of the impacts of dredged material disposal at both a site-specific level and a national level; and,
- To promote the development of scientific (or other) outputs under C6794.

In accordance with the format first established for Bolam et al. (2011a), and that used within subsequent reports (Bolam et al., 2012a; 2012b; 2014b; 2015), the conclusions regarding each site are contained within Section 2 (below). The more detailed scientific data (e.g., acoustic, sediment particle size, organic carbon, macrofauna, contaminants) for each site are presented in Appendix 1. For background information regarding each disposal site monitored, the reader is directed towards this appendix. Appendix 2 contains information regarding the analytical and numerical methods used during the assessments of sediment contaminants (the reader may need to consult these whilst appraising Section 2).

2. Conclusions and implications for further monitoring

The main findings of the monitoring undertaken during 2016-17 are presented within this section (see Appendix 1 for more detail), together with their implications regarding the need for subsequent monitoring under C6794. However, it should be noted that these data, and the conclusions based on them, do not represent the sole basis of such final decisions regarding monitoring; up-to-date intelligence regarding potential changes to the disposal regime and/or concerns raised from any stakeholder are all embraced within the selection process for disposal site monitoring under this project. Thus, the recommendations for monitoring presented here for each site, although representing an important component of the decision-making process, may or may not be altered by other factors.

2.1 Souter Point (TY081)

The Souter Point disposal site is a comparatively large, trapezoid-shaped site located approximately 6km from the coast of northeast England. Between December 2004 and April 2005, a trial bottom-capping project was undertaken within the centre of the disposal site. The Port of Tyne disposed 60,000 m^3 of contaminated dredged material (CDM) which was covered with 100,000 m^3 of silt and around 60,000 m^3 of sand. Further material was later deposited with the aim of ensuring isolation of the CDM.

Following this trial capping project, there have been ongoing concerns regarding the integrity of the cap, specifically relating to cap thickness. In response to this, Cefas conducted a detailed sampling programme during 2012 wherein 27 stations were sampled with a vibro-corer and the various sediment layers analysed to determine their physical and contaminant characteristics. The results obtained indicated that while the integrity of the cap remained, cap thickness was reduced to 15-18cm in areas where time-series bathymetric data had also indicated sediment erosion. Monitoring under C6794 during 2016 at Souter Point aimed to provide data to determine whether there is any evidence of a breach in the cap within these eroding areas. Finally, stations previously sampled from a wider area, both within and outside the disposal site, were sampled for sediment contaminants and associated macrofauna to provide a basis from which to assess changes resulting from a potential change to the disposal regime.

The results from polycyclic aromatic hydrocarbons (PAHs) revealed that the ERL (effects range low) for low molecular weight (LMW) PAHs was breached at all stations sampled. The ERL for high molecular weight (HMW) PAHs was breached at stations within the disposal site and on the capping area, while the ERM (effects range median) for HMW PAHs was not exceeded for any station. Summed PAH concentrations observed at Souter Point in 2016 were comparable to those found at other disposal sites around UK waters including others also located off the northeast coast such as North Tyne.

Analyses of organohalogens (OHs) indicated that concentrations of polychlorinated biphenyls (CBs) and dieldrin at all stations were below Cefas action level 1 (AL1). $\sum_6$DDTs concentrations were above Cefas AL1 for eight of the nine stations, while no Cefas ALs have been derived for BDEs including BDE209. According to OSPAR guidelines, most stations had 'good' environmental status for all ICES 7 CBs and 'good' status overall. One station, however, had 'bad' environmental status for CB118 but with 'good' status overall. At Souter Point, CB concentrations in 2016 were all in the range of concentrations observed in the period 2005 to 2010 at this site.

A time series analysis of the macrofaunal data from samples collected from within the capped area, within the disposal site (but outside the capped area) and those collected at varying distances outside the licenced boundary was conducted. This indicated that while the assemblages within the disposal site were relatively low in number of species and total abundance in 2005, these assemblages have shown a gradual progression towards those outside the site; this progression continued during 2016.

Of the surficial samples analysed from Souter Point, only stations located just outside the capping area displayed detectable levels of TBT. These concentrations, however, were all below AL 1 for TBT. Finally, no evidence of a temporal trend in trace metals concentrations was observed since Cefas monitoring was initiated in 2006. When compared to the regional baseline values, observed concentrations in 2016

were predominantly 'not enriched', meanwhile for several trace metals (e.g., lead, copper, cadmium), a 'low enrichment' (1-2 times above baseline values) was observed for a small number of stations.

The Souter Point data acquired during 2016 do not provide any evidence that a breach of the cap above the CDM is present. Although sampling was focussed on the regions where cap thickness had previously been shown to be the thinnest, the data acquired cannot rule out the possibility of a cap breach for areas not sampled. Long term integrity of the cap may be promoted by ensuring some maintenance material is annually placed above the CDM. Future monitoring following any change to the disposal regime should be conducted, and the results compared with those attained here in 2016 and with the time-series data available.

2.2 Boston 7 (HU170)

Boston 7 is a relatively small licensed disposal site, located within The Wash in the Southern North Sea. The site annually receives, on average, 38,000 wet tonnes of maintenance material (2000-2013 data), with a maximum in any one year of 60,000 wet tonnes. The Port of Boston currently claim that the site is shoaling to the extent that certain parts represent a navigation risk, and a significant proportion of the site is presently too shallow to allow dredgers to dispose material. LiDAR (or Light Detection and Ranging) data, aerial photography and data from single beam acoustic bathymetric surveys from 1998 to 2015 were acquired and used to assess the current extent of shoaling and its potential causes.

The various types of data, when analysed in conjunction, revealed that the area is naturally bathymetrically variable. The present shoaling is the result of a natural weakening of the channel within which the licenced site is located. The processes leading to the closure of the channel are natural, brought about by the movement of sediment north to south and a general building of the bank and confluence areas to the north and west of the licence area.

No further monitoring of the site is deemed necessary and, given that the current shoaling issue is unlikely to reverse, a new site to receive material from the Port of Boston should be sought.

2.3 Dover (DV010)

Dover disposal site, with a depth of approximately 16m to 33m, is located just south of the Port of Dover. The segment-shaped site annually receives significant amounts of maintenance dredged material, averaging approximately 430,000 wet tonnes per annum (based on data from 2000 to 2015). The site also occasionally receives additional material through capital projects, some of the larger episodes being during 1995 (almost 700,000 wet tonnes) and 1998 (147,000 wet tonnes). Monitoring at Dover under the auspices of C6794 during 2016 focussed on assessing the biological assemblages within and surrounding the site in view of proposed large amounts of capital material the site is expected to receive from the Port of Dover.

Sediments sampled within and surrounding the Dover site in 2016 were coarse, predominantly muddy sandy gravels. The substrata were either too hard or too coarse to allow successful Hamon grab deployments at four of the 17 stations sampled. The faunal data showed the area in and around the disposal site to consist of highly diverse and variable benthic communities supporting numerous taxa, sometimes in very high numbers. Furthermore, the data indicated that univariate metrics of community structure, together with taxonomic composition, do not show any impacts associated with current disposal activity. The hard nature of the seabed, combined with the dispersive nature of the site, could be the reasons why impacts from disposal material could not be detected. The data acquired during 2016 form a suitable baseline from which benthic impacts associated with the proposed large tonnage of capital material may be assessed. In this respect, monitoring the faunal characteristics of the region, by targeting those stations sampled in 2016, should be conducted following the disposal of the proposed capital material at this site.

2.4 Rame Head South (PL031)

Rame Head South, with a depth range of 18m to 38m, is located approximately 2km west of Rame Head and 6km west of the entrance to Plymouth Sound. The disposal site receives material, originating from areas dredged within the Tamar, mostly during the winter months. The coastal region within which the disposal site is located is important for a wide range of stakeholders including those associated with diving, fisheries and shellfisheries. There is also a large number of sewage and storm-water discharges in the locality.

There has been a large public and media interest regarding the impacts associated with dredged material disposal at Rame Head South. Sea-going survey work under C6794 during 2016 aimed to sample a number of stations for which temporal data already exist for sediment particle size, contaminants and associated macrofauna. These data represent a useful basis from which any potential changes in the disposal regime may be assessed. Additionally, stations within a muddy habitat within the recently designated Whitsand and Looe Bay MCZ were sampled to provide supplementary information regarding the physical and chemical characteristics of this habitat and of the biological assemblages present.

Summed PAH values found at Rame Head South in 2016 were comparable to those measured between 2007 and 2014. Sampled sediment concentrations have never exceeded 6,000 µg kg^{-1} at this site and concentrations have often been close to background levels (<200 µg kg^{-1}). The 2016 results, therefore, add further support of the stable nature of PAH concentrations across the stations surrounding the Rame Head South disposal site. None of the sediments collected in 2016 exceeded the ERL or ERM for low molecular weight or high molecular weight PAHs.

Results pertaining to organohalogens indicated that concentrations of CBs and dieldrin at all stations were below Cefas AL 1. ∑ 6DDTs concentrations were above Cefas AL 1 at only one of the 12 sampled stations, while no Cefas ALs exist for BDEs and BDE209. According to OSPAR guidelines, two stations had 'good' environmental status for all ICES 7 CBs, and 'good' status overall. The remaining ten stations had 'bad' environmental status for CB118, but 'good' status overall. Finally, no enrichment for any trace metal was observed across the stations sampled relative to regional baseline concentrations, except for cadmium where values sampled were between two and five times those of the regional baselines. No temporal trend is observed for most elements, except for zinc where a slight decrease can be seen and lead continues to display a notable decrease in concentration from 2006 to 2016.

The sediment contaminants data obtained for Rame Head South in 2016, together with those pertaining to the macrofaunal assemblages, imply that the sediments around this site have not altered with respect to these characteristics over recent years. Further monitoring of this site ultimately rests on the outcomes of decisions regarding the status of the site and whether significant changes to the disposal regime occur.

2.5 Lantic Bay (PL060)

Lantic Bay is located close to the rocky shore just east of the entrance to the Fowey Ria system, Cornwall, the mouth of which is represents a deep inlet surrounded by a steep-sided catchment. The disposal site, which is exposed to long-period Atlantic swell waves from a southwesterly direction, is comparatively little-used, being used for the disposal of maintenance and, very occasionally, capital material resulting from dredging within the River Fowey and the nearby Par Harbour. Quantities of material deposited to Lantic Bay have averaged approximately 66,000 wet tonnes per annum since the early 1980s, although larger quantities, circa 160,000 wet tonnes, were disposed during 1985, 1987 and 1993.

During the winter of 2015-16, maintenance dredged material from Corporation Wharf, Plymouth, which is normally disposed of at Rame Head South, was deposited at Lantic Bay. As this material originated from a different system (the Tamar catchment) compared to that previously, the MMO considered it prudent, in view of no available data hitherto, to undertake seabed sampling at Lantic Bay to ascertain the present spatial variability in sediment granulometry and contaminants concentrations. Under the auspices of C6794, Cefas sampled a small number of stations within and outside the disposal site. The survey was not conducted to assess impacts at this site resulting from the recent disposal of material from the Tamar, partly as there was no reason to believe that this material would result in alterations beyond those resulting from disposal of material from Fowey.

The PAH data revealed that none of the sediments sampled from the 11 stations exceeded the ERL or ERM for low molecular weight (LMW) or high molecular weight (HMW) PAHs. Summed PAH values

found at Lantic Bay are comparable to those found at other disposal sites in the southwest of England, and directly equivalent to those found at Rame Head South during 2016. These levels are low compared to those found at other disposal sites around UK waters, with values ten times higher being observed at sites off, for example, the northeast coast of England.

Concentrations of CBs, dieldrin and ∑ 6DDTs at all 11 stations at Lantic Bay were below Cefas AL 1, while no Cefas action levels exist for BDEs and BDE209. According to OSPAR guidelines, all stations bar one inside the disposal site had 'good' environmental status for all ICES 7 CBs, and 'good' status overall. The remaining station had 'bad' environmental status for CB118, but 'good' status overall.

Sediment trace metal concentrations at Lantic Bay were comparable to those observed at nearby Rame Head South. All metals except cadmium were found to show no enrichment relative to the regional baseline concentrations, while mercury was found to be below the limit of detection at all but one station sampled.

These data represent a suitable indication of the sediment contamination characteristics for Lantic Bay and its immediate locale. No specific monitoring is deemed necessary in forthcoming years, unless a notable change to the disposal regime for this site is planned.

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A large number of Cefas staff have helped contribute to the work which has been conducted to produce this report. Such staff have been involved in all aspects of the work from an early stage, e.g., during discussions of the specific issues regarding dredged material disposal sites around the England coast (e.g. Cefas' SEAL team), through to the field sampling and the laboratory processing of the various components. In particular, staff within Cefas' Chemistry Function i.e., Bobby Thomas and Matt Loar (organohalogens); Kerry Potter, Phil Mellor, Nathan Brown and James Brown (PAHs); and Lee Warford (metals), and the Sedimentology Function, i.e. Sara Stones and Caroline Limpenny, are gratefully thanked for processing the large numbers of samples that are required under C6794 and which form the core of this report.

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APPENDICES

Appendix 1. Results

1.1 Souter Point (TY081)

1.1.1 Background

The Souter Point disposal site, TY081, is a comparatively large, trapezoid-shaped site located approximately 6km from the coast of northeast England (Figure A1.1.1). The site, which has a maximum depth of 46m, receives reasonably large quantities of maintenance material, just above 200,000 wet tonnes per annum since 2000 (Figure A1.1.2), and has, on occasions, received additional material from capital projects, particularly during 2011 (251,000 wet tonnes) and 2006 (178,000 wet tonnes). The sediments within the vicinity of Souter Point disposal site are generally muddy sands, however, these vary to a large extent following dredged material disposal and in response to its earlier history of receiving solid industrial wastes or other (unregulated) discharges further inshore. Tidal currents in the vicinity of the disposal site are moderate in strength and run generally parallel with the coastline, with a net residual drift southwards, at least in surface waters.

Between December 2004 and April 2005, a trial level bottom-capping project was undertaken within the centre of the disposal site. The Port of Tyne disposed 60,000 m^3 of contaminated dredged material (CDM) which was covered with 100,000 m^3 of silt and around 60,000 m^3 of sand. On disposal of the silt, around 80% was siphoned off to leave a 1.5m cap: 90,000 m^3 of sand was subsequently placed on top. Further material was later deposited in an attempt to ensure isolation of the CDM. During this time the maintenance dredged material from the Tyne was disposed of to the North Tyne (TY070) disposal site.

Following this trial capping project, there have been ongoing concerns regarding the integrity of the cap, specifically related to cap thickness. Previous monitoring of this site under the auspices of SLAB5 has included a number of techniques to determine the temporal changes in bathymetry (using multibeam acoustic techniques) to assess areas of sediment/cap erosion, together with Nioz core sampling to allow acquisition of samples of the top 30 cm for sediment contaminant determination. Sediment Profiling Imagery (SPI) techniques have also been used to allow *in situ* visual descriptions of the sediment profiles and the presence of faunal activity (burrows, tubes, cavities). In 2012, a more intensive sampling programme was conducted under SLAB5, wherein 27 stations were sampled with a vibro-corer and the various sediment layers then being analysed to determine their physical and contaminants characteristics (Bolam et al., 2014). The results obtained indicated that while the integrity of the cap remained, cap thickness was reduced to 15-18cm in areas where time-series bathymetric data had indicated sediment erosion.

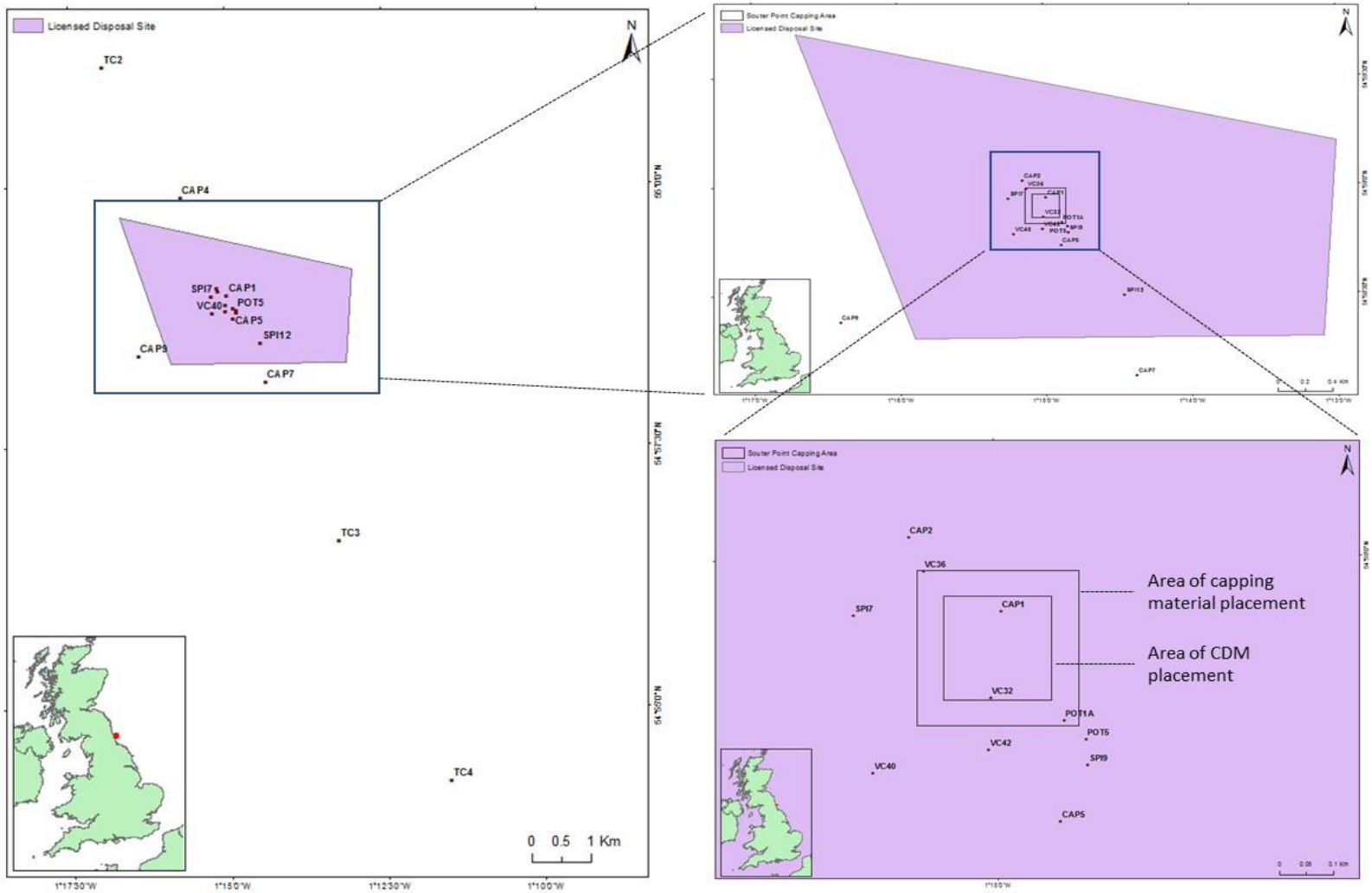


Figure A1.1.1. Location of the stations sampled around and within the Souter Point disposal site 2016. Position relative to CDM and capped material is shown.

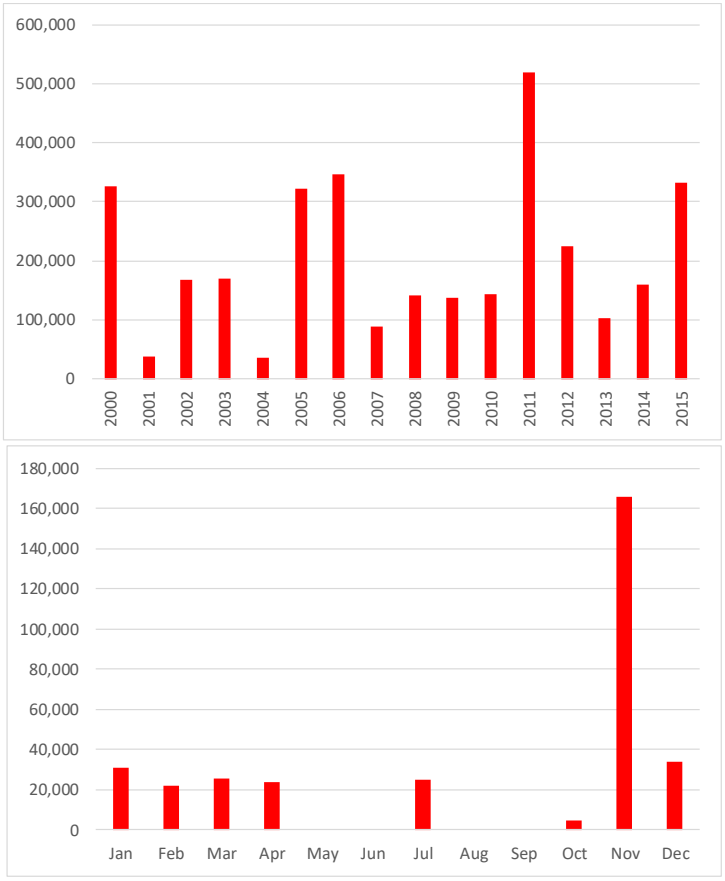


Figure A1.1.2. Disposal returns (wet tonnes) for material annually disposed of to Souter Point 2000-2015 (top) and for each month during 2015 (bottom).

Monitoring under C6794 during 2016 at Souter Point aims to provide data to determine whether there is any evidence of a breach in the cap. This will be undertaken by assessing the contaminants concentrations of the surface sediments over the capped area, focussing particularly on the regions previously identified as those of greatest risk of cap breach (see Bolam et al., 2014). This somewhat limited approach will allow an assessment regarding whether CDM is currently at the surface for these stations; it will not confirm integrity of the cap in its entirety nor will allow any assessment regarding cap thickness. Finally, stations previously sampled from a wider area, both within and outwith the disposal site, will be sampled for sediment contaminants and associated macrofauna in view of potential changes to the disposal regime to the site.

1.1.2 Parameters monitored:

Sediment particle size

Sediment organic carbon

Sediment contaminants (PAHs, organohalogens, organotin, trace metals)

Macrofaunal assemblages

1.1.3 Results

1.1.3.1 Sediment particle size

Sediments at Souter Point were predominantly muddy sands and sands, with some sandy muds, gravelly sands and gravelly muddy sands (Table A1.1.1), when considering all temporal samples analysed between 2005 and 2016, and including all core slices collected in 2012 (99 samples in total). Sediments analysed in 2016 were mainly muddy sands (13 in sediment group Sp2), with some muddy sands (3 in Sp3) and sands (2 in Sp2) (Table A1.1.1).

Table A1.1.1. Average sediment descriptions (top) and granulometric statistics (bottom) for each sediment group at Souter Point (2005 to 2016 inclusive).

Sediment group	Number of samples	Sample Type	Sediment description
Sp1	38	Trimodal, Very Poorly Sorted	Slightly Gravelly Sandy Mud
Sp2	61	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
Sp3	27	Trimodal, Very Poorly Sorted	Gravelly Muddy Sand
Sp4	30	Unimodal, Poorly Sorted	Gravelly Sand
Sp5	43	Unimodal, Moderately Sorted	Slightly Gravelly Sand

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
Sp1	0.61	41.32	58.07	0.65	1.55	7.31	14.75	17.07
Sp2	2.01	78.75	19.24	1.18	4.07	17.31	36.42	19.77
Sp3	9.50	71.79	18.71	4.80	7.65	15.68	19.83	23.82
Sp4	11.67	83.35	4.98	4.10	10.23	27.43	34.04	7.55
Sp5	0.91	94.88	4.20	1.03	3.80	16.68	59.25	14.13

The spatial variation in the proportional representation of gravel, sand and silt/clay for each sampling station in 2016 is shown in Figure A1.1.3 and the percentage of silt/clay content in Figure A1.1.4. The highest silt/clay contents were located at TC2, north of the site, and CAP5 and SPI7, both located within the disposal site. In general, there was relatively low variability in sediment silt/clay content between all the samples (ranging from ~10% at VC32 to ~27% at TC2) (Figure A1.1.3).

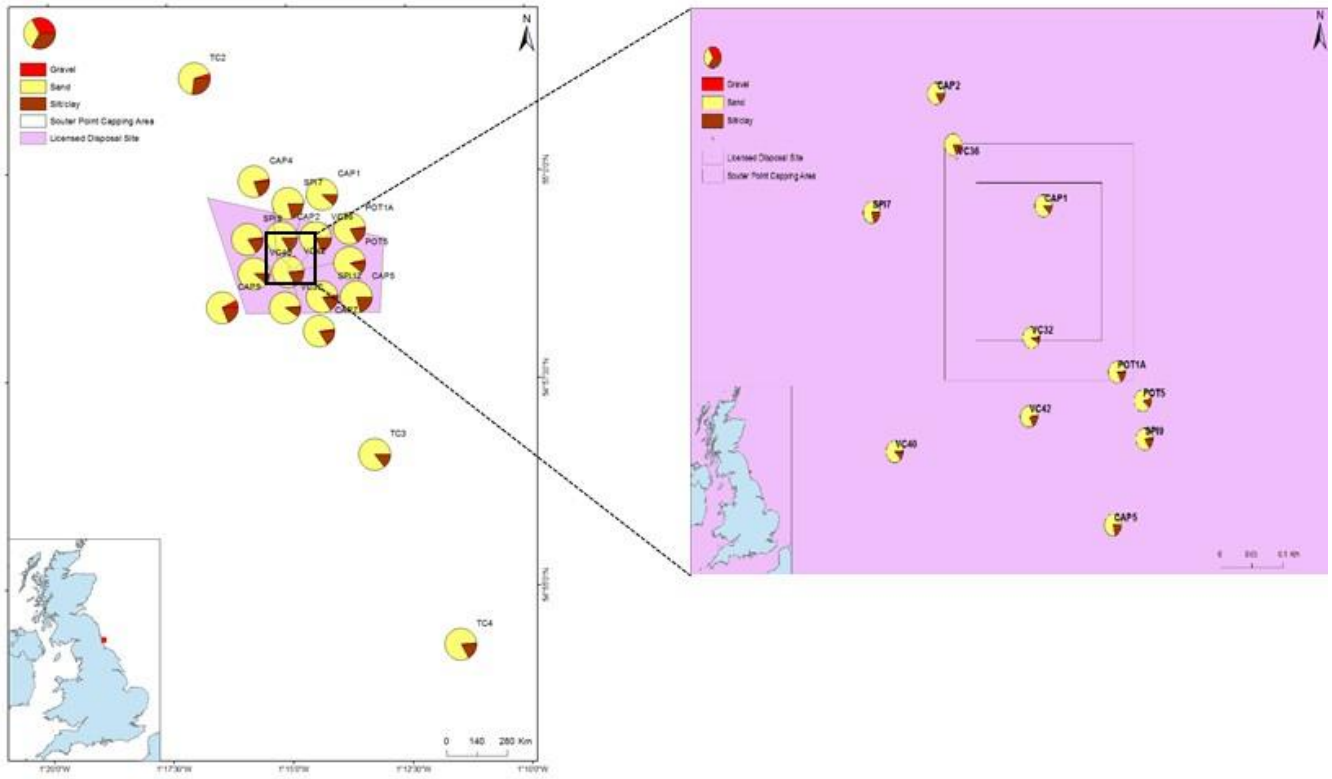


Figure A1.1.3. Pie charts of gravel, sand and silt/clay fractions of the stations sampled at Souter Point in 2016.

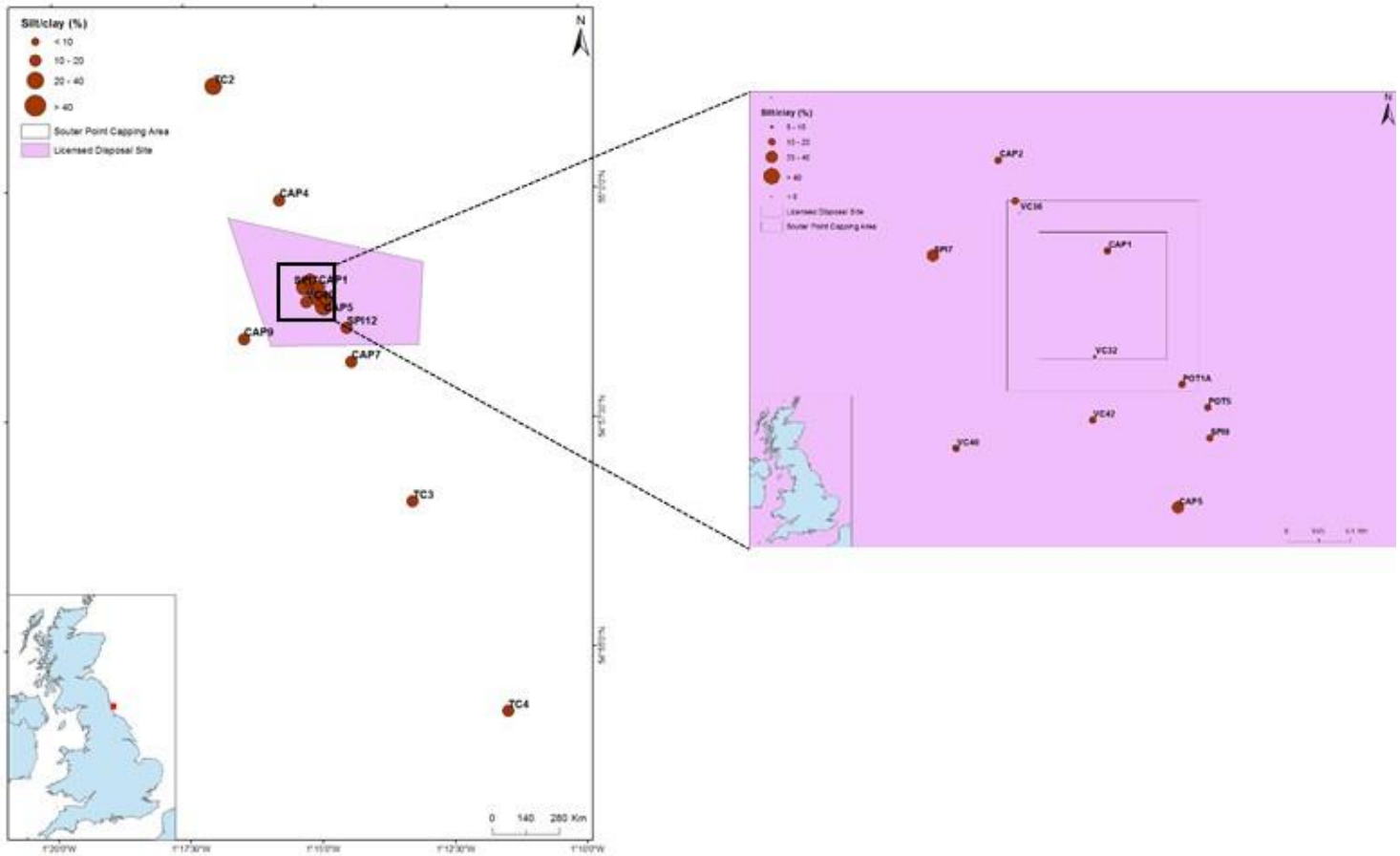


Figure A1.1.4. Sediment silt/clay content of the stations sampled at Souter Point in 2016.

The temporal changes in sediment groups for the stations sampled by Cefas at Souter Point since 2005 are presented in Table A1.1.2 (for stations sampled in 2016 only). Only minor changes have occurred at the reference sites TC2, TC3 and TC4, as well as CAP4, CAP5, CAP7, CAP9, SPI2, SPI7, SPI9 and VC32. CAP1, CAP2 POT1A, VC36, and VC42 are slightly muddier than when previously sampled in 2012. POT5 contained less gravel in 2016 to 2012, and VC40 was sandier in 2016 than in 2012. Care should be taken when comparing 2012 and 2016 as the former samples were taken using a vibrocorer. The vibrocore samples were subsequently sliced according to sediment horizons (Bolam et al., 2014) and, therefore, are not directly comparable to the surface scrapes taken during 2016.

Table A1.1.2 Sediment groups for each station sampled between 2005 and 2016 inclusive at Souter Point (for stations sampled in 2016 only).

	Year								
Sample code	2005	2006	2007	2008	2009	2010	2011	2012	2016
CAP1	Sp5	Sp5	Sp4	Sp4	Sp4	Sp4	Sp4	Sp4	Sp5
CAP2	Sp5	Sp5	Sp5	Sp5	Sp2	Sp5	Sp2	Sp5	Sp2
CAP4	Sp2	Sp2	Sp2	Sp4	Sp3	Sp2			Sp2
CAP5	Sp5	Sp5	Sp4	Sp4	Sp5	Sp4	Sp5	Sp2	Sp2
CAP7	Sp2	Sp2	Sp2	Sp3	Sp2				Sp2
CAP9	Sp2	Sp2	Sp2	Sp3	Sp2	Sp3	Sp3		Sp3
POT1A								Sp5	Sp2
POT5								Sp4	Sp2
SPI12								Sp2	Sp2
SPI7								Sp2	Sp2
SPI9								Sp2	Sp2
VC32								Sp5	Sp5
VC36								Sp5	Sp2
VC40								Sp1	Sp2
VC42								Sp5	Sp2
TC2	Sp3	Sp3	Sp3		Sp3	Sp3			Sp3
TC3	Sp2	Sp2	Sp2	Sp2	Sp2	Sp2	Sp2		Sp2
TC4	Sp3	Sp3	Sp3	Sp3	Sp3	Sp3	Sp3		Sp3

1.1.3.2 Sediment organic carbon

Sediment organic carbon values (in the <2mm sediment fraction) range from 1.1 to 5.2 % (Figure A1.1.5). A significant proportion of the organic carbon for this area is present in coarser sediment, possibly as coal. These are similar values to those observed in previous years (e.g., Bolam et al., 2014).

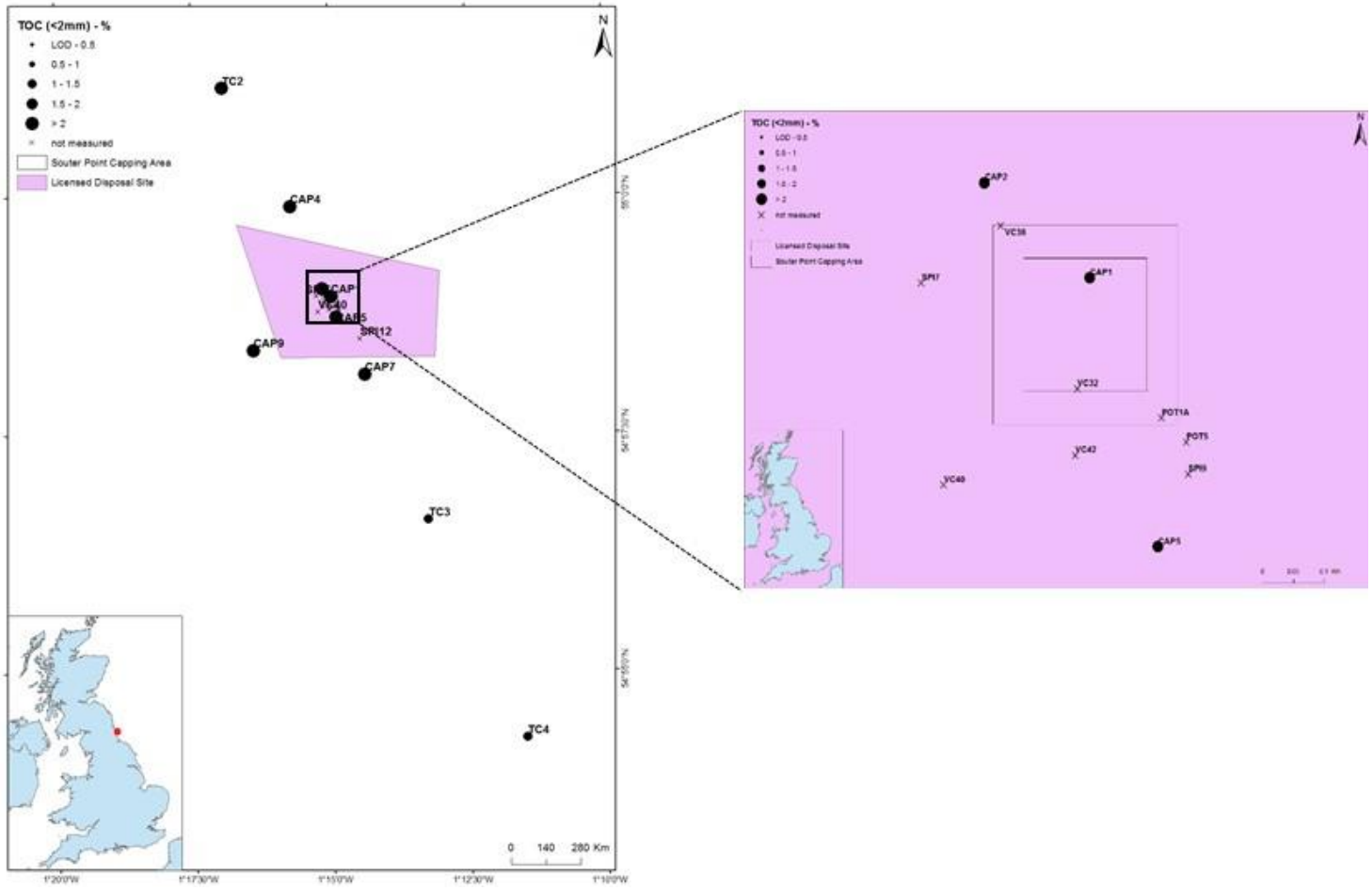


Figure A1.1.5. Organic carbon (%) content in the <2mm fraction of the sediment sampled at Souter Point in 2016.

1.1.3.3 Sediment contaminants

1.1.3.3.1 PAHs

The CDM disposed of, and subsequently capped, in 2004 originated from three different dredged areas, which makes direct comparisons of summed PAH concentrations found at Souter Point with source concentrations difficult. However, the overall average summed PAH concentration for the CDM was 50,994 µg kg^{-1} dry weight, with a percentage deviation of 66%. Using this indicative value, we can make observations of the integrity of this capping exercise where applicable.

In 2016, the highest summed PAH concentration (ΣPAH) was 46,600µg kg^{-1} dry weight, found at VC36 on the northwestern corner of the capped area (Figure A1.1.6-A1.1.7). This concentration is comparable (i.e. 50,994 µg kg^{-1} dry weight) with that of the original CDM disposed and later capped. The second highest ΣPAH concentration found during 2016 was 36,900 µg kg^{-1} dry weight, located at CAP4 found approximately 400m northwest of the disposal site (Figure A1.1.6). Similar ΣPAH concentrations of 35,400 µg kg^{-1} was found at CAP5, situated approximately 0.2 km south east of the capping area.

The lowest ΣPAH concentration in 2016 was 7,100 µg kg^{-1} dry weight, found at both TC3 and TC4 which are located 700m and 1,700m southeast of the disposal site respectively (Figure A1.1.6). Lowest ΣPAH concentrations have been observed at these stations in previous years.

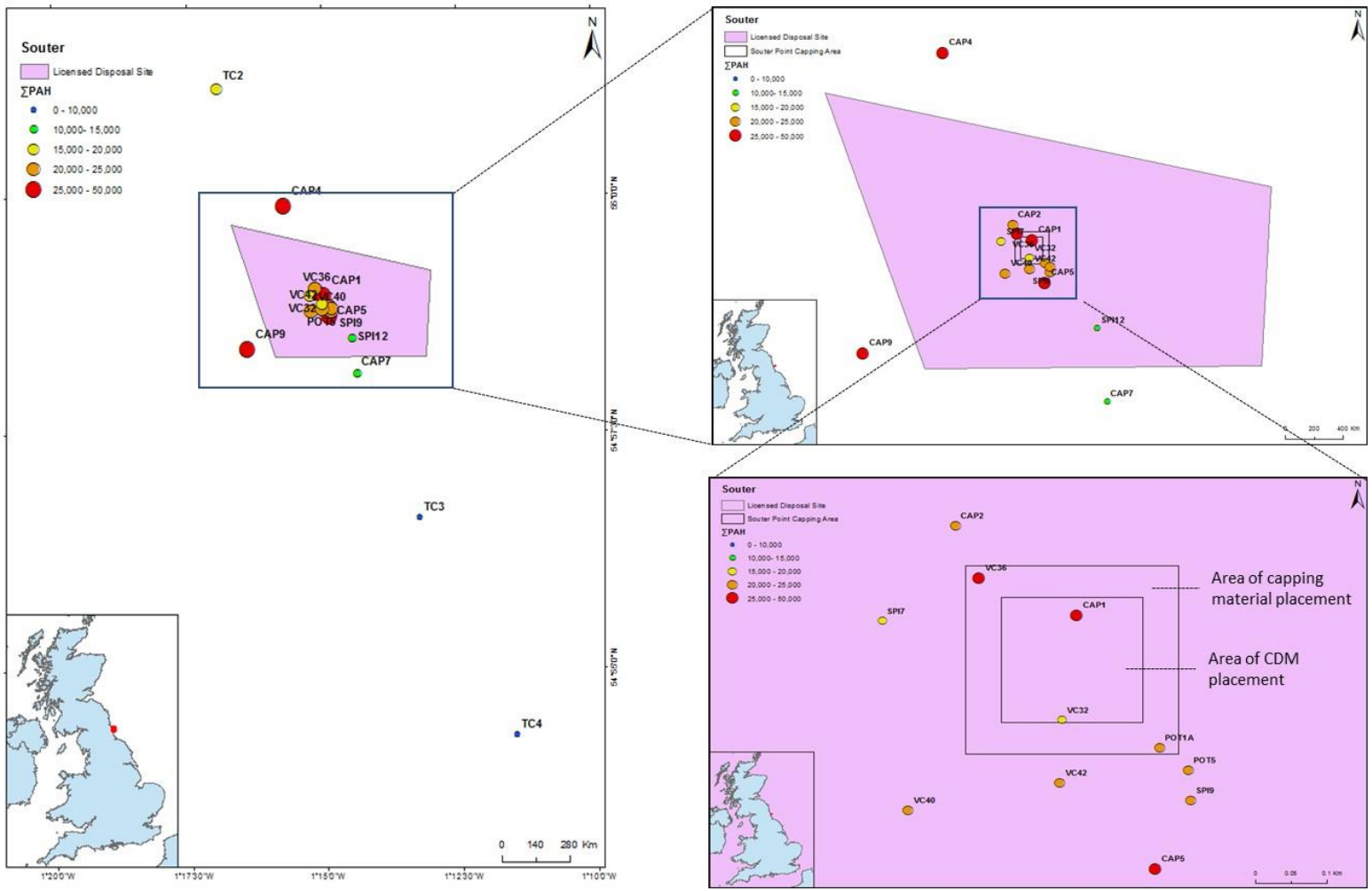
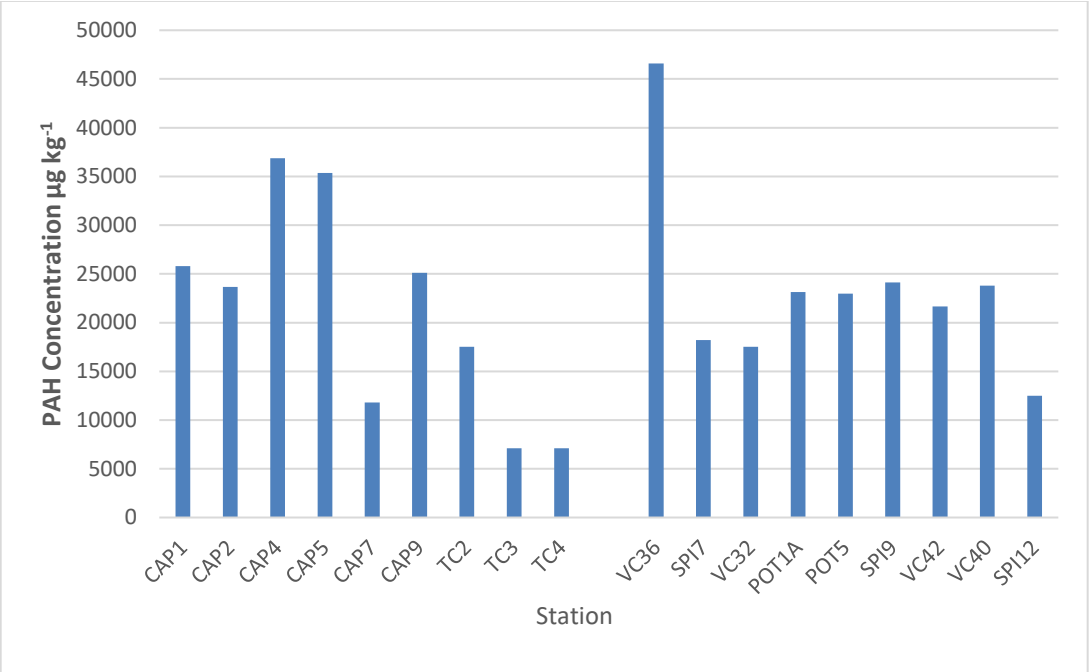


Figure A1.1.6. Summed PAH concentrations (µg kg^{-1} dry weight) of the sediments for the stations sampled in 2016 at Souter Point. The area in which capping was conducted in 2004 is highlighted in the lower right-hand image



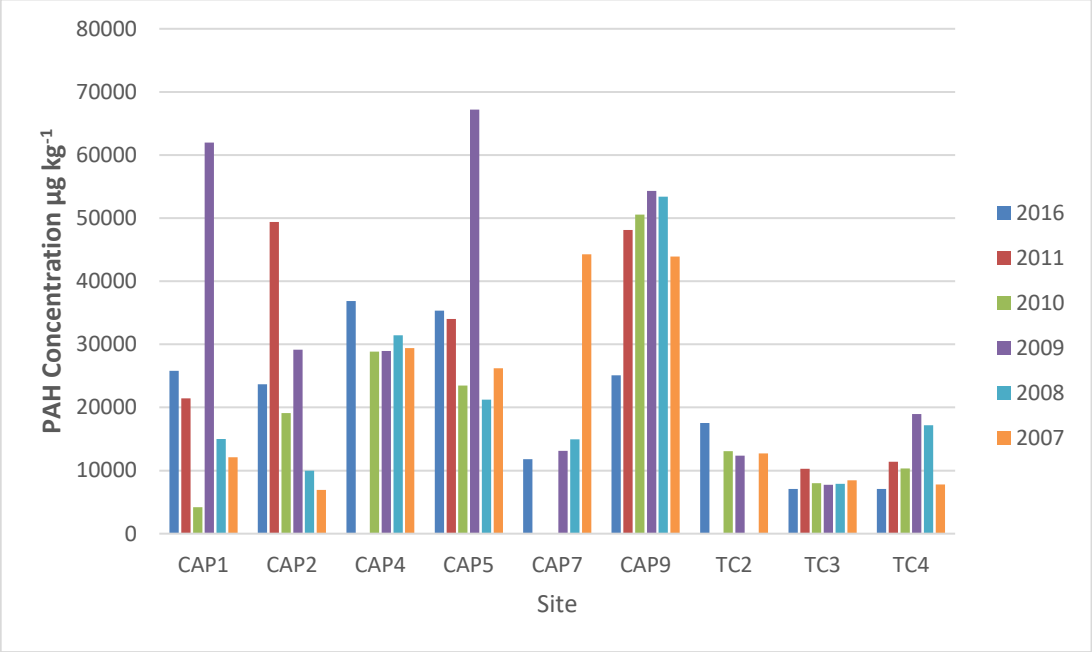


Figure A1.1.7. Summed PAH concentration of the sediments of the stations sampled in 2016 at Souter Point (top) and the temporal data for stations sampled at Souter Point since 2007 under the auspices of Cefas monitoring projects.

Comparisons with previous years indicate that ΣPAH concentrations are less than, or generally comparable with, those of previous years except for small increases at CAP1 on the cap site, at CAP4 to the north of disposal site, at CAP5 within the disposal site but outside the cap area, and finally at TC2 located further north of the disposal site (Figure A1.1.6-A1.1.7).

Figure A1.1.8 shows the ERL (effects range low; see Section 2.1.2) and ERM (effects range median; see Section 2.1.2) levels for low molecular weight (LMW) PAHs from the stations sampled in 2016. The ERL for low molecular weight (LMW) PAHs was breached at all stations sampled, including all those outside the disposal site boundary. Some stations displayed concentrations between the ERL and ERM limits. These were found along northwest to southeast transect across the survey site and included stations outside the licenced site, inside the site and one station on the capping area (e.g., VC32). The ERM for low molecular weight PAHs was breached at all other stations (Figure A1.1.8).

The ERL and ERM levels for high molecular weight (HMW) PAHs for the stations sampled are displayed in Figure A1.1.9. The ERL for HMW PAHs was breached at stations within the disposal site (CAP4, CAP9, POT5, SPI9, VC40, CAP5) and on the capping area (VC36 and CAP1). The ERM for HMW PAHs was not exceeded for any of the stations sampled in 2016.

Evaluation of the PAH data indicated that the source in all the sediment samples were predominantly petrogenic, generally with approximately >80% of the PAH content arising from oily sources as opposed to combustion sources, with the highest percentage at 86% oil dominated source found at SP17.

Summed PAH concentrations observed at Souter Point in 2016 are comparable to those found at other disposal sites around UK waters including those also located off the northeast coast such as North Tyne where concentrations of 40,000 µg/kg have recently been observed at a number of stations during monitoring under the auspices of C6794 and SLAB5 (Bolam et al., 2015).

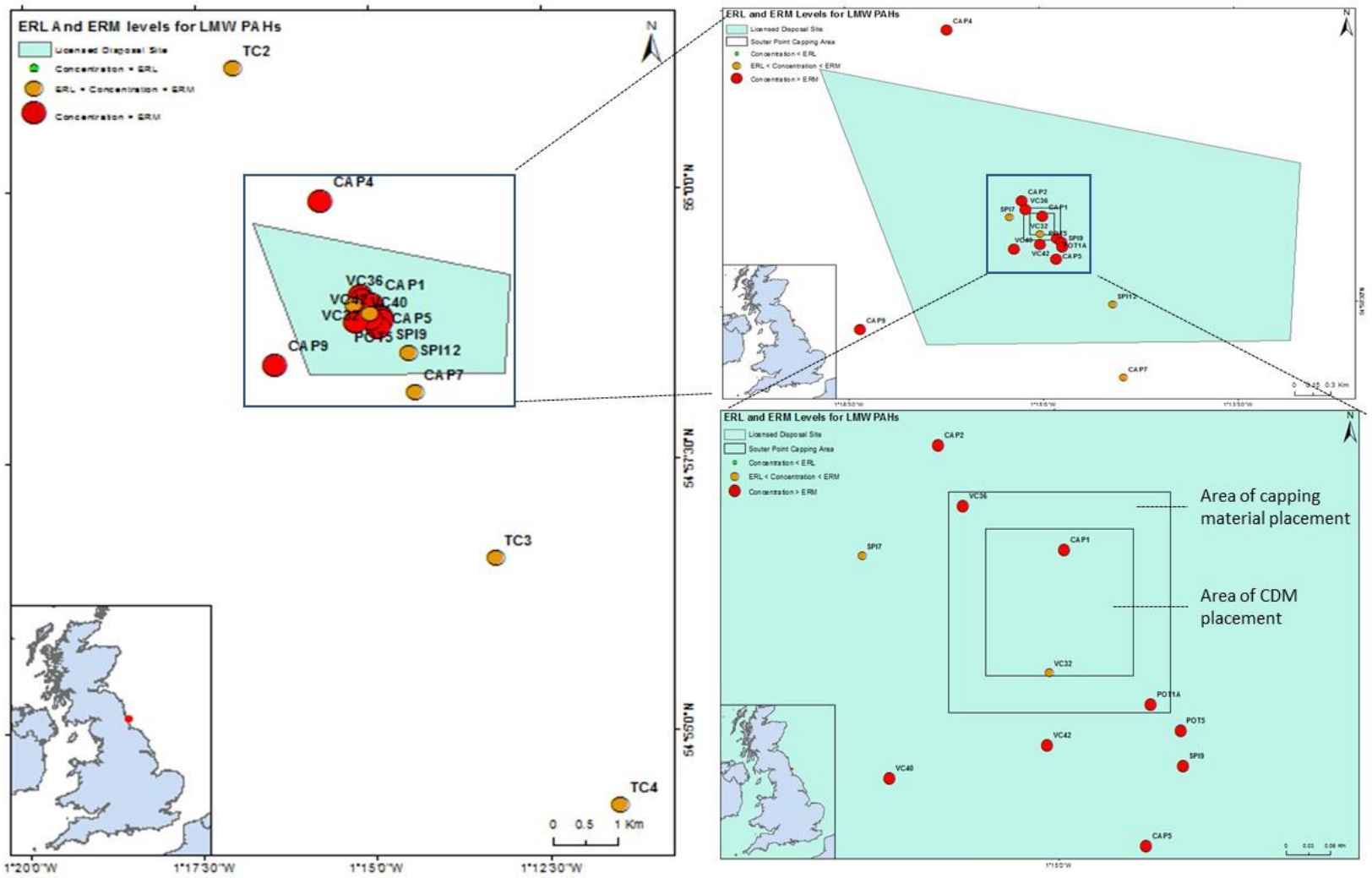


Figure A1.1.8. ERL and ERM categories for low molecular weight (LMW) PAHs for the stations sampled at Souter Point in 2016.

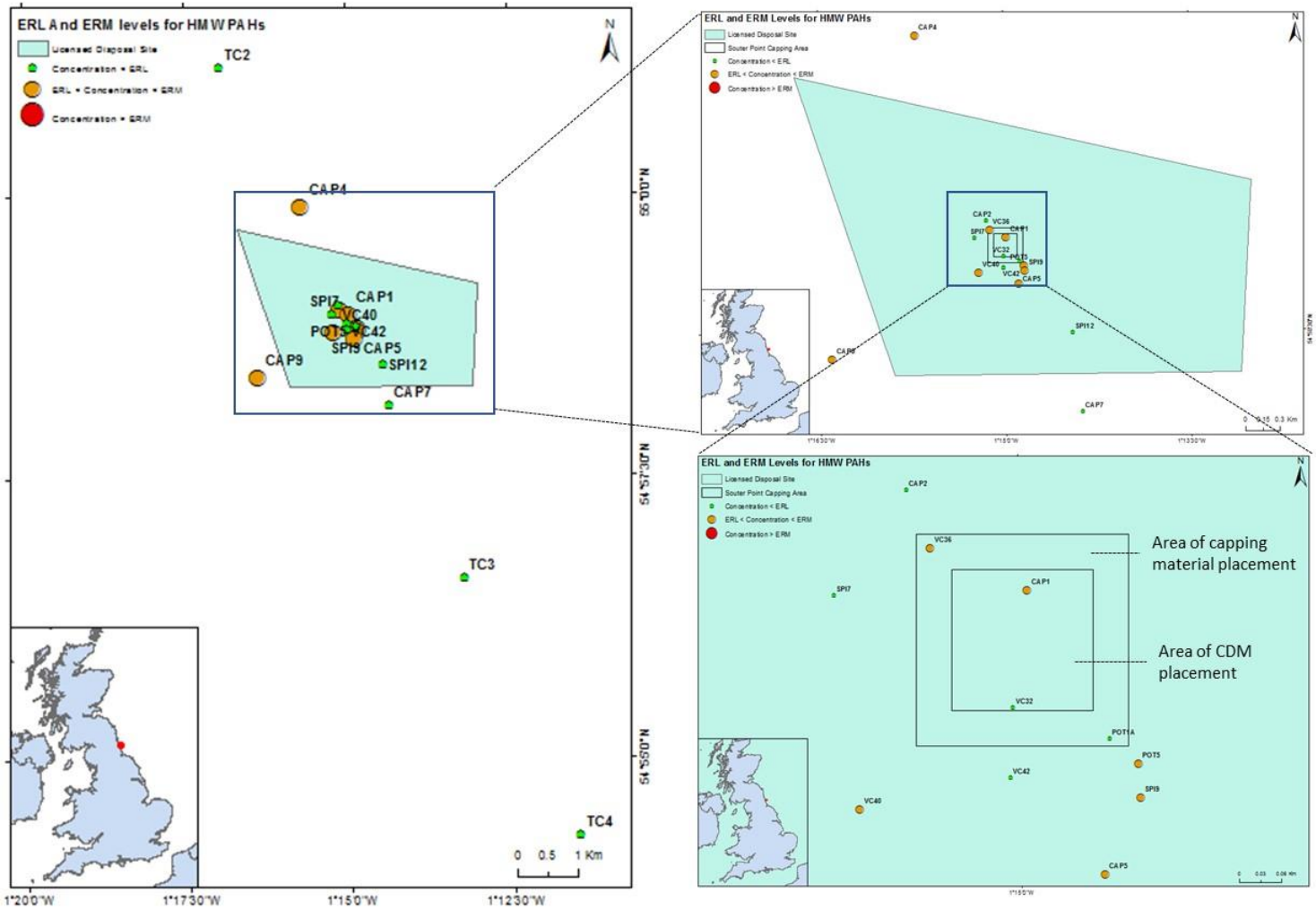


Figure A1.1.9. ERL and ERM categories for high molecular weight (HMW) PAHs for the stations sampled at Souter Point in 2016.

1.1.3.3.2 Organohalogens

At Souter Point, polychlorinated biphenyls (CBs) were detected at all stations (∑ICES7 CBs range 0.84-4.7 µg/kg dw; Figure A1.1.10; Table A1.1.3). CB concentrations were lowest at TC3 and TC4 to the south of the disposal site, with ∑ICES7 CB concentrations of 0.84 and 0.86 µg/kg dw, respectively. In contrast, the highest ∑ICES 7 concentrations (i.e. 4.7 and 2.6 µg/kg dw) were found within the disposal site at CAP2 and CAP5, respectively, with 2.5 µg/kg dw at CAP9 to the west of the disposal site (Figure A1.1.10).

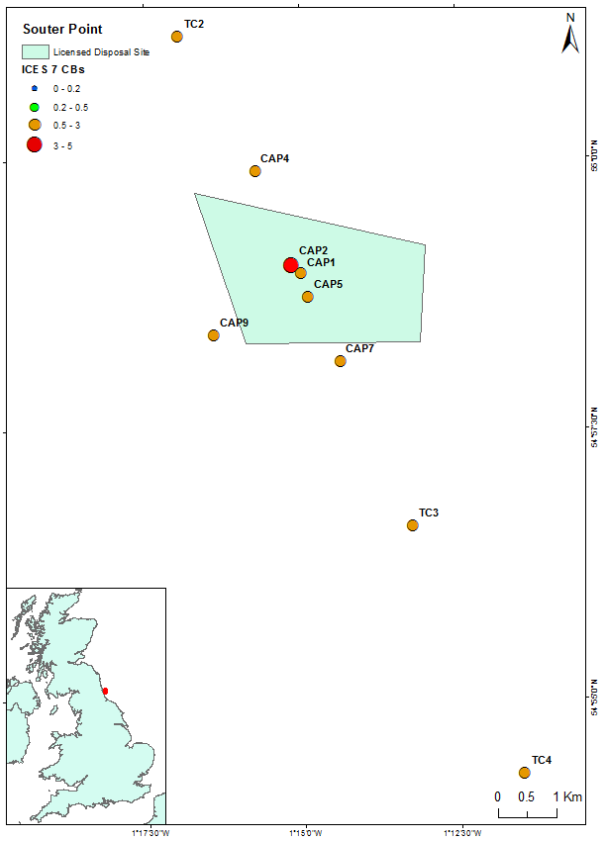


Figure A1.1.10. ∑ ICES7 CB concentrations for the stations sampled at Souter Point, 2016.

Brominated diphenyl ethers (BDEs) were detected at all stations (∑11 BDEs range 0.75-2.6 µg/kg dw). The highest concentration was found at TC2 to the north of the disposal site, while the next highest (1.8 µg/kg dw) was observed at CAP5 within the disposal site (Figure A1.1.11). The lowest (∑11 BDEs concentration of 0.75 µg/kg dw) was sampled at CAP1 within the disposal site, with concentrations of 0.90 and 0.76 µg/kg dw found at TC3 and TC4 to the south of the disposal site, respectively (Figure A1.1.11). BDE47 and BDE99 are the dominant congeners present, indicative of the pentaBDE technical mixture, but BDE183 was also detected at all stations, suggesting that the octaBDE or decaBDE technical mixture had also been in use.

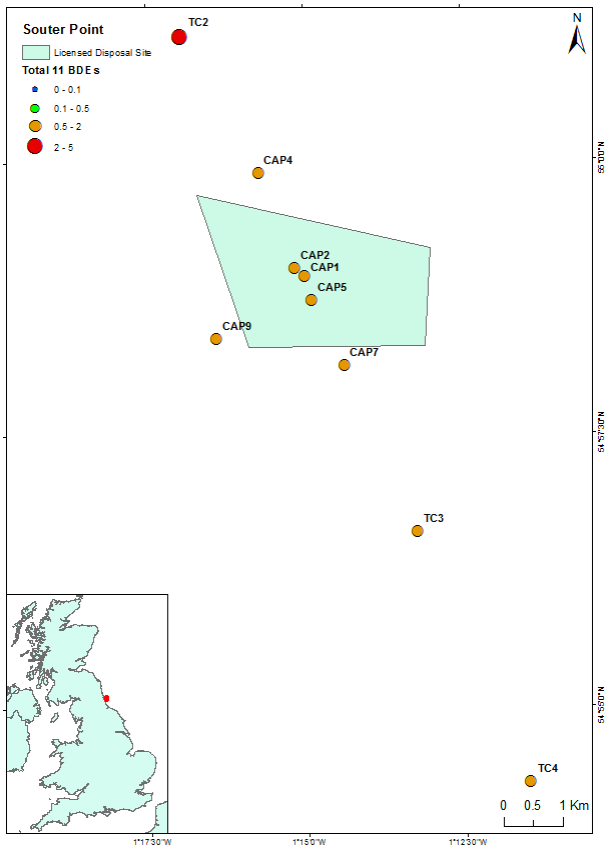


Figure A1.1.11. ∑11 BDE concentrations for the stations sampled at Souter Point, 2016.

BDE209, present at all stations, was at higher concentrations than the other measured organohalogens (range 6.5-58.2 µg/kg dw; Figure A1.1.12). When included with the other BDEs, BDE209 made up >78% of the BDEs present (range 78-94%). BDE209 is indicative of the decaBDE technical mixture, which had been in use more recently than the other technical mixtures, although it's use has been restricted in the EU since 2008. The highest BDE209 concentrations (58.2 and 56.3 µg/kg dw) were detected at CAP2 (within the disposal site but outside the capping area) and CAP7 (south of the disposal site) respectively, with 26.4 µg/kg dw measured at TC2 to the north of the disposal site (Figure A1.1.12). Concentrations observed at all other stations were all in the range 5.9-18.1 µg/kg dw, the two lowest measured at TC3 and TC4 to the south of the disposal site.

Organochlorine pesticides (OCPs) were detected at all stations sampled in 2016. $\sum_6$DDTs concentrations ranged from 0.94-2.84 µg/kg dw, with the highest values at CAP4 to the north of the disposal site (2.84 µg/kg dw), TC3 to the south of the disposal site (2.23 µg/kg dw) and CAP5 within the disposal site (2.09 µg/kg dw) (Figure A1.1.13). Dieldrin was detected at all nine stations (range 0.18-0.34 µg/kg dw), with the highest value at CAP9 and the lowest at TC3.

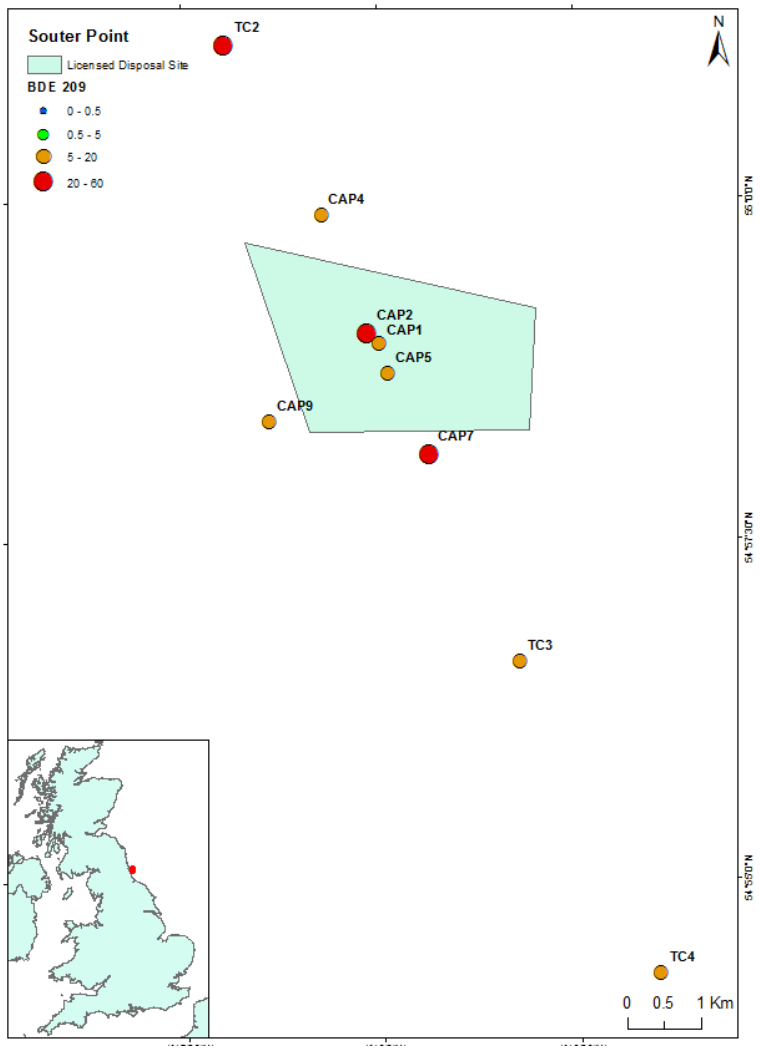


Figure A1.1.12 BDE209 concentrations for the Souter Point Stations, 2016.

Concentrations of CBs and dieldrin at all stations were all below Cefas action level 1 (AL1). $\sum_6$DDTs concentrations were above Cefas AL1 for eight of the nine stations. No Cefas ALs have been derived for BDEs including BDE209. According to the OSPAR guidelines, most stations had 'good' environmental status for all ICES 7 CBs and 'good' status overall. The exception was CAP2 (northwest of the capping area) which had 'bad' environmental status for CB118 but with 'good' status overall. No OSPAR guidelines presently exist for BDEs and OCPs.

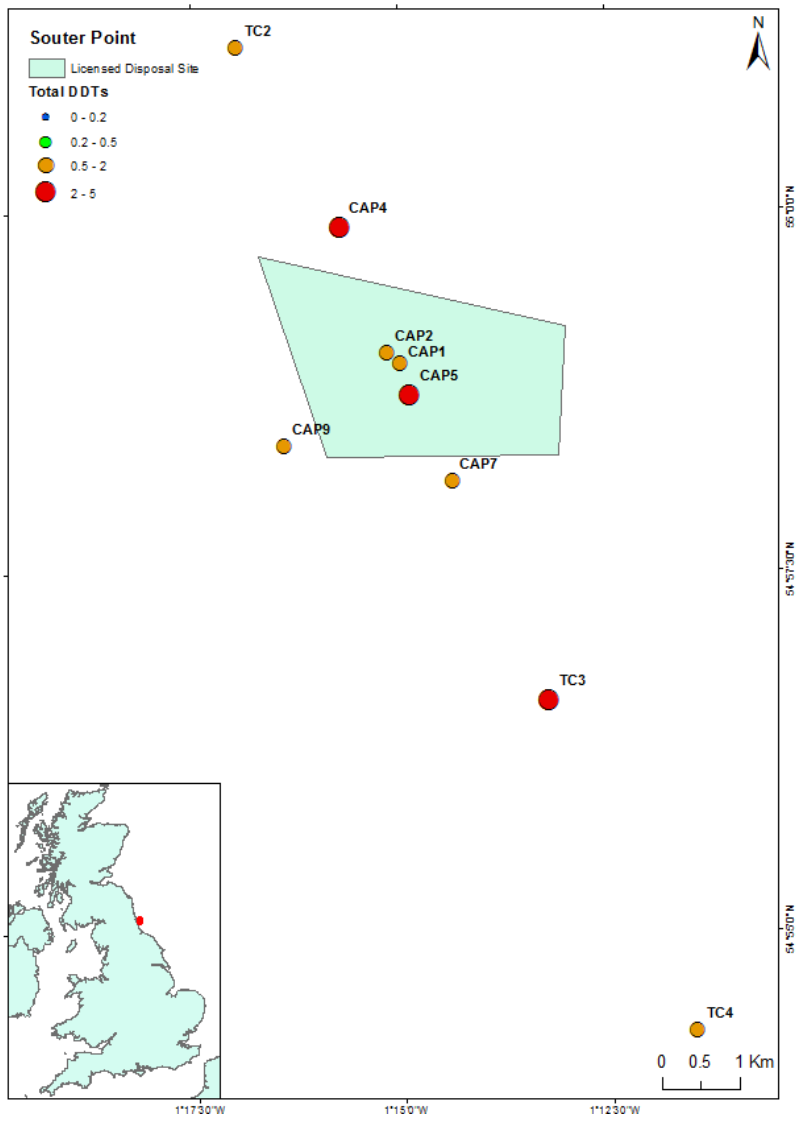


Figure A1.1.13. Total DDT concentrations for the Souter Point Stations, 2016.

In 2015, the Souter Point disposal site received just over three hundred thousand tonnes of maintenance dredged material (Figure A1.1.2), the highest annual tonnage since 2011. There are data available to assess the temporal trends of OHs concentrations from 2005 to 2016 (see Tables A1.1.3-A1.1.5). At Souter Point, CB concentrations in 2016 were all in the range of concentrations observed in the period 2005-10. Comparing values with the 2010 survey reveals mixed temporal trends, with TC2, CAP1, CAP2 and CAP5 increasing, and CAP9 displaying decreasing concentrations.

Similarly, for BDEs, most stations in 2016 showed concentrations in the range of those observed during 2005-10, except for CAP5 (south of the capping region) which displayed an increase in 2016 (Table A1.1.4). Comparing the 2016 values with those from the survey in 2010 reveals mixed trends, with TC2,

CAP1, CAP5, and CAP7 increasing, and CAP4, CAP2, CAP9, TC3 and TC4 exhibiting decreasing concentrations.

Table A1.1.3 Temporal trends (2005-2016) of ∑ICES 7 CBs concentration (in µg/kg dw) at Souter Point.

Station	∑ICES 7 CBs concentration (in µg/kg dw)							
	2005	2006	2007	2008	2009	2010	~	2016
TC2		6.2	2.58		1.54	1.47		1.91
CAP4	3.7	3.6	2.35	3.39	3.11	1.50		1.45
CAP2	0.83	1.01	*0.7*	*0.7*	7.23	2.96		4.65
CAP1	1.1	0.84	*0.7*	0.96	1.88	*0.7*		1.24
CAP5	1.1	0.86	0.7	3.22	1.11	0.8		2.56
CAP9	4.97	2.91	2	2.84	3.25	3.13		2.53
CAP7	1.34	1.12	2.23	1.51	1.24			1.44
TC3	0.96	1.19	*0.7*	*0.7*	0.96	*0.7*		0.84
TC4	1.17	1.14	*0.7*	2.62	1.3	1.09		0.86
SPI15						56.0		
SPI16						3.61		

Concentrations in italic represent estimates of concentrations for samples where all ICES 7 congener concentrations were below LODs. Limits of detection for CBs improved between 2010 and 2016, resulting in a step decrease in ∑7 CBs concentration for samples with congeners below LODs.

For BDE209, concentrations in 2016 were the highest measured since 2008, with the exception of the background 'reference' stations TC3 and TC4 (Table A1.1.5). In particular, BDE209 concentrations at CAP7 were 10 times higher in 2016 than had previously been measured. These increases may reflect the increased volume of material disposed in the area rather than any degradation of the cap as there was a lack of a big increase in PCB concentrations, and CAP7 is located outside the disposal site. BDE209 is not usually measured in dredge sediments as part of the licensing process, so it's concentration in the source material is unknown.

Table A1.1.4. Temporal trends (2005-2016) of ∑11 BDEs concentration (in µg/kg dw) at Souter Point.

Station	∑11 BDEs concentration (in µg/kg dw)							
	2005	2006	2007	2008	2009	2010	~	2016
TC2	3.95	8.30	2.94		1.36	2.16		2.59
CAP4	5.84	2.15	2.57	1.37	1.18	1.95		1.25
CAP2	1.11	1.01	0.79	0.41	1.55	1.24		0.98
CAP1	0.83	0.80	0.96	0.26	0.62	0.28		0.75
CAP5	1.13	1.07	0.91	0.41	0.54	0.88		1.75
CAP9	3.77	12.6	5.92	1.02	1.92	1.95		1.35
CAP7	1.94	2.37	3.96	0.85	0.80			1.34
TC3	1.45	5.96	1.36	0.55	0.73	1.45		0.90
TC4	1.78	8.59	1.51	0.82	0.86	1.34		0.76
SPI15						1.28		
SPI16						2.75		

Concentrations in italic represent estimates of concentrations for samples where all 11 BDE congener concentrations were below LODs. Limits of detection for BDEs improved between 2007 and 2008 and again between 2010 and 2016, resulting in step decreases in ∑11 BDEs concentration for samples with congeners below LODs.

Table A1.1.5. Temporal trends (2008-2016) of BDE209 concentration (in µg/kg dw) at Souter Point.

Station	BDE209 concentration (in µg/kg dw)					
	2008	2009	2010	2011	~	2016
TC2		9.00	6.68			26.4
CAP4	3.37	3.88	7.63			12.2
CAP2	0.90	49.2	17.8	6.36		58.2
CAP1	0.77	7.49	0.89	2.95		9.79
CAP5	2.75	12.0	3.79	6.35		18.1
CAP9	4.08	13.6	5.08	11.9		13.8
CAP7	3.72	3.92				56.3
TC3				6.14		1.59
TC4				5.68		1.69

1.1.3.3.3 TBT

Of the surficial samples derived from the grabs, only stations located just outside the capping area (SPI7, SPI9, VC40, VC42 and POT5) displayed detectable levels of TBT (Figure A1.1.14). These concentrations, however, were all below AL 1 for TBT. All other stations (most of them located within the capping area) depicted levels of TBT below the method limit of detection (LOD, 0.002mg/kg). Out of the nine stations sampled, only one from station, VC40 to the southwest of the capping area, recorded levels of DBT above the LOD (Figure A1.1.14). This concentration, however, is below the AL1.

At station POT5, CDM was identified in the sediment layer 31-39cm sediment depth during 2012 with DBT and TBT levels of 0.14 and 4.63mg/kg respectively (Bolam et al., 2014). The DBT and TBT concentrations observed in 2016, where above LOD, are significantly lower than these 2012 values inferring that either the cap is still intact at these stations or, but less likely, both capping sediments and the CDM have eroded away.

1.1.3.3.4 Trace metals

When assessing the level of metal concentrations within the Souter Point area, findings from both the regional baseline assessment concentration (RAC) and OSPAR approaches show no enrichment of arsenic (As) at Souter Point for the most stations. Only a few stations located within the disposal site (CAP1, POT1A; within capping area, and VC40 and VC42; outside capping area) depict slight enrichment with the OSPAR assessment method (Figure A1.1.15). Similar observations are found for Cd for both assessment methods where slight enrichment is mainly recorded for stations located within the disposal site.

Cr and Ni were found to be slightly enriched with the OSPAR approach but not with the RAC, this finding concurs with observations made in 2012. When assessing using the OSPAR BAC value, most stations are found to be slightly enriched for Zn and to a more enriched level for Pb. However, all those stations have become less or not enriched when comparing their levels with the baseline values, where a slight enrichment was mainly observed at stations located within the disposal site.

Hg generally shows the highest enrichment ratios for all stations (2-5 times above the OSPAR BAC value at two stations, both within the disposal site) (Figure A1.1.15). The enrichment is notably reduced when assessing Hg levels against the proposed baseline values where slight enrichment is observed at stations within the disposal site and no enrichment is recorded elsewhere.

Since most of the proposed RAC baselines values are higher than the current OSPAR BACs values (the latter does not take into account historical solid industrial wastes or other (unregulated) discharges), thus, using OSPAR BACs as a tool to assess metal enrichment in this region could be misleading for some metals, in particular Cu, Zn, Hg and Pb. The proposed baselines give a more accurate level of enrichment for the Tyne/Tees region. Generally, levels of Cu, Zn, As, Cd, Pb and Hg are higher at stations within the disposal site than those situated outside the disposal site.

No particular temporal trend is detected over the surveyed period (2006-2016) (Figure A1.1.16).

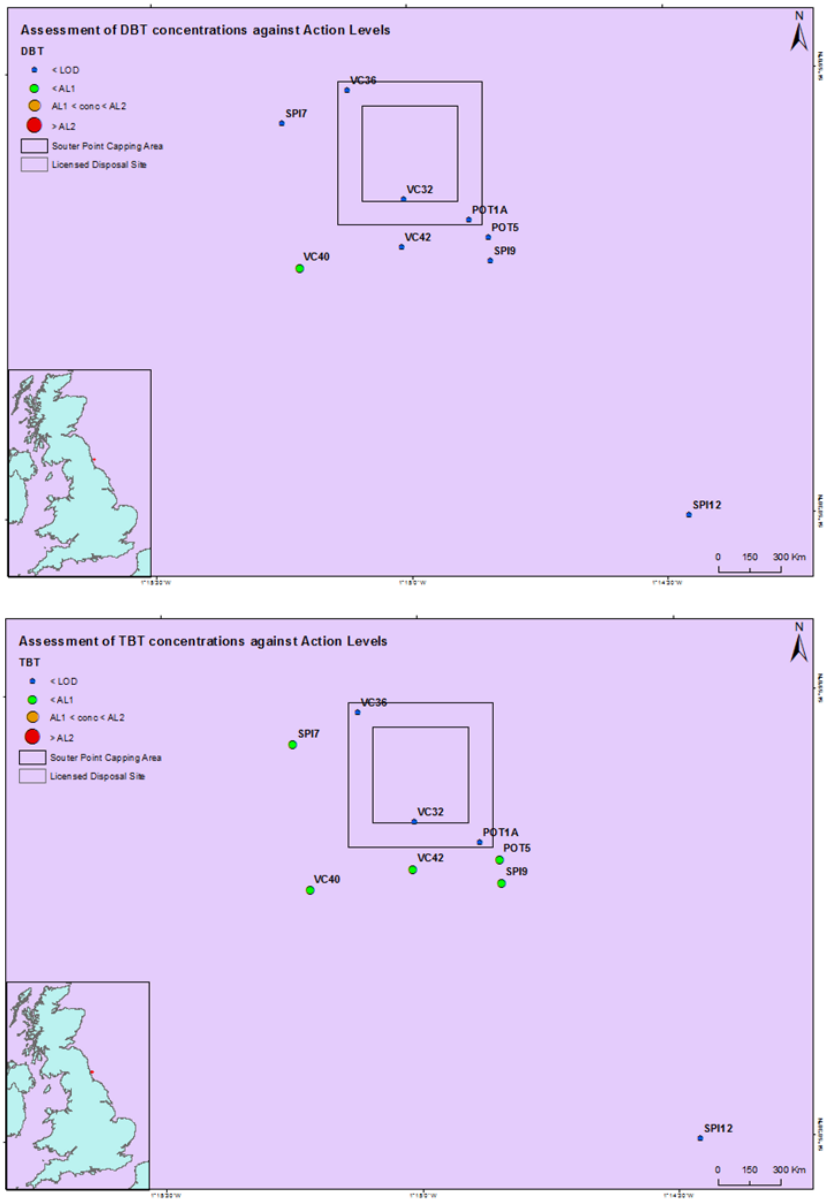


Figure A1.1.14. Sediment DBT (top) and TBT (bottom) concentrations for the stations sampled in the vicinity of the capping area, Souter Point, in 2016.

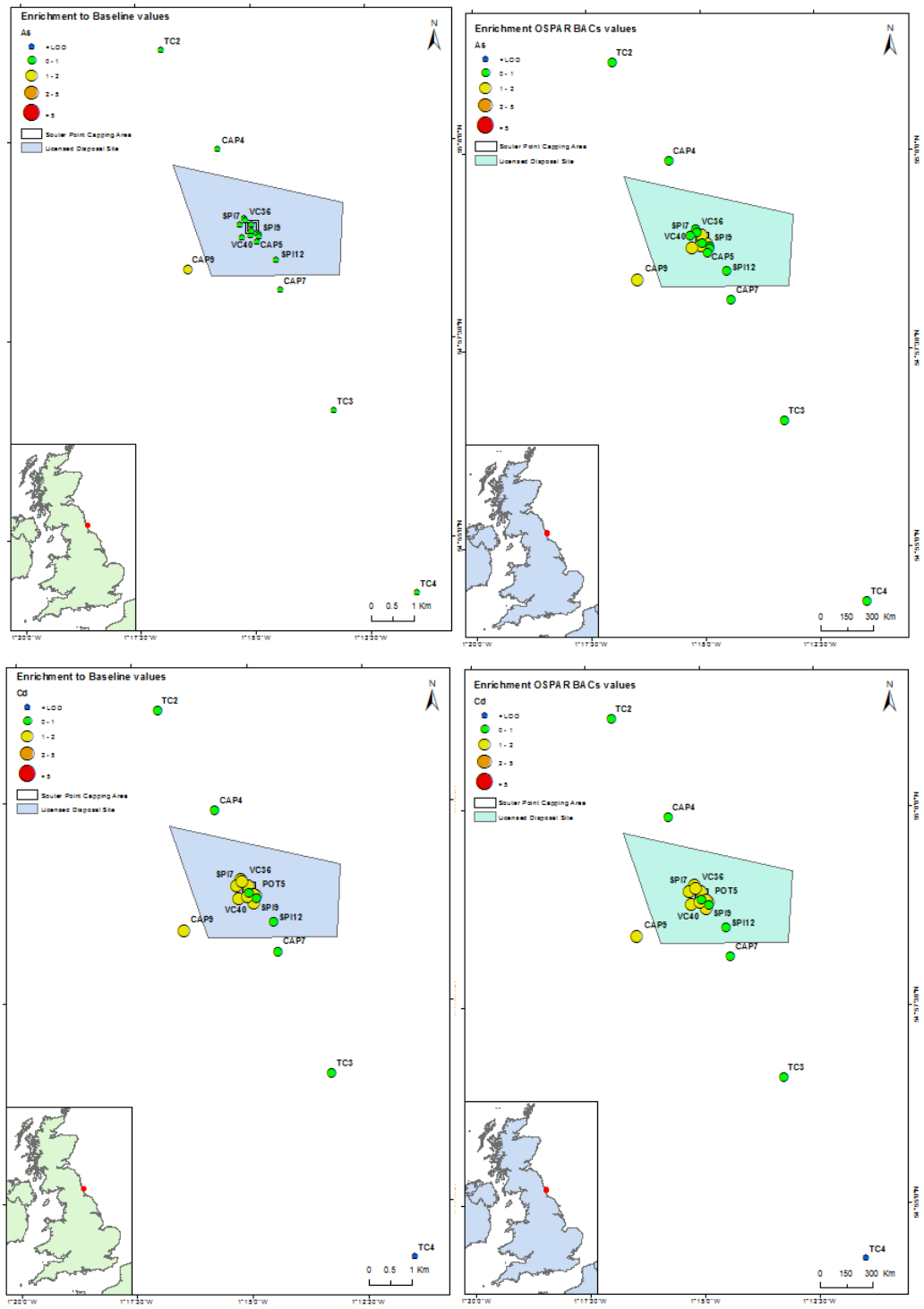


Figure A1.1.15. Enrichment of regional baseline (left) and OSPAR BACs for trace metals sampled at Souter Point in 2016.

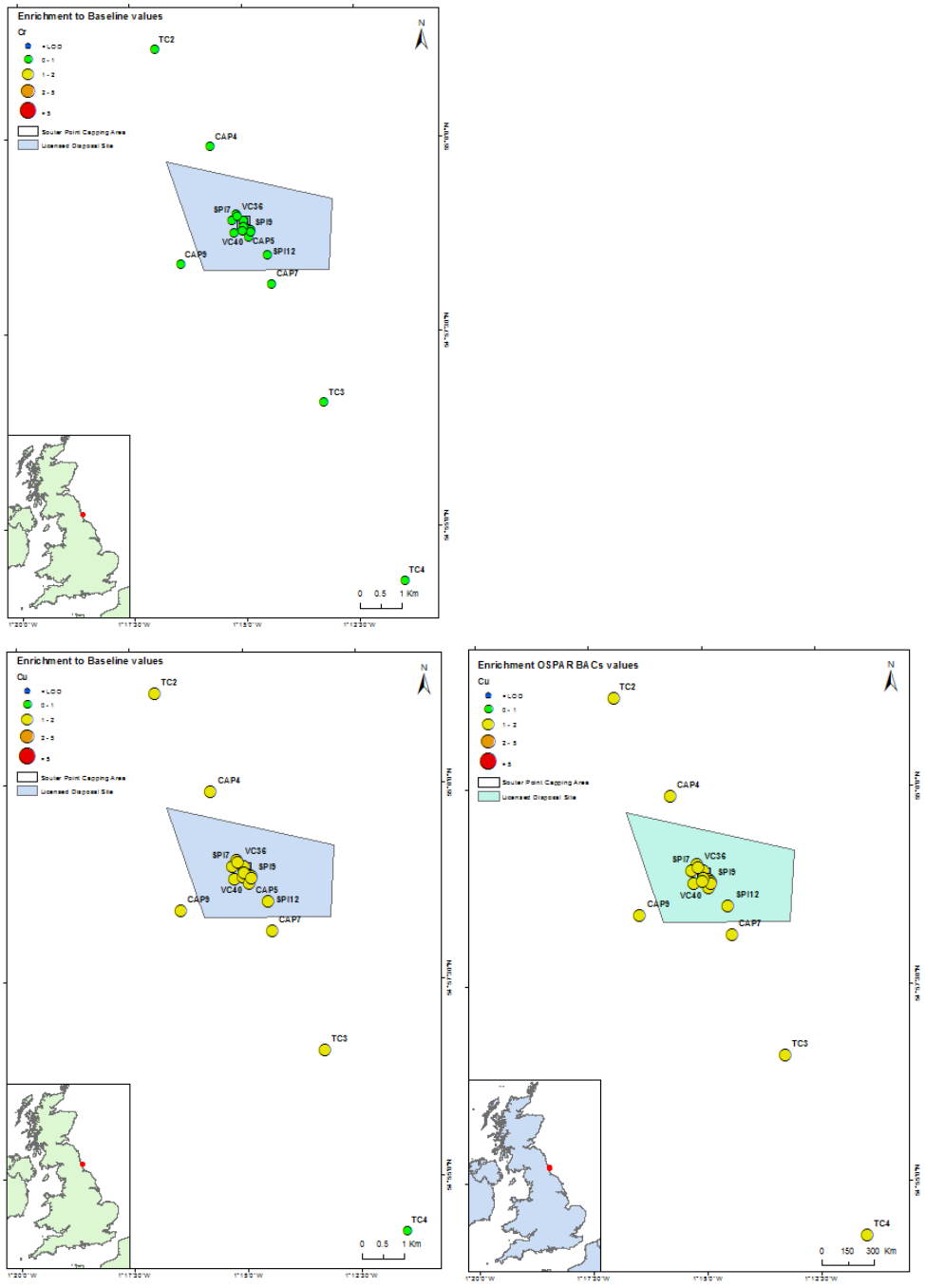


Figure A1.1.15. Continued.

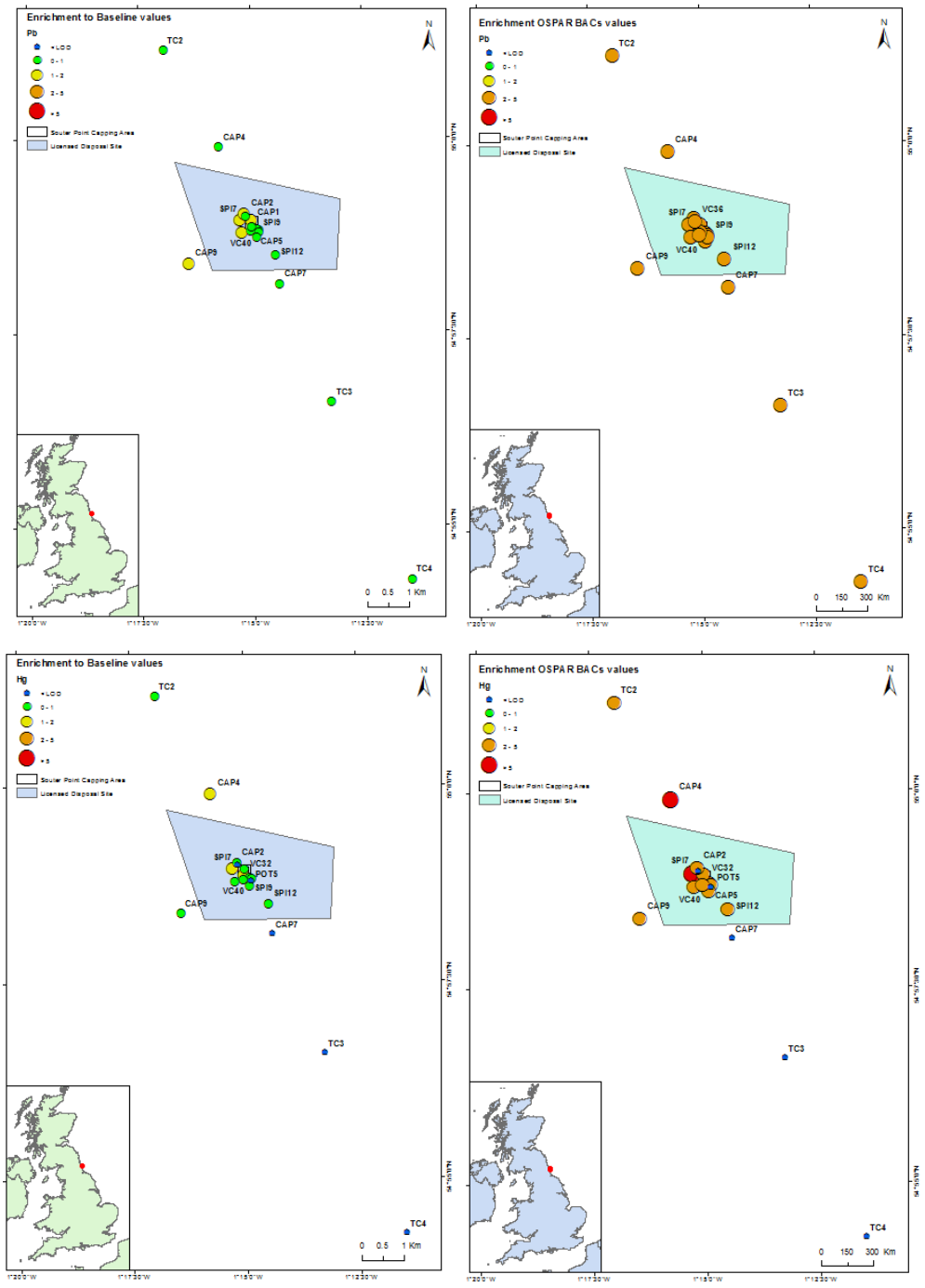


Figure A1.1.15. Continued.

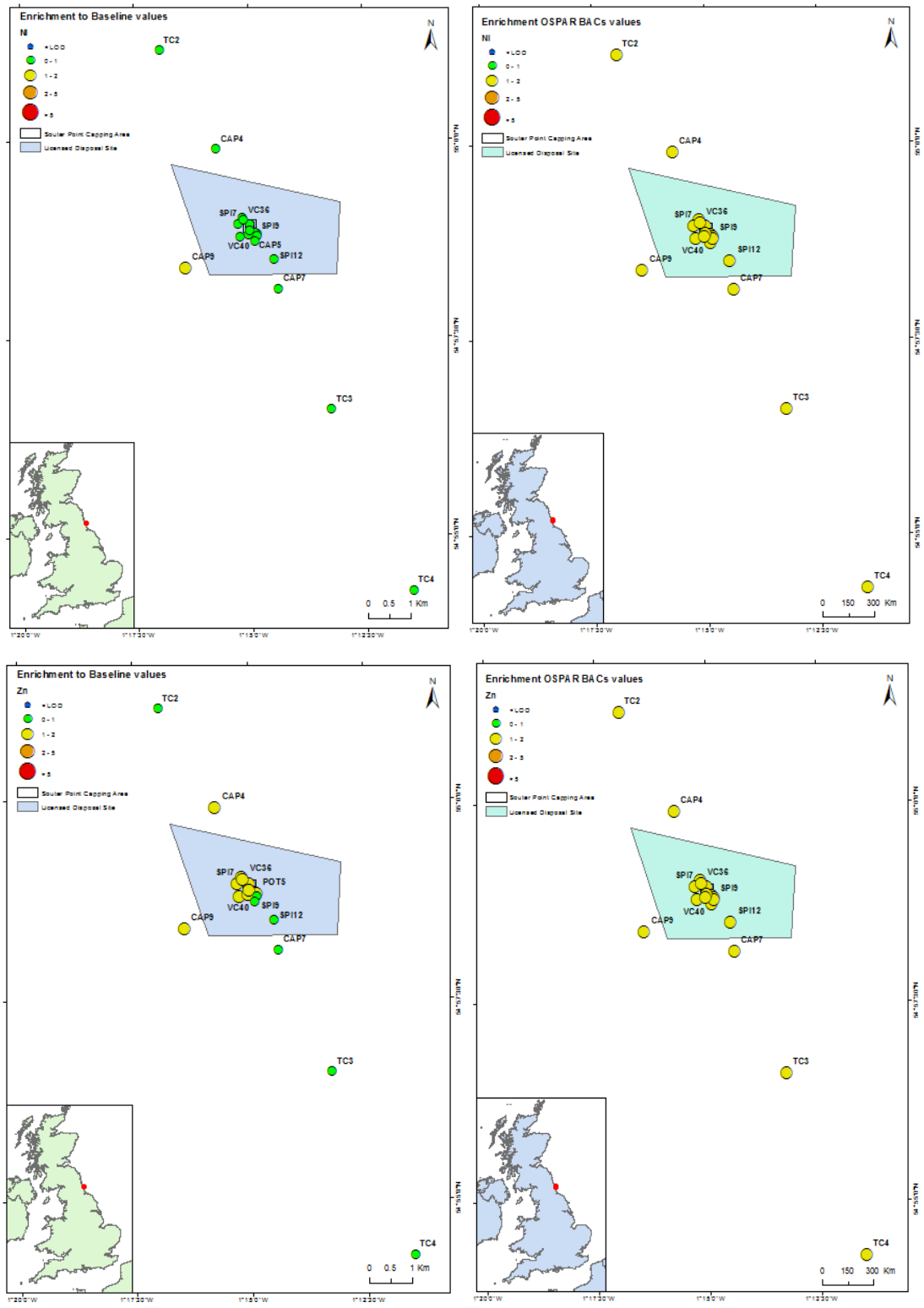


Figure A1.1.15. Continued.

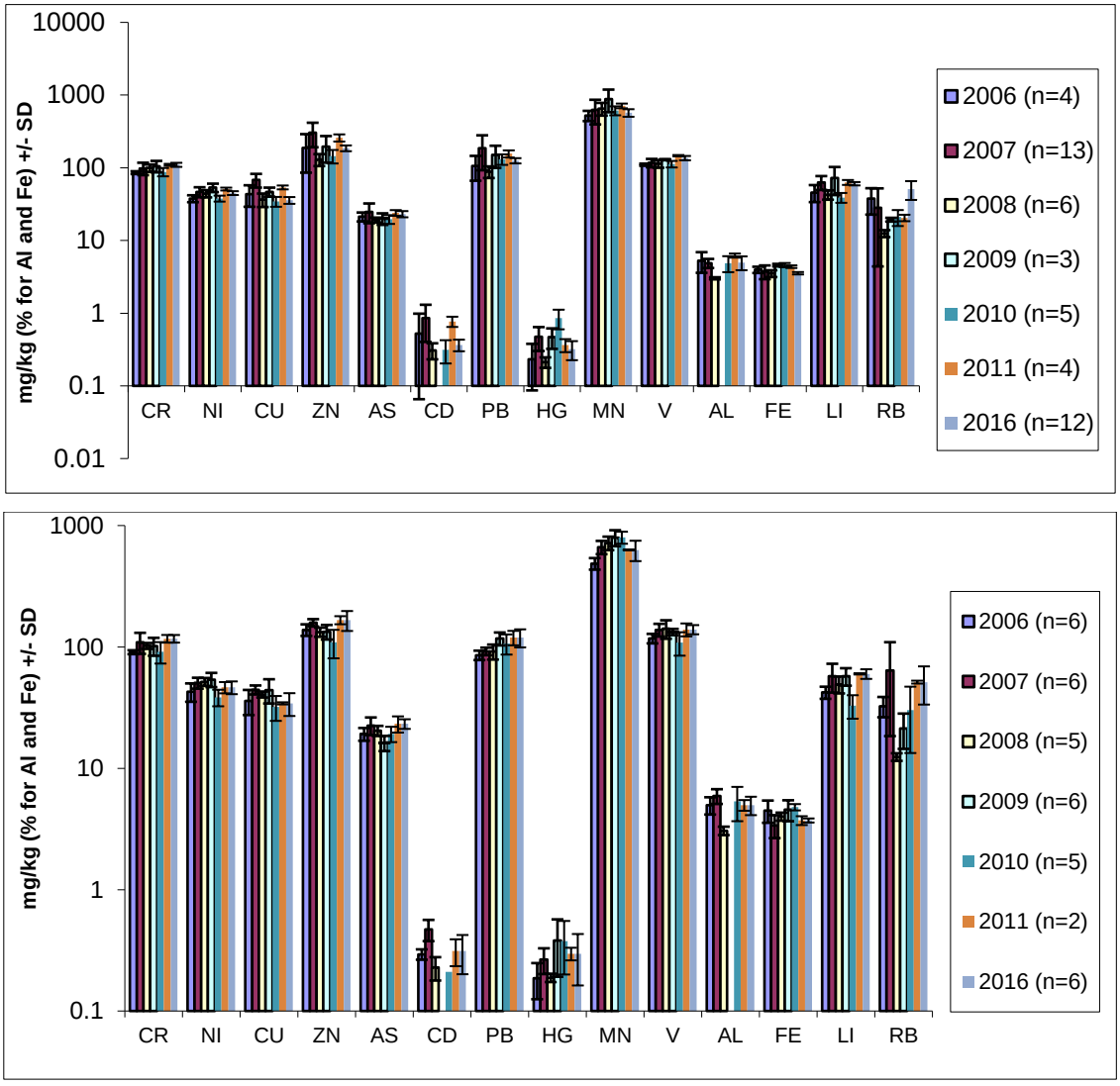


Figure A1.1.16. Average trace metals concentrations of the stations inside (top) and outside (bottom) the Souter Point disposal site from 2006 to 2016.

1.1.3.4 Macrofaunal assemblages

The macrofaunal survey completed at Souter Point in 2016 consisted of 9 stations (each sampled in triplicate). Stations were located inside the capping area (CAP1), inside the disposal site (CAP2, CAP5), just outside the disposal site (CAP4, CAP7, CAP9) and distant (reference) stations (3 km to 10 km away from the disposal site boundary; TC2, TC3, TC4). The station locations matched those from monitoring conducted in previous years giving a time series of 8 years for several locations (Table A1.1.6 and Figure A1.1.17). The data analysis below has concentrated on the temporal changes in the macrofaunal assemblages at the different stations between

years. A spatial analysis based solely on the 2016 data is not presented although the spatial trends are discussed for all years in the interpretation below.

1.1.3.4.1 Multivariate analyses

Previous studies have, at various times, described the spatial differences in macrofaunal assemblages at the Souter Point disposal site (Birchenough et al., 2007; Bolam et al., 2009, Bolam et al., 2011a; Bolam et al., 2012a; Bolam et al., 2012b). To determine the changes over time at each station the rationalised macrofaunal dataset (all years and replicates) was analysed with the PRIMER V7 statistical package. Data were square root-transformed prior to testing. A two-way ANOSIM on the overall abundance resemblance matrix indicated that there are significant differences between both 'year' (global R =0.79, P=0.01) and 'station' (global R = 0.73, P=0.01) and was replicated by the biomass (square root transformed) resemblance ('year' global R =0.593 P=0.01 and 'station' global R = 0.693 P=0.01). Two nMDS ordinations of the station averaged data by year (i.e. replicates averaged by station) are shown in Figure A1.1.18, one based on abundance data and one based on biomass data. These figures illustrate how samples from stations CAP1, CAP2 and CAP5 are consistently more separated from the main grouping of samples. However, the locations of samples in more recent years (e.g. 2010, 2011 and 2016) are closer (and therefore having a more similar assemblage type) to the main groupings. This would suggest that a) stations CAP1, CAP2 and CAP5, which are the only sites within the disposal site boundary, are considerably dissimilar to other sites, and b) the dissimilarity has reduced over time from 2005 which appears to show the largest difference, to 2016 where samples appear closer to the main groupings of other stations. To explore these apparent trends in more detail each station was then considered separately to describe the changes observed between years.

An ANOSIM test of 'year' on each station showed there was statistically significant variability between years at every station ($P<0.01$, R values >0.68). However, it is important to consider the scale of the variability between years to demonstrate if certain stations have undergone a greater change that others. A series of nMDS ordination plots is shown in Figure A1.1.19 which shows the trajectory of change in the benthic faunal assemblages at each station over time. A similarity 'ring' at 40% has also been overlaid onto each nMDS (generated from clustering dendrograms, not shown). These plots show that the stations inside the disposal boundary (CAP1, CAP2 and CAP5) show a high dissimilarity between years, with years typically having less than 40% similarity to one another. The trajectory (broad progression from left to right across the nMDS) also indicates that the variation between years is not random (e.g. the product of continuous short disturbance and recovery cycles with each disposal event), but represents a long-term progression towards the assemblages sampled in 2016. SIMPER testing between years at these stations show that in 2005 very few species were present in the samples with generally low abundance (e.g. at CAP 1 in 2005 the benthic community was characterised by just two species *Spiophanes bombyx* and *Scolelepis squamata* both occurring at just one or two individuals per sample). The number of species and abundance of individuals tended to increase year on year (discussed further in section 1.1.3.4.2 below) with, for example at CAP1 in 2016, species such as *Amphiura*,

Diplocirrus glaucus, Galathowenia oculata, and *Lumbrineris cingulate* characterising the faunal assemblage at average abundances of up to 50 individuals per sample.

It is likely that the observed differences at stations CAP1, CAP2 and CAP5 are a response to the capping trial in 2005 where contaminated dredged material was capped with silt and sand. Localised remobilisation and settlement of the capping material may have altered, and likely diminished, the benthic community. Although it is not clear if there has been a recovery to a pre-capping state as samples from the area are not available prior to 2005, it is apparent that there has been a succession to a more abundant and diverse benthic community at these stations since 2005 with dominant species typical of those which may be expected in shallow sandy/muddy sand habitats in the North Sea.

1.1.3.4.2 Univariate analyses

Univariate metrics of S (number of taxa) and N (abundance) per 0.1 m^2 are shown for each station over the years of sampling in Figure A1.1.20. The graphs illustrate, as with the multivariate patterns, that there is a clear upward trend in S and N from 2005 onwards at stations inside the disposal area (CAP1, CAP2 and CAP5). At these stations, the number of taxa was low in 2005 (lowest at station CAP1, with 5 to 15 taxa per 0.1 m^2). In later years (2010, 2011, 2016) the number of taxa at these stations increased to around 40 to 50 taxa per 0.1m^2. Notably this range is similar to the number of taxa observed at the nearby stations (CAP4, CAP7 and CAP9) and distant (reference) stations (TC2, TC3 and TC4).

In terms of the abundance of individuals, a similar pattern was seen again, with stations inside the disposal area initially (in 2005) displaying diminished abundance values (as few as 8 ind. per 0.1m^2). Overall abundance is observed to increase yearly to >200 ind. 0.1m^2 in the 2016 samples. Again, this is comparable to the abundances at the stations outside the disposal site.

In conclusion, the univariate indices support the multivariate interpretation that the stations inside the dredge disposal boundary show a marked succession in the benthic assemblage towards a more abundant and diverse community in 2016 compared to low abundance and low diversity community observed in earlier years.

Table A1.1.6. Time series of macrofaunal samples stations at Souter Point.

Station	Survey year – number of replicate samples							
	2005	2006	2007	2008	2009	2010	2011	2016
CAP1	3	3	3	3	3	3	1	3
CAP2	3	3	3	3	3	3	1	3
CAP4	3	3	3	3	3	3	-	3
CAP5	3	3	2	3	3	3	1	3
CAP7	3	3	3	3	3	-	-	3
CAP9	3	3	3	3	3	3	1	3
TC2	3	3	3	-	3	3	-	3
TC3	3	3	-	3	3	3	1	3
TC4	3	3	3	3	3	3	1	3

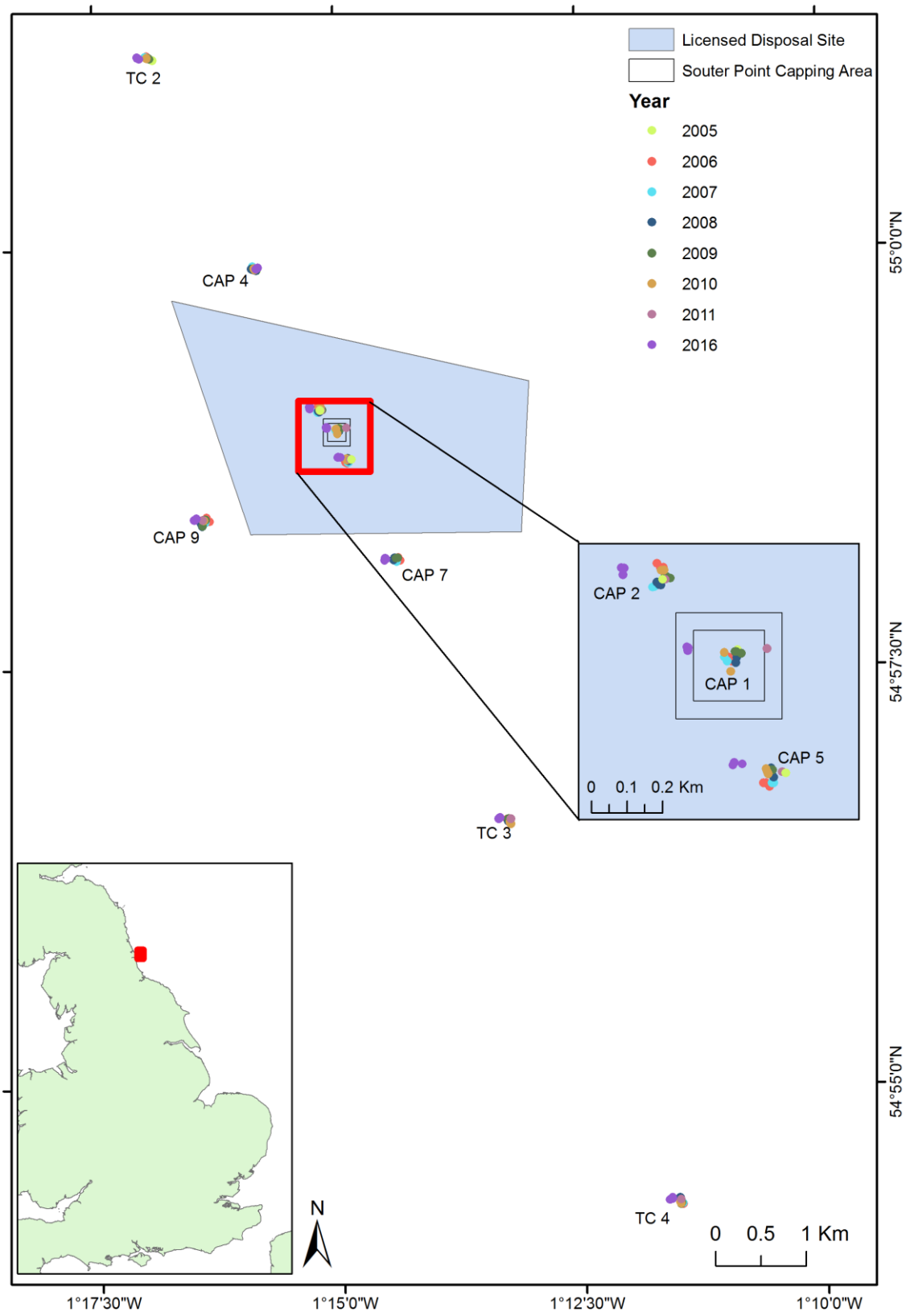


Figure A1.1.17. Station and sample locations of the macrofaunal time series at Souter Point (2005 to 2016).

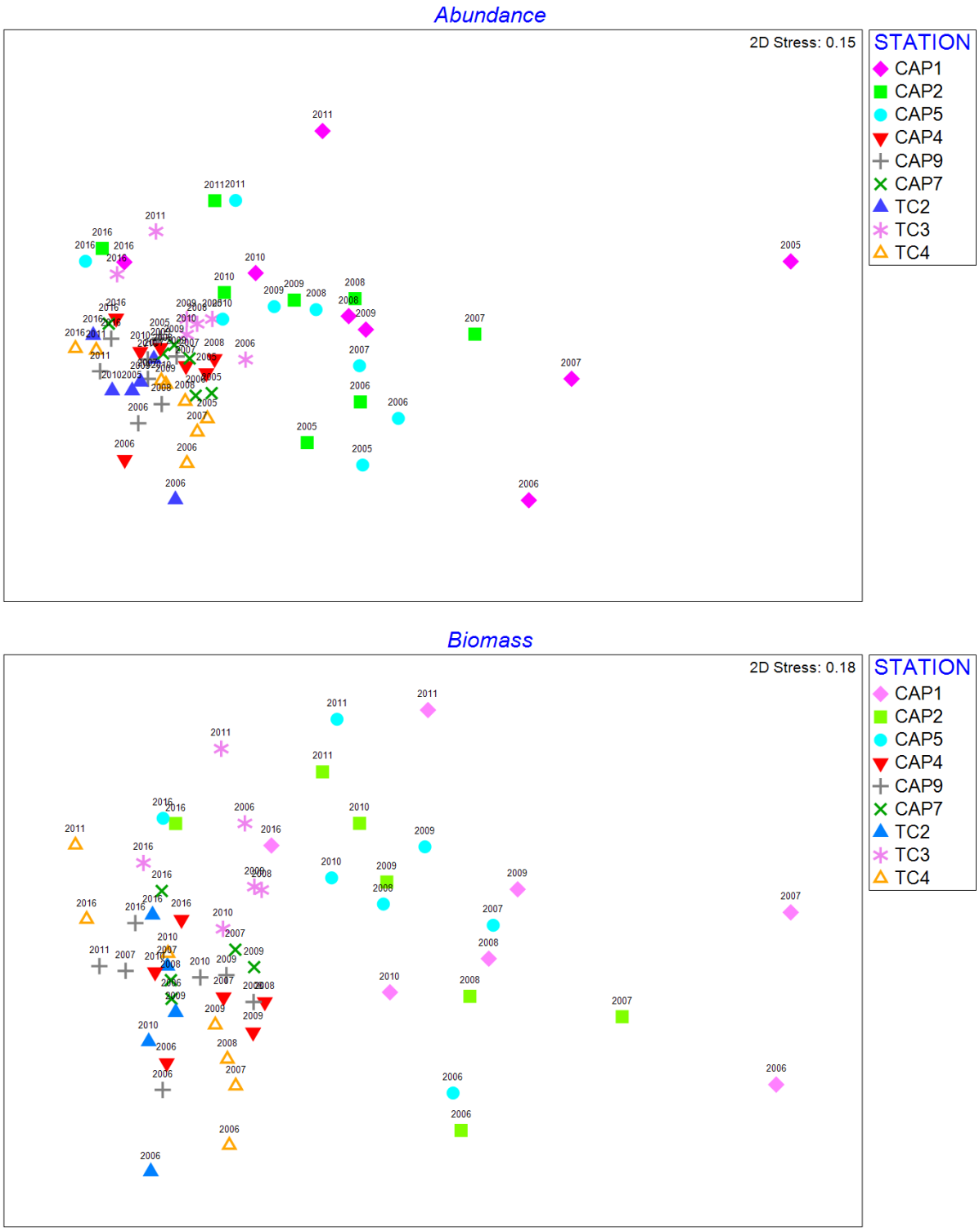


Figure A1.1.18. Station averaged nMDS ordination of macrofaunal assemblages at Souter Point between 2005 and 2016 based on abundance (top) and biomass (bottom).

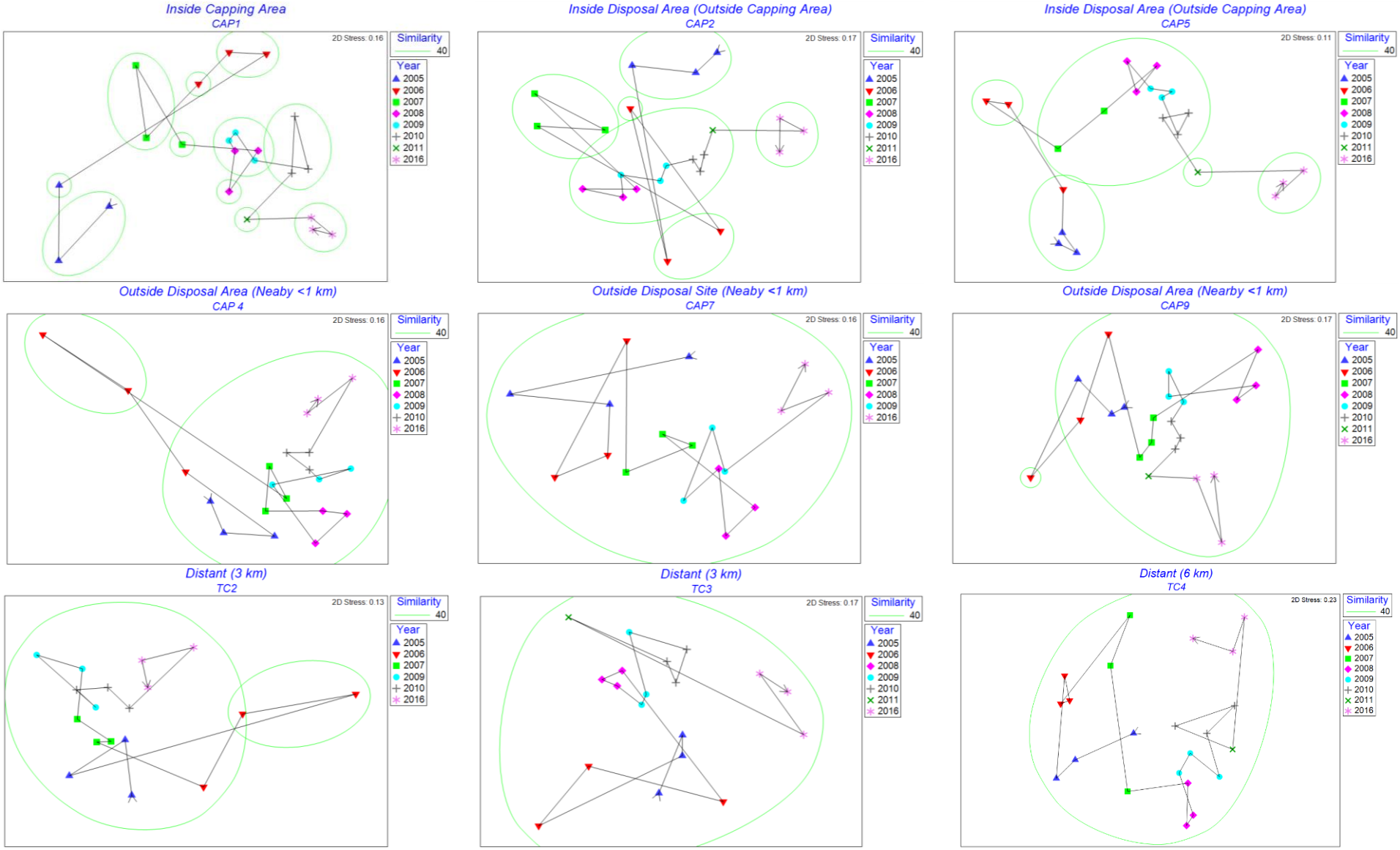


Figure A1.1.19. nMDS ordinations of macrofaunal assemblages over time at Souter Point stations between 2005 and 2016. Trajectory (lines) show the temporal progression.

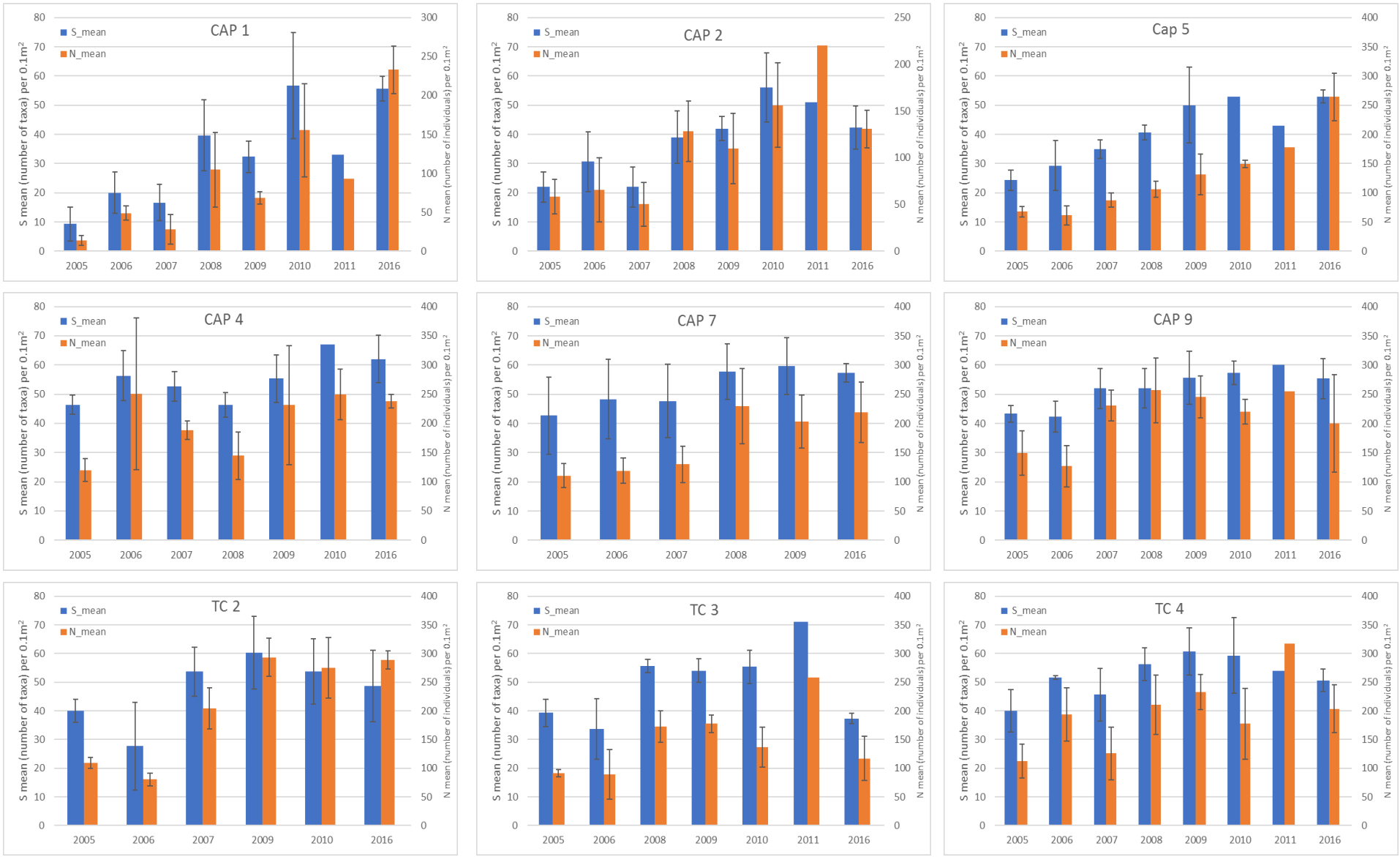


Figure A1.1.20. Univariate metrics (S = number of taxa per grab; N – total abundance per grab) of the macrofaunal assemblages over time at Souter Point stations between 2005 and 2016. Error bars show 95% confidence intervals.

1.2 Boston 7 (HU170)

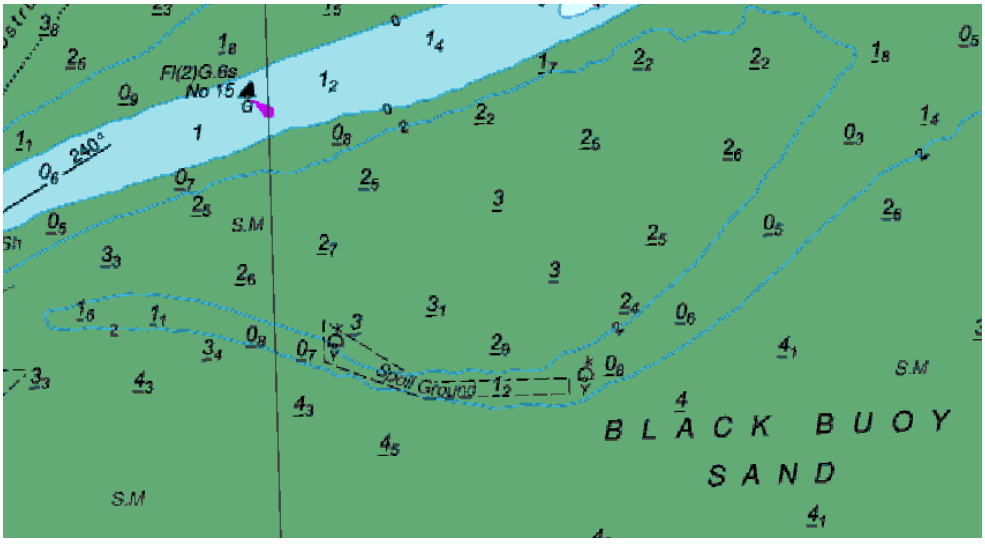


Figure A1.2.1 Location of Boston 7 disposal site in the Wash, eastern England. This figure has been derived from material obtained from the UK Hydrographic office (UKHO) with the permission of her Majesty's Stationary Office and UK Hydrographic office (www.ukho.gov.uk). Not to be used for navigation.

1.2.1 Background

Boston 7 is a relatively small licensed disposal site, located within the Wash in the Southern North Sea. The site is situated to the south of the main channel from Tabs Head to the black buoy and straddles a relic creek forming part of the Black Buoy sand. Boston 7 is located within shallow water, and receives material from Boston which lies on The Haven that drains the fens. The site annually receives, on average, 38,000 wet tonnes of maintenance material (between 2000-2013), with a maximum in any one year of 60,000 wet tonnes in 2000 (Figure A1.2.2).

As part of the current licence, licencees are required to deposit material as evenly as possible over the entire licenced disposal site. However, the Port of Boston claim that the site is currently shoaling to the extent that certain parts represent a navigation risk, and a significant proportion of the site is presently too shallow to allow dredgers to dispose of material.

It was initially planned that monitoring at Boston 7 under C6794 during 2016-17 would comprise a bathymetric survey of the disposal site and its immediate vicinity, together with grab sampling of the seabed sediments for particle size analysis. The bathymetric data obtained would be used to ascertain the extent of the current shoaling issue and the depth of the rest of the licensed site. These data would aid subsequent management of the site, and to potentially test compliance with the current licence condition regarding uniform disposal of material across the site. It was the intention that the particle size data would aid an assessment as to whether the shoaled material depicted deposited material or whether it resulted from natural sediment movement within The Wash due to natural physical coastal processes.

However, discussions with potential surveyors for the area led to the conclusion that the area was deemed too difficult to safely conduct a multibeam survey. Flighted autonomous unmanned vehicles (AUVs) were also not viable because the distance of the site from the mainland, where such a survey would originate, precluded such an approach. Thus, other types and sources of data, that could provide some information regarding the current and historic bathymetric status of the site, were investigated. Eventually, suitable accessible data comprised LiDAR, aerial photography and data from single beam echo sounder surveys ranging over a time period from 1998 to 2015. The data were downloaded from the UK INSPIRE and Coastal Channel Observatory data portals. While the data analysed here under C6794 were, therefore, not those initially planned for the site, we believe that the data obtained equally allow an assessment as to the current extent and potential causes of shoaling to be established.

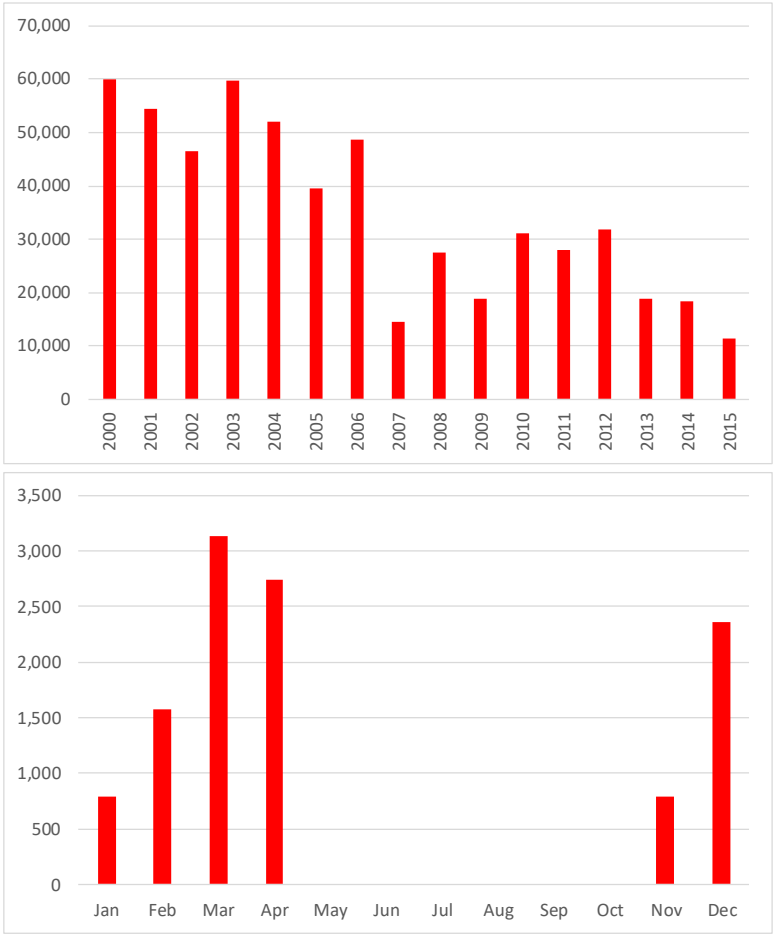


Figure A1.2.2. Disposal returns (wet tonnes) for material annually disposed of to Boston 7 2000-2015 (top) and for each month during 2015 (bottom).

1.2.2 Parameters monitored:

Review of LiDAR data

aerial photography

single beam acoustic bathymetry

1.2.3 Methods

Data found on the INSPIRE portal consisted of single beam echo sounder surveys undertaken on behalf of Port of Boston between, these surveys are listed in Table A1.2.1. These surveys were aimed at identifying the main channel, and cover the relic channel and disposal area in the extreme southern edge.

Data obtained from the Coastal Channel Observatory portal consisted of LiDAR data conducted for the Anglian Coastal Monitoring Programme between 2013 and 2015, together with two tiles of ortho-rectified aerial photographic images from each of the years 2011 to 2015. The LiDAR composite is made from data covering 2014. The LiDAR data is full coverage extremely high resolution bathymetry rendered in a 0.5m cell size to 1 cm vertical resolution. The aerial images are ortho-rectified and of a similar resolution. The single beam data is not full coverage and has been processed into 10m grid tiles for visualisation.

Table A1.2.1. Summary for single beam echo sounder surveys at Boston 7 disposal site.

Survey Year	Survey title
1998	Tab tower and no 11 buoy
1999	Tab tower and no 11 buoy
2004	Tab tower and no 11 buoy
2005	Tab tower and no 11 buoy
2007	Tab tower and no 11 buoy
2008	Tab tower and no 11 buoy
2015	Boston approaches (PV Lyn Ellis)

1.2.4 Results

1.2.4.1 Single beam echo sounder surveys

The 1998 survey was treated as a baseline survey and displayed as a monochromatic base surface. The 1999 survey is overlain to show the regions that have increased in height visible in colour (note this does not apply where the underlying coverage is missing). The subsequent surveys were treated similarly with the aim of assessing the changing nature of the bathymetry as a time series. The licenced area for Boston 7 is plotted as a white polygon.

The 1998 survey depicted in grey in Figure A1.2.3 provides a backdrop of the following year 1999. The main channel is situated in the central part of the figure and the relic southern channel curves around the lower part. Between these years, a small increase in height can be seen around the middle bank and in the southern channel. The 1999 survey (Figure A1.2.4) is again depicted in grey with the subsequent 2004 survey again showing a height increase in the middle bank and southern channel, with a widening of the main channel. The 2005 survey (depicted in colour in Figure A1.2.5) shows almost no change from the 2004 survey depicted in grey. Any changes are probably due to survey accuracy limitations due to factors such as tidal height variation.

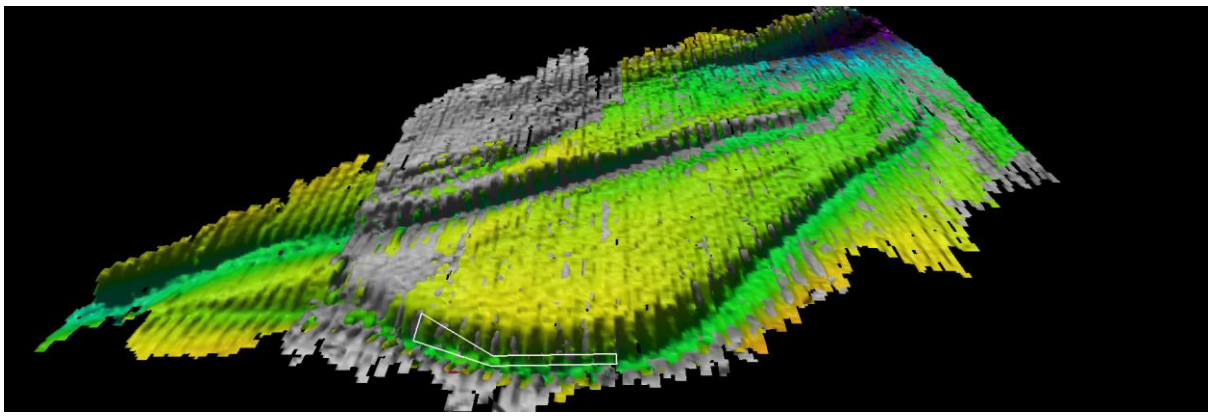


Figure A1.2.3 Surveys in years 1998 and 1999 (Western third of area is new coverage in 1999)

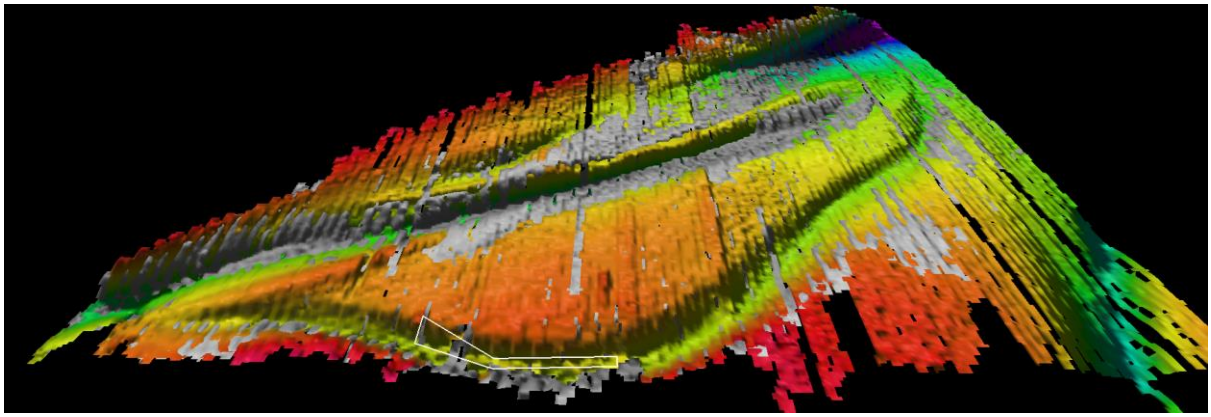


Figure A1.2.4 Surveys in years 1999 and 2004

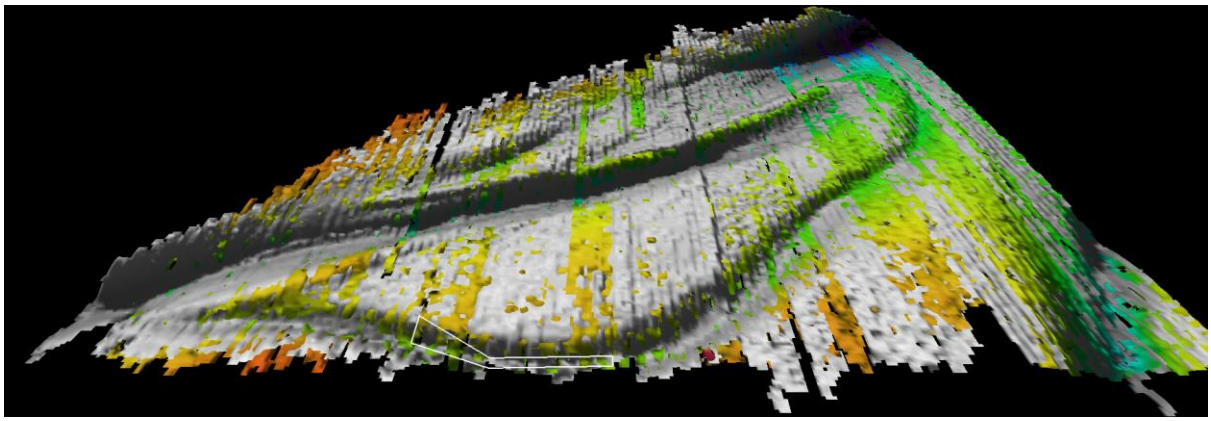


Figure A1.2.5 Surveys in years 2004 and 2005

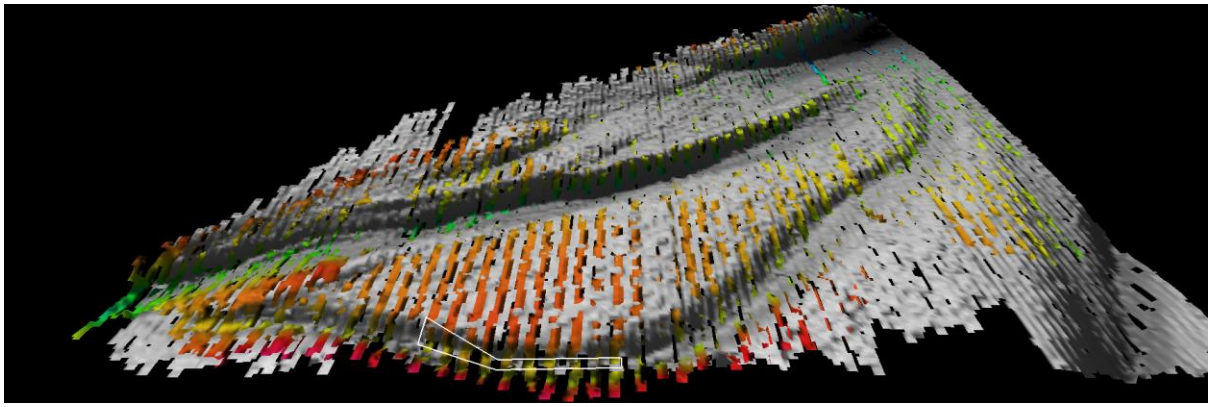


Figure A1.2.6. Surveys in years 2005-2007 (2007 has alternate lines only surveyed)

The 2007 survey (depicted in colour in Figure A1.2.6), although containing only 50% of the survey lines of previous years, still shows an increase in height over the middle bank and, in particular, around the channel join in the left hand end of the figure. This could lead to reduced scouring action in the lower southern channel and over the licence area. The main channel also shows its northern bank building to the south.

As the 2007 survey captured only 50% of the survey coverage it was not suitable to compare with the later 2008 survey. Thus, in Figure A1.2.7, 2005 was kept as the grey comparison layer. In 2008 a similar increase to 2007 can be seen in the joining of channels to the left, the main channel borth bank and in the southern channel including the licence area.

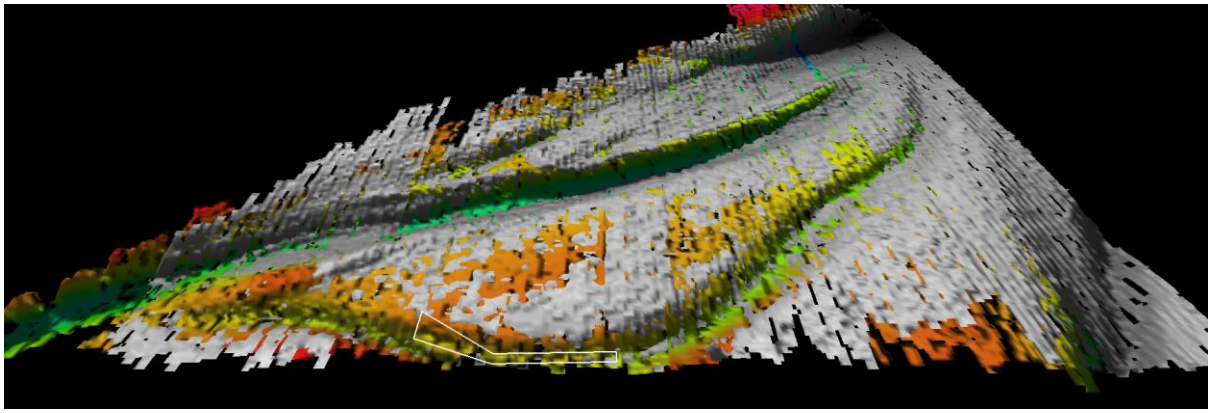


Figure A1.2.7 Surveys in years 2005-2008

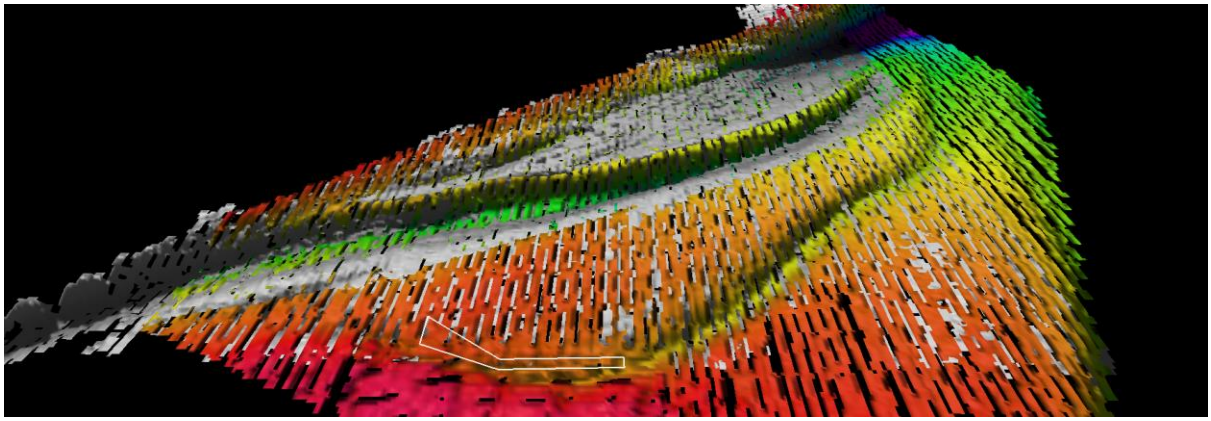


Figure A1.2.8 Surveys in years 2008-2015

The 2015 survey, as compared to the 2008 survey, is depicted in colour in Figure A1.2.8. Here, possibly due to the longer period between surveys, a clear overall increase can be seen, except for the main channel and the north bank. However, the same southern migration of the main channel's north bank, as in previous years, is evident. The poorer definition of the southern channel joining the main channel in the right of the figure can also be seen, describing the weakening of the south channel as a feature. From 2008, apart from the 2015 survey, no subsequent single beam data could be found on the portal covering this area but LiDAR and aerial photographic images were available. The LiDAR contains very high resolution bathymetry of the area from 2014.

1.2.4.2 LiDAR

Lidar data extends to only one year in time series and was tiled from 2014 data. The licence area Boston 7 is plotted as a white polygon in the remaining Figures A1.2.9.

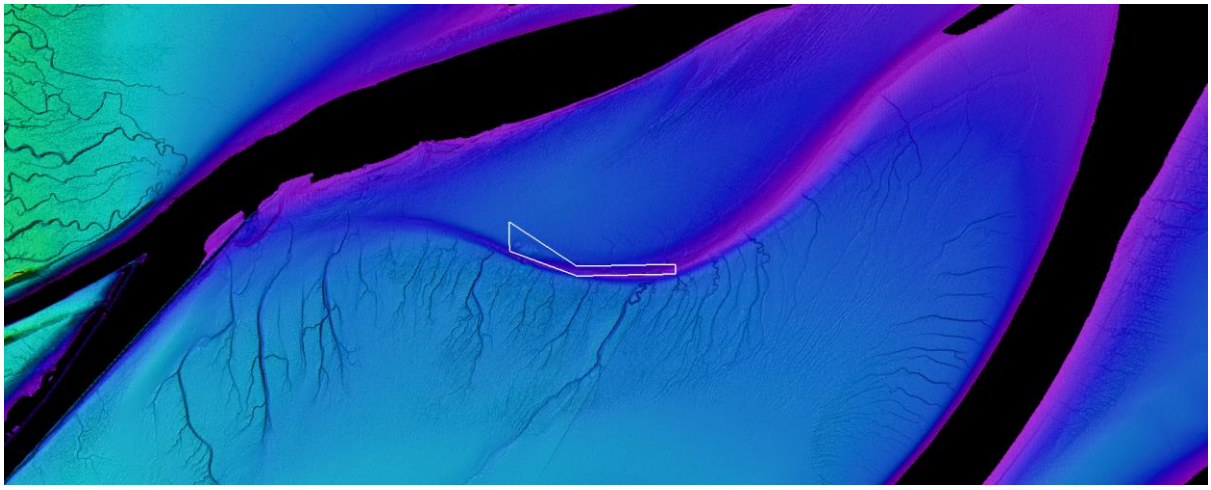


Figure A1.2.9. Survey in year 2014 LiDAR composite image.

The LiDAR image in Figure A1.2.9 depicts the bathymetry as a sun illuminated colour plot. The black areas contain no LiDAR data due to the channels not being fully emerged from the tide. Inspection of this high resolution LiDAR data shows a feature in the licence area depicted in Figure A1.2.9. The view has been rotated

to better show the feature which forms a ridge of material lining the bank. This feature can also be seen in the aerial imagery and persists from 2011 to 2015. The narrowing of the channel next to this ridge can also be seen.

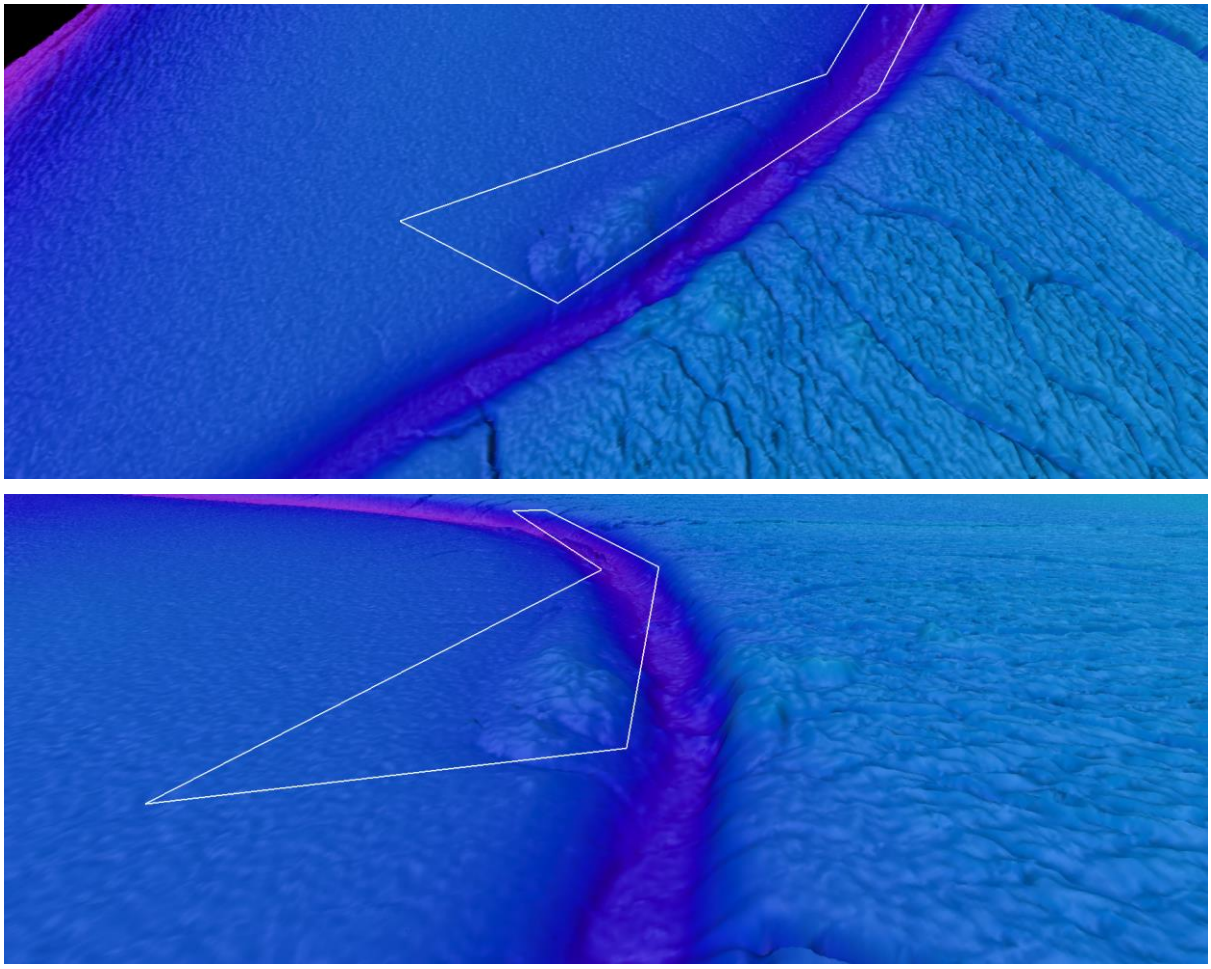


Figure A1.2.10. Zoomed views showing potential disposal marks on the north bank in western end of Boston 7.

1.2.4.3 Aerial Photographic imagery

Figure A1.2.11 shows an image, taken in 2011, with the feature referenced in the LiDAR data in the Western half of the licence area. Clear cut drainage channels on both banks can be seen leading into the channel (marked by the dark broad line traversing the image west to east). These channels indicate drain off from the banks into the channel and contribute to the flow through the channel. The situation in 2012 (Figure A1.2.12) is akin to that in 2011 but the feature seen in the LiDAR is now more visible. The length of the drainage channels in the North has shortened, indicative of more water draining from the northern bank to elsewhere, and not into the channel.

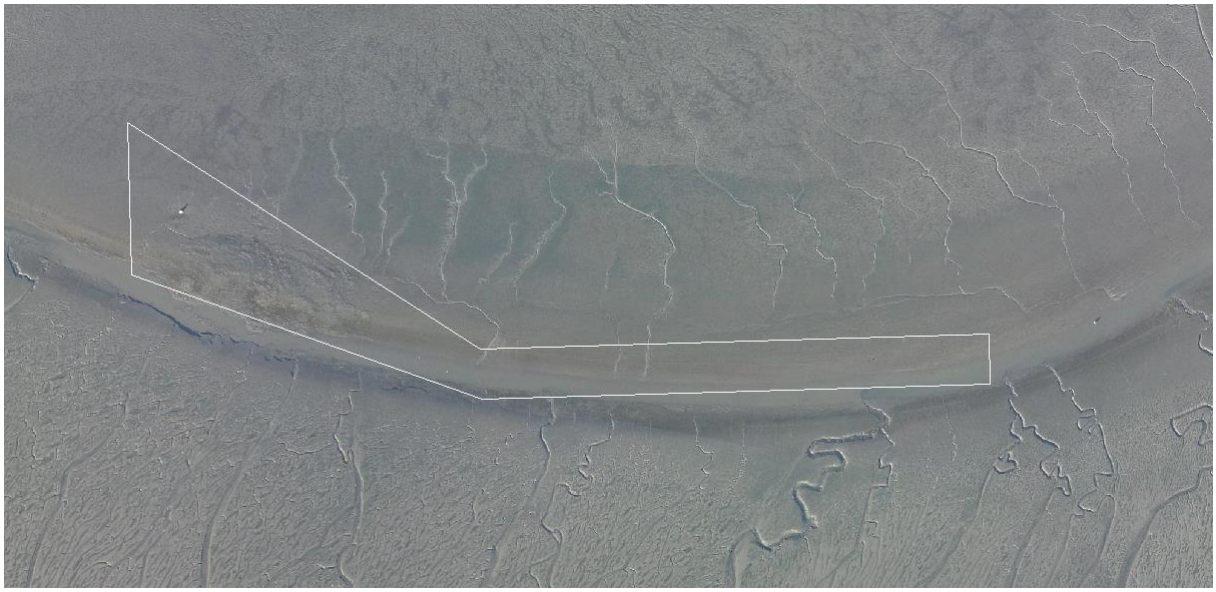


Figure A1.2.11. Aerial photographic data taken during 2011 of the Boston 7 disposal site. North is upwards in the image, and the white dot is the marker buoy.

Figure A1.2.12. Aerial photographic data taken during 2012 of the Boston 7 disposal site. North is upwards in the image, and the white dot is the marker buoy.

Figure A1.2.13. Aerial photographic data taken during 2014 of the Boston 7 disposal site. North is upwards in the image, and the white dot is the marker buoy.

Figure A1.2.13, taken in 2014, shows a similar trend to that of 2012 in truncation of the northern bank drainage channels. Evidence of cockle dredging is visible in the northern edge of the scene depicted by the characteristic circular marks created by the vessel manoeuvres around anchors which is used to expose the catch.

Figure A1.2.14. Aerial photographic data taken during 2015 of the Boston 7 disposal site. North is upwards in the image.

Finally, in 2015 (Figure A1.2.14), the feature previously described and main channel are now poorly defined with now just a small drainage channel describing the eastern end of the previous larger channel leading out of the eastern end of the licence area. The drainage channels on the north bank are now almost non-detectable. The southern channels remain clearly defined in all four images and indicate hydrographic changes that have

occurred have been to the north of the channel and bank not the south. Thus, one can conclude that most, if not all, of the processes leading to the closure of the channel are natural (Dr J Rees, Cefas; pers. Comm.) brought about by the movement of material north to south and a general building of the bank and confluence areas to the north and west of the licence area leading to a loss of the channel feature.

Figure A1.2.15 supports the notion regarding the movement of the channels and banks when overlaying contours from selected years of the 1.5m level. This illustration clearly shows the widening of the main channel (mid picture) with a concomitant narrowing of the south channel.

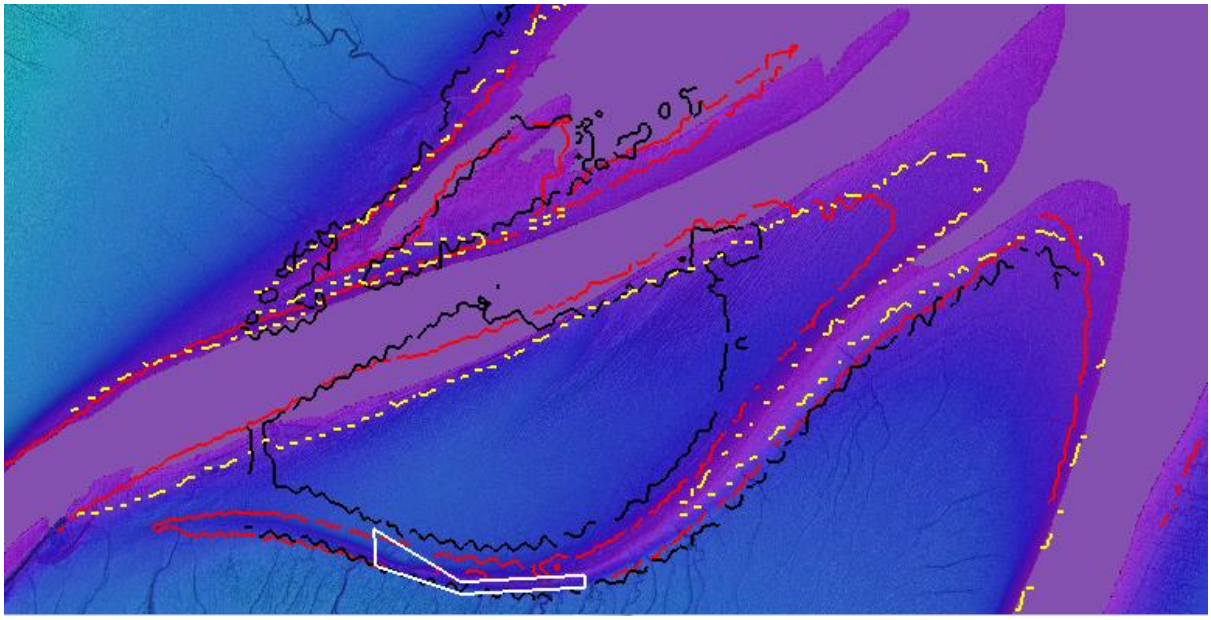


Figure A1.2.15. Composite contour map of 1.5m contour from 1998 (black) 2004 (red) 2015 (yellow) overlaying 2014 LiDAR survey.

1.3 Dover (DV010)

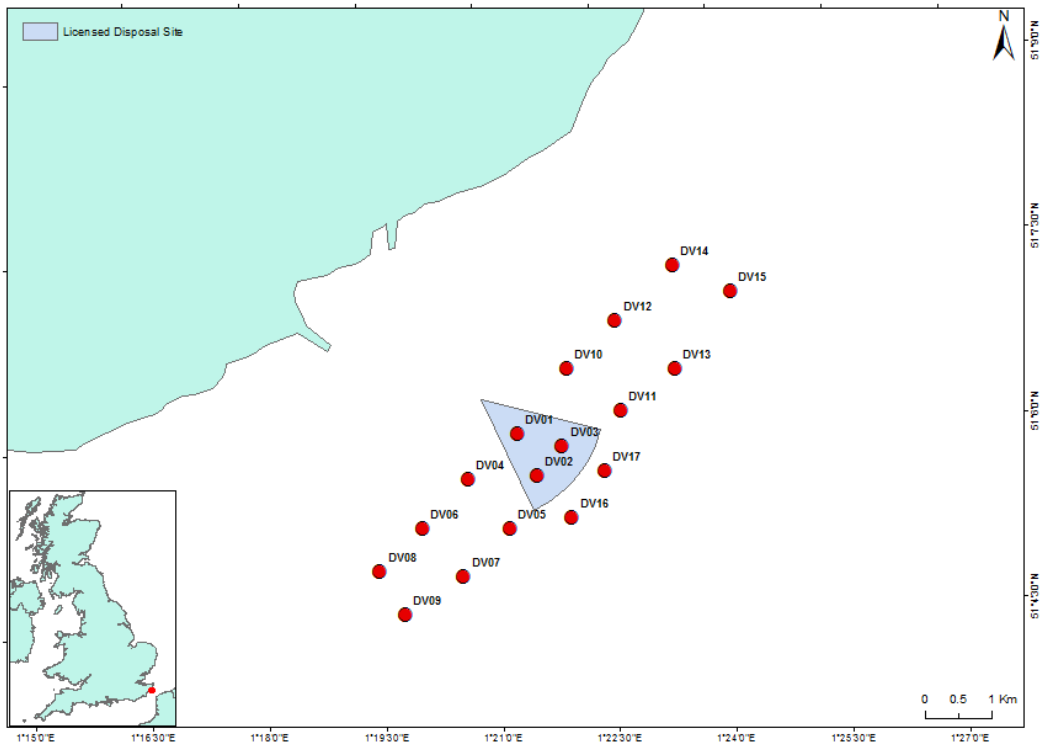


Figure A1.3.1. Location of 17 sampling stations for the Dover 2016 survey. Not all stations were successfully sampled due to hard/coarse substrata.

1.3.1 Background

Dover disposal site DV010 is located just south of the Port of Dover (Figure A1.3.1) with a depth of approximately 16m to, at its most offshore section, 33m. The segment-shaped site receives significant amounts of maintenance dredged material during most years, with an average of approximately 430,000 wet tonnes per annum (based on data from 2000 to 2015; Figure A1.3.2). The site also occasionally receives further material following capital projects, some of the larger episodes being during 1995 (almost 700,000 wet tonnes) and 1998 (147,000 wet tonnes).

The disposal site is located within a busy shipping area, and within close proximity to a number of designatory sites such as Dover to Kingsdown Cliffs SAC (1.6km north), Dover to Deal rMCZ (1km northeast) and Dover to Folkestone rMCZ (0.6km west).

The predominant tides in the area of the site run in a southwest to northeast direction, with stronger flows to the northeast. No direct sampling of the benthic ecology of the disposal site has recently been undertaken, partly as the strong tides and busy ship traffic in the area constrain such activities. However, it is likely that the benthic fauna are adapted to a high energy environment given the coarse nature of the sediments and the relatively high current speeds.

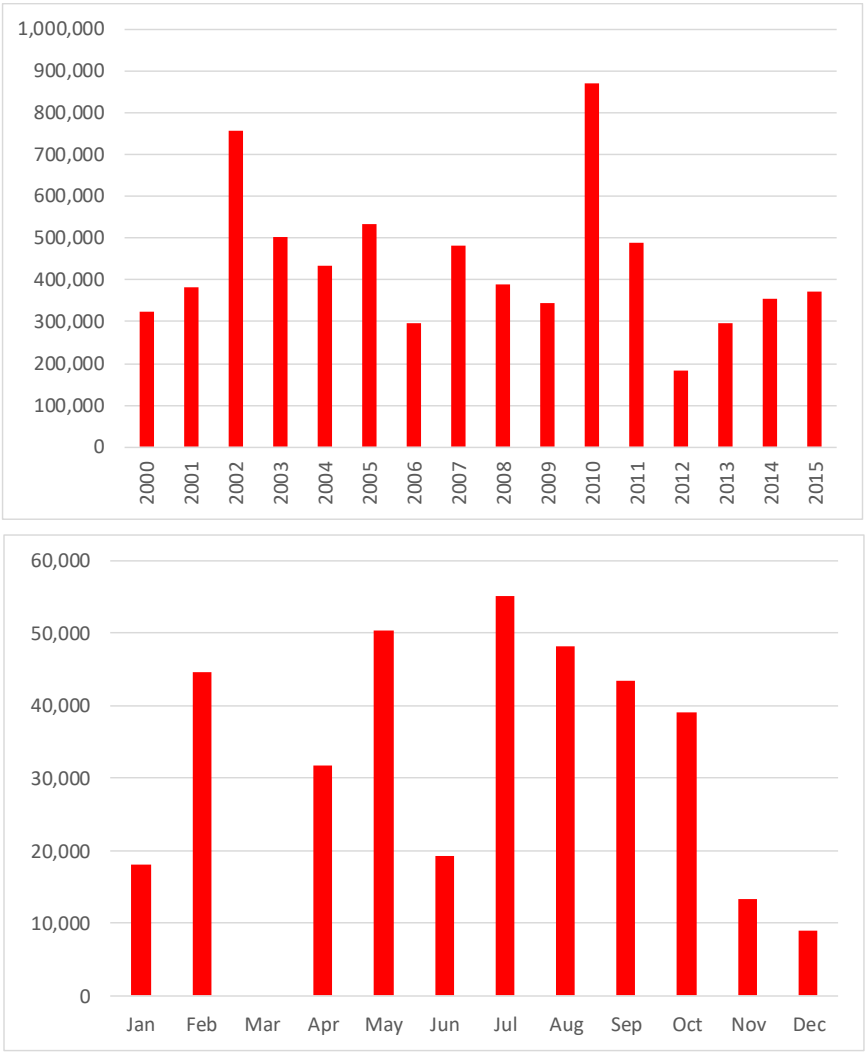


Figure A1.3.2. Disposal returns (wet tonnes) for material annually disposed of to Dover 2000-2015 (top) and for each month during 2015 (bottom).

Monitoring at Dover under C6794 during 2016-17 focussed on assessing the biological assemblages within and surrounding the site in view of proposed large amounts of capital material the site is expected to receive from the Port of Dover.

1.3.2 Parameters monitored:

Sediment particle size

Macrofaunal assemblages

1.3.3 Results

1.3.3.1 Sediment particle size

Sediments sampled at Dover in 2016 were predominantly muddy sandy gravels (Table A1.3.1). Sediment distributions were grouped for replicates collected at sample stations, which included a total of 31 samples.

Table A1.3.1 Average sediment descriptions (top) and granulometric statistics (bottom) for each sediment group at Dover, 2016.

Sediment group	Number of samples	Sample Type	Sediment description
Dov1a	4	Bimodal, Extremely Poorly Sorted	Muddy Sandy Gravel
Dov1b	9	Bimodal, Very Poorly Sorted	Muddy Sandy Gravel
Dov2a	10	Trimodal, Very Poorly Sorted	Muddy Sandy Gravel
Dov2b	11	Trimodal, Very Poorly Sorted	Muddy Sandy Gravel
Dov2c	5	Trimodal, Very Poorly Sorted	Muddy Sandy Gravel
Dov3a	1	Unimodal, Very Well Sorted	Gravel

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
Dov1a	56.46	26.72	16.82	6.18	6.12	6.81	4.17	3.44
Dov1b	71.13	22.85	6.03	5.54	8.22	6.18	1.74	1.17
Dov2a	51.64	38.99	9.37	7.07	11.54	14.87	3.64	1.86
Dov2b	39.26	51.71	9.02	8.47	14.91	22.53	3.99	1.80
Dov2c	70.64	24.75	4.60	6.82	9.28	6.41	1.46	0.77
Dov3a	98.16	1.48	0.36	0.28	0.34	0.58	0.20	0.08

For all stations except DV08, between-replicate differences in sediment groups were found (Table A1.3.2) which was largely a reflection of the difficulty in sampling at this site. At a number of stations, only small volumes of sediment were grabbed. For both DV04 and DV14, for example, sufficient sediment was PSA analysis only; no faunal processing was conducted. Average granulometric results were produced (Table A1.3.2) which most likely represent the sediment types for each station.

Table A1.3.2 Sediment groups for each sample replicate for each station at Dover, 2016.

	Replicate			
Sample code	A1	A2	A3	Average
DV01	Dov2a	Dov1a	Dov2c	Dov2a
DV02	Dov2b			
DV03	Dov1b	Dov2b	Dov1a	Dov2a
DV04			Dov1b	
DV06	Dov2b	Dov2b	Dov2a	Dov2a
DV07	Dov2b	Dov2b	Dov1b	Dov2a
DV08	Dov2b	Dov2b	Dov2b	Dov2b
DV09	Dov2a	Dov2b	Dov2a	Dov2a
DV10			Dov2c	
DV12	Dov2a	Dov1b	Dov1b	Dov1b
DV14			Dov1b	
DV15	Dov2c	Dov1a	Dov2c	Dov2c
DV17	Dov3a	Dov1a	Dov1b	Dov1b

The spatial variation in the averaged proportional representation of gravel, sand and silt/clay for each sampling station is shown in Figure A1.3.3 and the average silt/clay content in Figure A1.3.4. The results highlight the coarse nature of the sediments across the survey area. Substrata either too hard or too coarse to successfully grab were present at DV05, DV11, DV13 and DV16 (Figure A1.3.3). The highest silt/clay contents were located at DV03 and DV01 (average silt/clay content ~14% and ~11% respectively) both within the disposal site, and at DV06 (average silt/clay content ~13%) southwest of the site (Figure A1.3.4).

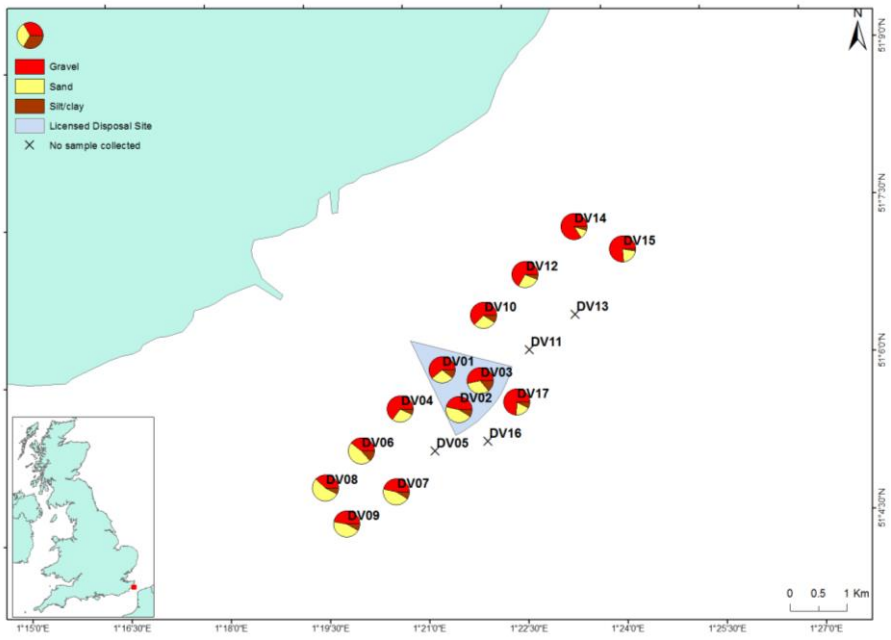


Figure A1.3.3. Pie charts of average gravel, sand and silt/clay for the stations sampled at Dover, 2016.

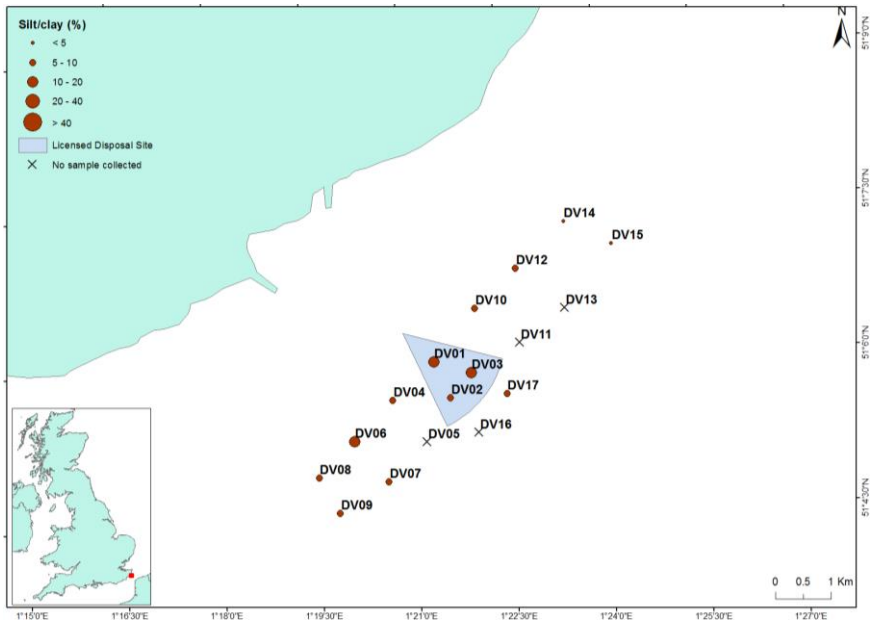


Figure A1.3.4. Average sediment silt/clay content (%) of the stations sampled at Dover, 2016.

1.3.3.2 Macrofaunal assemblages

Only 11 stations of the 17 planned stations at Dover were successfully sampled, only one single successful sample was taken for macrofaunal analysis at two of the 11 (DV02 and DV10). The total number of samples (replicates) from these 11 stations was 29. A total of 19,182 macrofaunal individuals were sampled from 355 taxa (including colonials) from the 29 samples. This number of taxa from 29 samples may be regarded as relatively high, nominally indicating the sampling region as being species rich. The most well-represented phylum was annelids, or segmented worms (136 taxa sampled), followed by crustaceans (63 taxa), molluscs (60 taxa) and bryozoans (47 taxa). The most abundant non-colonial taxon sampled was the worm *Sabellaria spinulosa* with 6,041 individuals identified (31.5 % of total individuals) and the barnacle *Balanus crenatus* (1,100 individuals). Two species, the brittlestar *Amphipholis squamata* and the bryozoan *Escharella immersa*, were found in every grab sample taken and a further 22 taxa were found at least once at every station. Several notable species were identified during the macrofaunal analysis including the non-native species *Crepidula fornicata* (Slipper limpet), found in small numbers at eight stations, and the commercially important species *Mytilus edulis* (Blue mussel) found at all 11 stations sampled (Table A1.3.2). The highest density of M*ytilus edulis* was found at DV01, within the disposal site, with 964 individuals found across the three replicate samples. Of the total, the vast majority (i.e. 879) M*ytilus edulis* were identified as juveniles suggesting the high density seen at this station is due to recent spatfall rather than an established population.

The variability in the mean number of taxa, mean abundance and mean biomass between stations (Figure A1.3.5.A1.3.5) shows there is no obvious spatial pattern in these metrics. If ongoing disposal activity at this site was negatively impacting the fauna, it would be expected that the stations within and near to the disposal ground would have reduced number of taxa, abundance and biomass but this is not evident from the data collected.

Table A1.3.2. Notable species identified from the 2016 Dover macrofaunal samples.

Species	Notes
Cancer pagurus	Commercially important
Buccinum undatum	Commercially important
Mytilus edulis	Commercially important
Aequipecten opercularis	Commercially important
Galeomma turtoni	Nationally Rare
Cestopagurus timidus	Nationally Scarce
Monocorophium sextonae	Listed as non-native
Austrominius modestus	Non-native in the UK
Crepidula fornicata	Non-native in the UK
Fenestrulina delicia	Non-native in the UK
Syllis garciai	Not formally recorded from UK
Syllis licheri	Not formally recorded from UK
Syllis pontxioi	Not formally recorded from UK
Paradoneis ilvana	Not formally recorded from UK
Rullierinereis ancornunezi	Only recently published as a UK species
Golfingia margaritacea	Rarely recorded
Epilepton clarkiae	Rarely recorded
Caprella erethizon	Rarely recorded Southern species in UK
Sabellaria spinulosa	Represents priority habitat
Arca tetragona	Southern species in UK
Striarca lactea	Southern species in UK
Gibbomodiola adriatica	Southern species in UK
Gibbomodiola adriatica	Southern species in UK
Lepton squamosum	Southern species in UK
Rocellaria dubia	Southern species in UK
Athanas nitescens	Southern species in UK

Multivariate numerical analyses were conducted on the taxonomic structure of the faunal data using Primer V6. Figure A1.3.6 shows the relative similarities in assemblage structure of each station (replicates shown separately) in 2-dimensions in an ordination plot following non-metric multidimensional scaling (MDS) based on log (x+1) transformed abundance data. The stations have been coloured according to their broad location outside of the disposal site (southwest, northeast and east) and inside the disposal site. The plot shows the macrofaunal assemblages within the same location are more similar than with assemblages from another

location. This was explored further using cluster analysis (SIMPROF) to identify significantly different communities ($p < 0.05$) to see if this matched location. This analysis revealed 13 distinct assemblages, two more than stations sampled, suggesting a high degree of variability between stations and, in some cases, replicates. The sampling station DV17, located just outside of the southeastern boundary of the disposal site, displayed a disproportionate amount of within-station faunistic variability (Figure A1.3.6). This station showed the greatest replicate variability in sediment granulometry, with one replicate representing the only example of the unimodal, very well sorted gravel sediment code DV03a (Table A1.3.1-A1.3.2).

In summary, the 2016 Dover survey showed the area in and around the disposal site to consist of highly diverse and variable benthic communities supporting numerous taxa, sometimes in very high numbers (e.g. at DV07 where N=2,132). The macrofaunal assemblage data indicate that univariate metrics of community structure, together with taxonomic composition, do not show any impacts associated with current disposal activity. The hard nature of seabed in the vicinity of the disposal ground alongside the dispersive nature of the site could be the reason that impacts from disposal material could not be detected. The data presented here form a suitable baseline from which benthic impacts associated with the proposed large tonnage of capital material may be assessed.

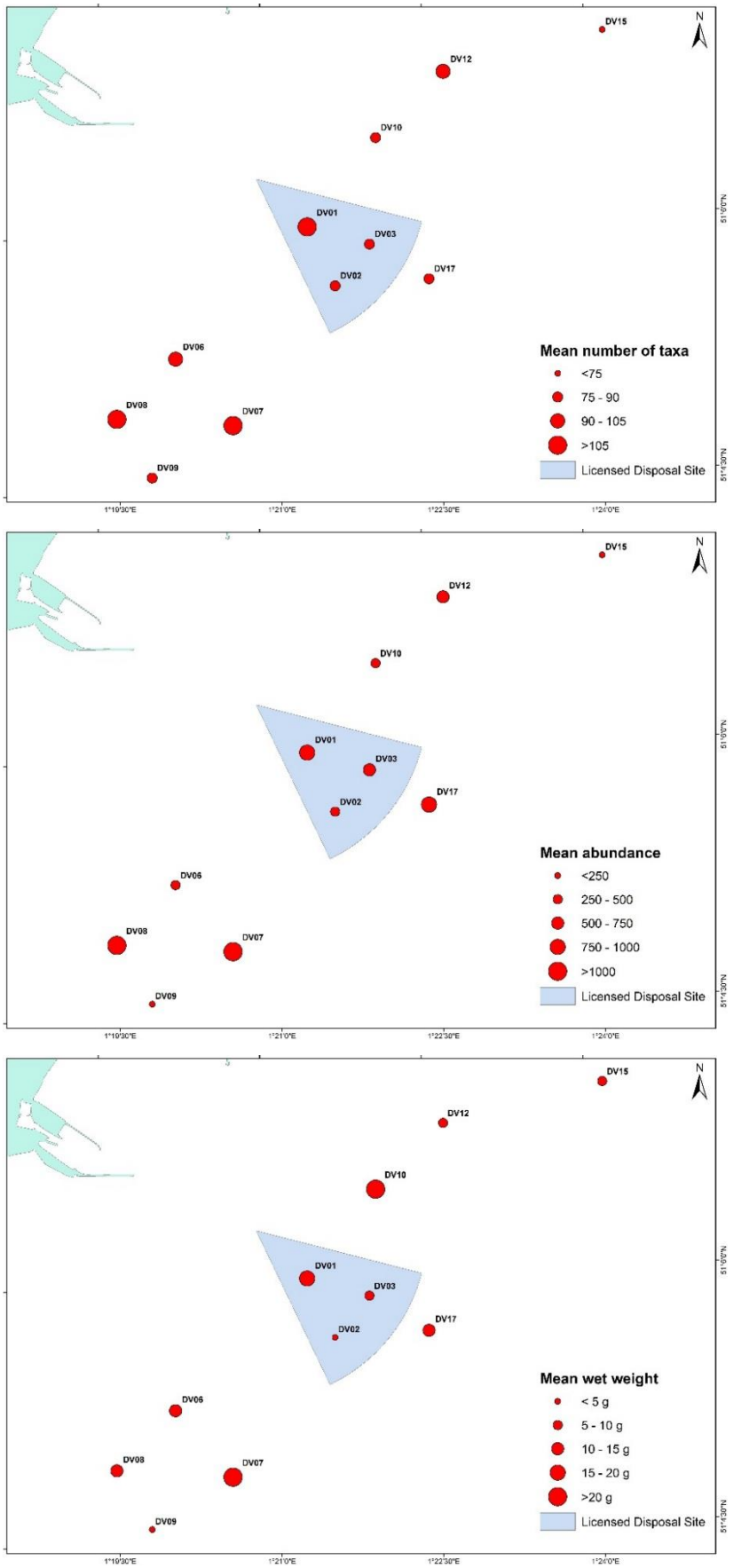


Figure A1.3.5. Mean number of taxa (top), mean abundance (centre) and mean wet biomass (g) (bottom) per grab for each of the stations sampled for macrofauna at Dover, 2016.

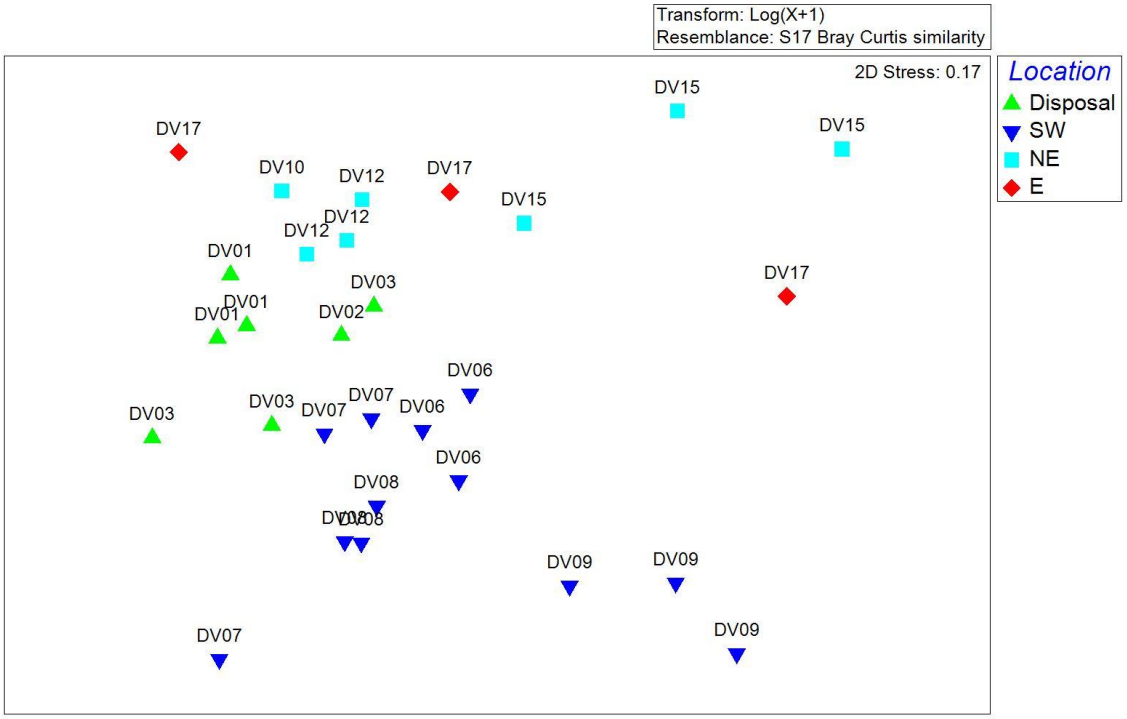


Figure A1.3.6. MDS ordination plot showing the relative similarities of the macrofaunal assemblages of the stations sampled at Dover, 2016. Stations are colour-coded according to their locations either inside the disposal site (green triangles) or outside and direction from the disposal site.

1.4 Rame Head South

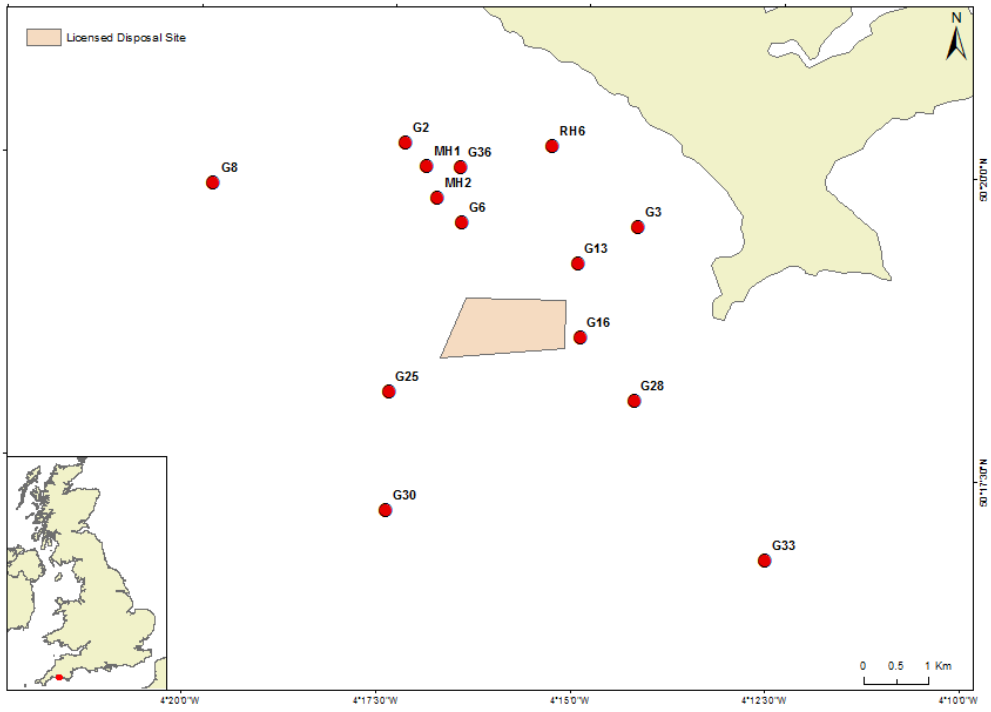


Figure A1.4.1. Location of the 14 stations sampled at Rame Head South, June 2016.

1.4.1 Background

Rame Head South is a disposal site with a depth range of 18m to 38m. The site, located approximately 2km west of Rame Head (Figure A1.4.1) and 6km west of the entrance to Plymouth Sound, is used for dredged material disposal mostly during the winter months (Figure A1.4.2). The site has been used for almost 100 years although during the early part of this period it was primarily used for munitions disposal. Dredged material disposed originates from the ports, harbours, berths and navigation channels in and alongside the rivers Tamar and Plym and the Sound, with principle locations being Devonport Dockyard and associated Ministry of Defence (MoD) areas. The site, thus, receives material from a variety of sources. Between 1976 and 2005, over 5 million tonnes of material was disposed of, being composed typically of sandy mud, with > 70 % silt/clay fraction. Over the last 30 years, the amount of material being disposed of at this disposal site has slowly decreased with exception of two peaks in 1986 and 2001 (the latter being evident in Figure A1.4.2).

The coastal region within which the disposal site is located is important for a wide range of stakeholders including those associated with diving, fisheries and shellfisheries. There is also a large number of sewage and storm-water discharges in the locality. There has been a large public and media interest regarding the impacts associated with dredged material disposal at Rame Head South: concerns have primarily been based around the potential of the disposed material as a source of contamination at Polhawn Cove and of turbidity around the dive sites (e.g., HMS Scylla) in Whitsand Bay. A large amount of litter being found along the intertidal areas of the disposal site has also been alleged to have been derived from the disposal activity. Rame Head South, partly in response to the relatively high level of public interest regarding impacts associated with disposal activity to it,

has been the recipient of monitoring under the auspices of SLAB5 from 2000 onwards. Until 2008, sampling had been conducted at a number of stations within and surrounding the licensed site. However, changes in health and safety policies in 2008 prevented the deployment of bottom-contacting gear within the site due to its historic munitions disposal. In January 2011, the MMO published a report (Elliott and Mazik, 2011) documenting the results of an independent review regarding the ecological impacts associated with the disposal activity at Rame Head South, including an appraisal of the monitoring work undertaken under SLAB5. Sampling in recent years under SLAB5 has comprised an acoustic survey of the southeastern section of the site in 2011 (Bolam et al., 2012b), together with a grabbing survey in 2014 to compare the spatial variability in sediments and sediment contaminants with those observed in previous years (Bolam et al., 2015b).

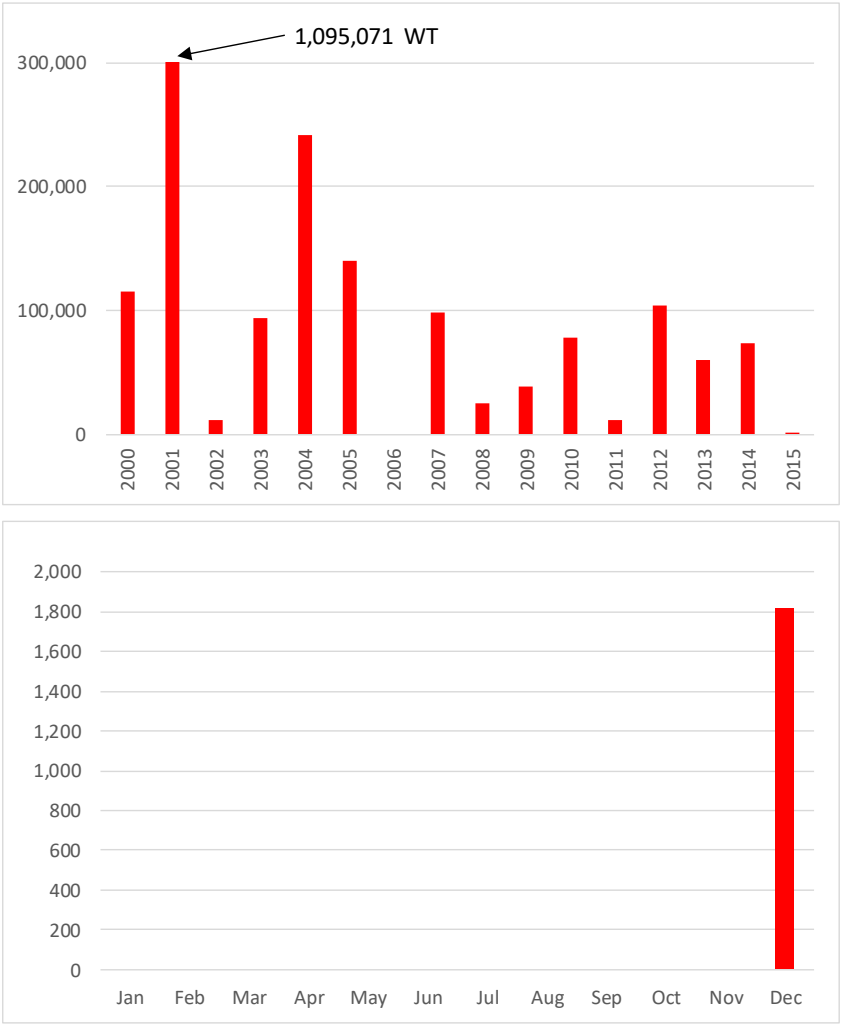


Figure A1.4.2. Disposal returns (wet tonnes) for material annually disposed of to Rame Head South 2000-2015 (top) and for each month during 2015 (bottom).

Sampling under C6794 at Rame Head South during 2016-17 aimed to sample a number of stations for which temporal data already exists for sediment particle size, contaminants and associated macrofauna. These data form a useful assessment from which any potential changes in the disposal regime may be compared. Additionally, stations within a mud habitat within the recently designated Whitsand and Looe Bay MCZ will be sampled to provide additional information regarding the physical and chemical characteristics of this habitat and the biological assemblages present.

1.4.2 Parameters monitored: Sediment particle size
Sediment organic carbon
Sediment contaminants (PAHs, organohalogens, trace metals)
Macrofaunal assemblages

1.4.3 Results

1.4.3.1 Sediment particle size

Sediments around the Rame Head South disposal site, based on 182 samples taken from 2001 to 2016, are predominantly muddy sands, sands and gravelly muddy sands, with some gravelly sands and muddy sandy gravels (Table A1.4.1). Sediments analysed in 2016 were mainly muddy sands (7 samples in sediment group RaH1), with some gravelly sands (2 samples in RaH4), gravelly sands (2 in RaH5a) and gravelly muddy sand (1 in RaH2).

Table A1.4.1. Average sediment descriptions (top) and granulometric statistics (bottom) for each sediment group at Rame Head (2001 to 2016 inclusive).

Sediment group	Number of samples	Sample Type	Sediment description
RaH1	42	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
RaH2	36	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand
RaH3	11	Polymodal, Very Poorly Sorted	Muddy Sandy Gravel
RaH4	25	Unimodal, Poorly Sorted	Gravelly Sand
RaH5a	27	Unimodal, Poorly Sorted	Slightly Gravelly Sand
RaH5b	41	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
RaH1	0.58	55.51	43.91	0.72	2.02	3.07	7.78	41.92
RaH2	15.51	60.71	23.78	5.64	8.36	8.79	15.10	22.82
RaH3	62.02	30.57	7.41	9.69	7.68	4.69	4.54	3.98
RaH4	26.49	69.25	4.26	28.98	26.39	9.32	3.15	1.42
RaH5a	1.95	91.86	6.19	2.16	12.13	35.84	33.62	8.10
RaH5b	0.29	97.78	1.93	0.72	2.53	11.51	65.19	17.83

The spatial variation in the proportional representation of gravel, sand and silt/clay for each sampling station in 2016 is shown in Figure A1.4.3 and the percentages of silt/clay content displayed in Figure A1.4.4. The results

showed sandy sediments close to the coast (RH6, G3 and G13), with increasing silt/clay contents further offshore (G2, G6, G36 and the new sites MH1 and MH2). There was a higher gravel content northwest of the disposal site at G8. G25 and G33, both south of the disposal site, contained the highest silt/clay content, while sediment at G30, southwest of the disposal site, was more mixed.

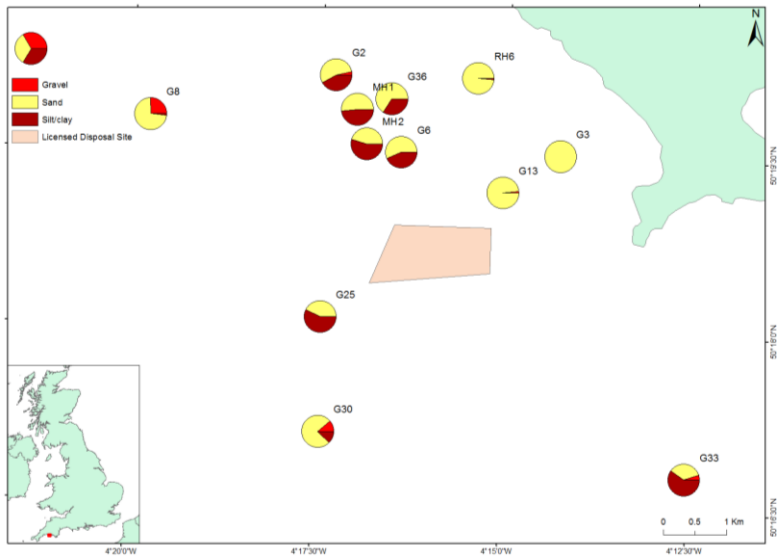


Figure A1.4.3. Pie charts of gravel, sand and silt/clay of sediments sampled at Rame Head in 2016.

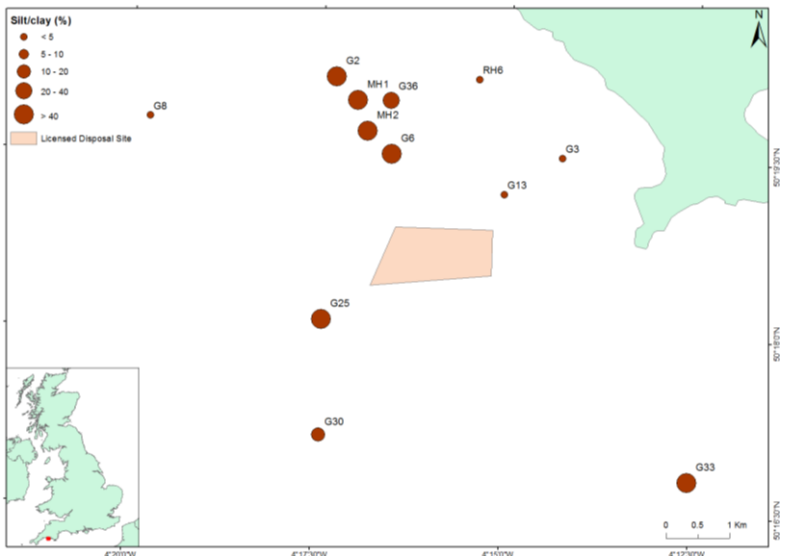


Figure A1.4.4. Sediment silt/clay content (%) of stations sampled at Rame Head in 2016.

The temporal changes in sediment groups for sampling stations since 2001 are presented in Table A1.4.2 for sample stations targeted in 2016 only. Small changes to the sediments, as defined by changes in sediment groups, have occurred at most stations sampled during this period. The sediment at G13 was slightly more gravelly in 2016 than in 2014, while at G30 it was more mixed. In harmony with that observed in 2014 (Bolam

et al., 2015), G33 to the southeast of the survey area, continues to display greater mud proportions compared to prior to 2014. A similar trend is apparent for G02 to the north of the disposal site, although this switch occurred earlier (between 2007 and 2008) for this station.

Table A1.4.2. Sediment groups for each station sampled between 2001 and 2016 at Rame Head. Only stations that were sampled in 2016 are shown for earlier samples.

	Year									
Sample code	2001	2002	2003	2005	2006	2007	2008	2009	2014	2016
G02	RaH2	RaH2	RaH2	n	n	RaH2	RaH1	RaH1	RaH1	RaH1
G03	n	RaH5b	RaH5b	n	RaH5b	RaH5b	RaH5b	RaH5b	RaH5b	RaH5b
G06	n	n	n	n	RaH1	RaH1	RaH1	RaH1	RaH1	RaH1
G08	n	RaH3	RaH4	RaH4	RaH4	RaH4	RaH4	RaH4	RaH4	RaH4
G13	n	RaH4	RaH3	RaH5a	RaH4	RaH3	RaH4	RaH4	RaH5a	RaH4
G25	n	RaH1	RaH1	n	RaH1	RaH1	RaH1	RaH1	RaH1	RaH1
G30	n	n	n	n	n	RaH5a	RaH5a	RaH4	RaH5b	RaH2
G33	n	RaH2	RaH2	RaH2	RaH2	RaH2	RaH2	RaH2	RaH1	RaH1
G36	n	n	RaH1	n	n	RaH1	RaH1	RaH1	RaH1	RaH1
RH06	n	n	RaH5b	RaH5b	n	RaH5b	RaH5b	RaH5b	RaH5b	RaH5b
MH01	n	n	n	n	n	n	n	n	n	RaH1
MH02	n	n	n	n	n	n	n	n	n	RaH1

1.4.3.2 Sediment organic carbon

Sediment organic carbon values (in the <2mm sediment fraction) range from 0.18 to 1.85 %, while those in the <63µm sediment fraction range from 1.17 to 1.85 % (Figure A1.4.5). G3, G13 and RH6 all had low silt/clay content (<2 % silt/clay) rendering it impossible to measure the organic carbon on the finer fraction at these stations. Although small variations are observable, these organic carbon values are comparable to those observed in previous years across the stations.

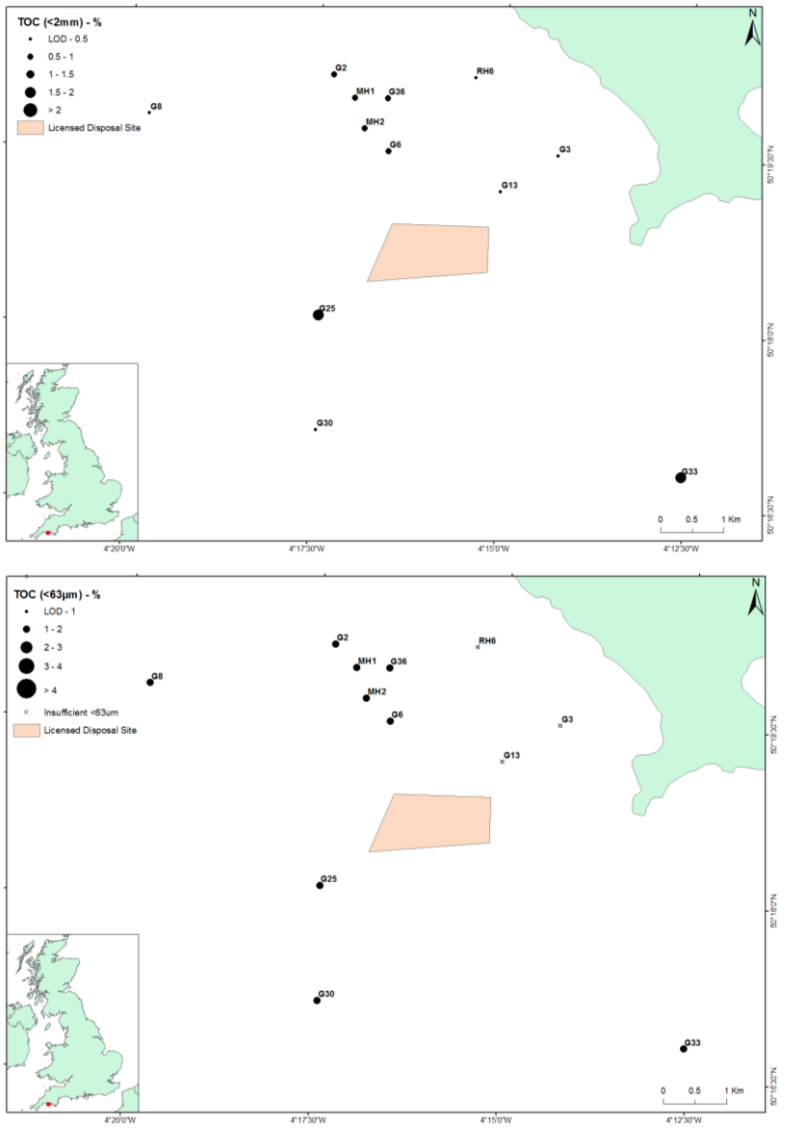


Figure A1.4.5. Sediment organic carbon (%) in the <2mm fraction (top) and <63µm fraction (bottom) at Rame Head South in 2016.

1.4.3.3 Sediment contaminants

1.4.3.3.1 PAHs

The highest summed PAH concentration (ΣPAH) sampled at Rame Head South in 2016 was 3,120 µg kg^{-1} dry weight at G6, approximately 1.5km to the north of the disposal site (Figure A1.4.6). The second highest concentration (2,950 µg kg^{-1} dry weight) was measured at G33, approximately 4.5km southeast of the disposal site boundary (Figure A1.4.6). The highest summed PAH concentration (ΣPAH) in 2014, when Rame Head South was last sampled under the auspices of this project, was 4,230 µg kg^{-1} dry weight, at G28, also southeast of the disposal site (Bolam et al., 2015). This station was not, however, sampled during 2016. The second highest concentration found during 2014 was 3,550 µg kg^{-1} dry weight (slightly higher than in 2016) at G6 to the north of the disposal site. While one would expect small variations in concentrations measured from single samples, the comparable maximum concentrations sampled across the 2014 and 2016 surveys indicate that summed PAH concentrations have not changed in two years. In 2014, concentrations at G33 were lower (1,830 µg kg^{-1} dry

weight) than was observed in 2016 (Figure A1.4.6). During the 2016 survey, summed PAH concentrations of 1000-2500 µg kg^{-1} dry weight were found at G2 and G36 approximately 3km northwest and north respectively of the disposal site, at G25 approximately 1km off the southwest corner of the disposal site and at two newly surveyed sites at MH1 and MH2 approximately 2 km north west of the disposal site.

The lowest summed PAH concentration was 155 µg kg^{-1} dry weight, found at G8 which is located approximately 4km to the northwest of the disposal site, comparable to the concentration (40 µg kg^{-1} dry weight) sampled at this station in 2014. Lower levels (<300 µg kg^{-1} dry weight) were also found at G13 and RH06 in a northerly transect from the eastern corner of the disposal site. These results continue to be consistent with previous years and add further support of the stable summed PAH concentrations across these stations during recent years.

None of the sediments collected at Rame Head South in 2016 exceeded the ERL or ERM for low molecular weight (LMW) or high molecular weight (HMW) PAHs. Evaluation of the PAH data indicated that the source in all the sediment samples were mixed, generally with approximately 60% of the PAH content arising from combustion sources and approximately 40% being derived from oil sources except at G3, where approximately 30% of the PAH content originated from combustion sources and approximately 70% from oil sources.

Disposal activity (maintenance dredging) in 2013 and 2014 remained consistent, while in 2015 total tonnage disposed significantly reduced to 1,814 wet tonnes (Figure A1.4.2). The generally stable, or decreasing at some stations, summed PAH concentrations at Rame Head South between 2014 and 2016, may directly reflect the contemporary change in the disposal regime to this site.

Summed PAH values found at Rame Head between 2007 and 2014 have never exceeded 6,000 µg kg^{-1}, and measured concentrations have often been close to background levels (<200 µg kg^{-1}) (Figure A1.4.6). These concentrations are very low compared to those found at other disposal sites around UK waters, with values ten and twenty times higher being found at disposal sites off the northeast coast of England (e.g., North Tyne and Tees respectively) (Bolam et al., 2015).

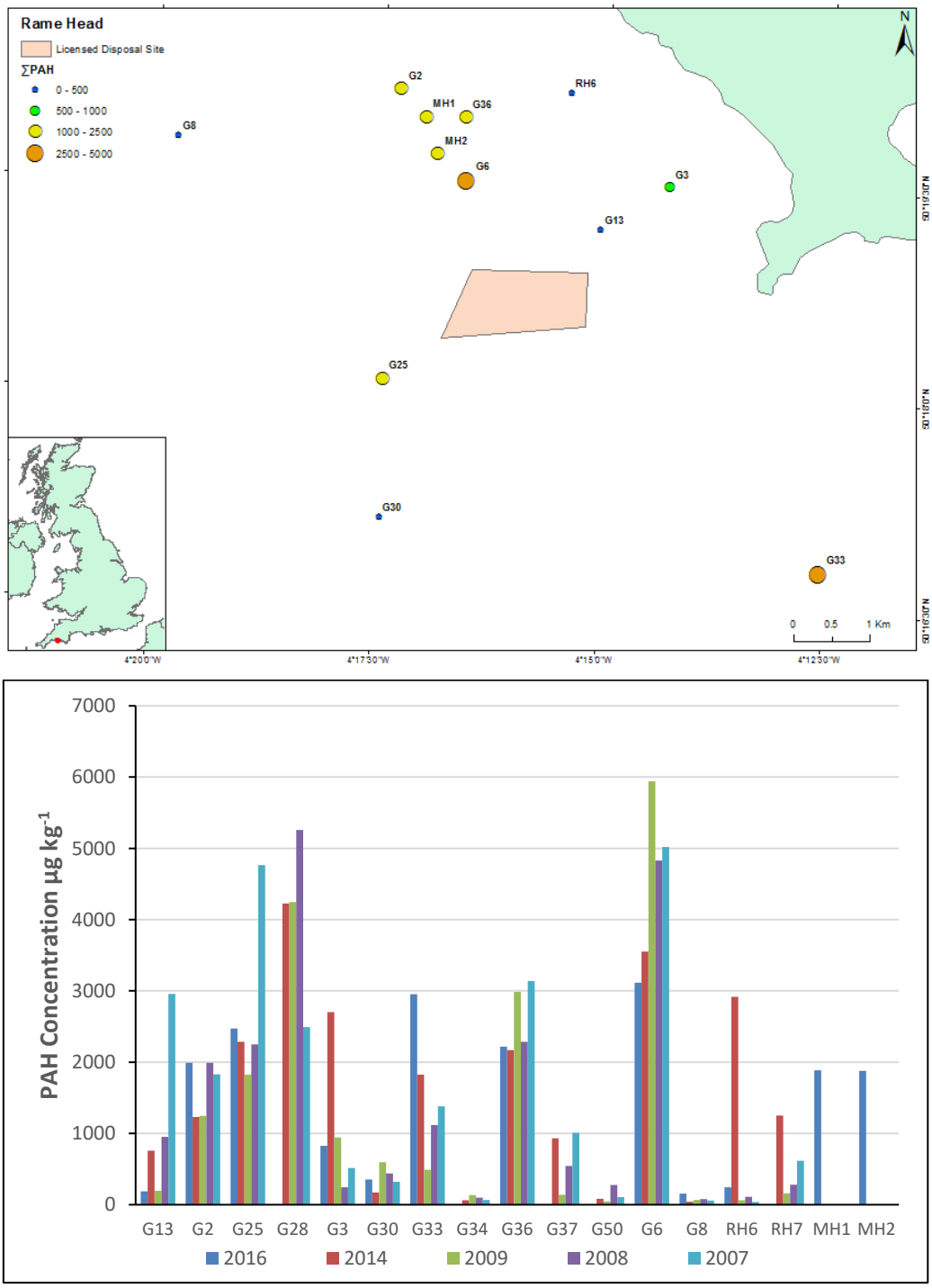


Figure A1.4.6. Summed PAH concentrations (µg kg^{-1} dry weight) for stations sampled at Rame Head South in 2016 (top) and concentrations observed between 2007 and 2016 (bottom).

1.4.3.3.2 Organohalogens

At Rame Head South, ∑ICES7 CBs concentrations range from 0.21-4.83 µg/kg dw. The highest ∑ICES 7 CB concentration, 4.83 µg/kg dw, was measured at station G33 to the southeast of, and along the main sediment transport pathway from, the disposal site (Figure A1.4.7). Station G25 to the southwest of the disposal site had a lower ∑ICES 7 CB concentration of 3.04 µg/kg dw. The three stations to the northwest of the disposal site: G6,

G2 and MH2, displayed the highest ∑ICES 7 CB concentrations after these former two stations (2.75, 2.36 and 1.95 µg/kg dw, respectively).

BDE concentrations at Rame Head South are low, generally at or below limits of detection (LODs) (∑11 BDEs range <0.075-0.40 µg/kg dw; Figure A1.4.8). All BDE congeners were below LODs at seven of the 12 stations sampled. The two stations to the southeast and southwest of the disposal site (Figure A1.4.8), G25 and G33, possessed the highest ∑11 BDEs concentrations of 0.40 and 0.12 µg/kg dw, respectively, but these can also be considered to be low.

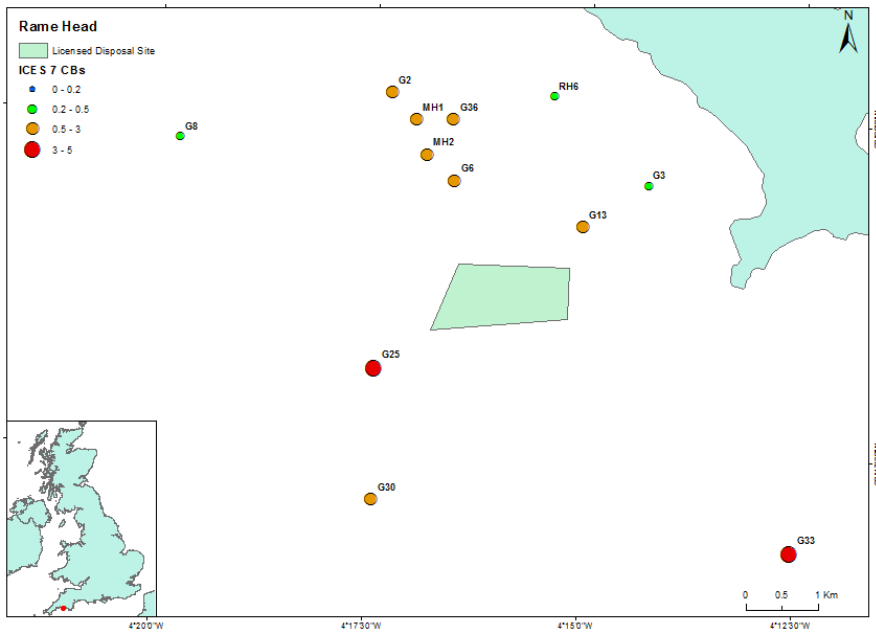


Figure A1.4.7. Summed ICES7 CB concentrations for the stations sampled at Rame Head South, 2016.

BDE209 was detected at nine of the 12 stations (BDE209 was below LOD at the three inshore stations G3, RH6 and G13) and was at higher concentrations than the other measured organohalogens (range <0.1-10.5 µg/kg dw; Figure A1.4.9). The highest concentration of 10.5 µg/kg dw was measured at G6 to the north of the disposal site, with 8.2, 7.8 and 5.9 µg/kg dw measured at G25, MH2 and G35, respectively. The 3 stations to the northwest of the disposal site, G2, MH1 and G36, exhibited much lower BDE209 concentrations (3.2, 3.3 and 2.8 µg/kg dw, respectively).

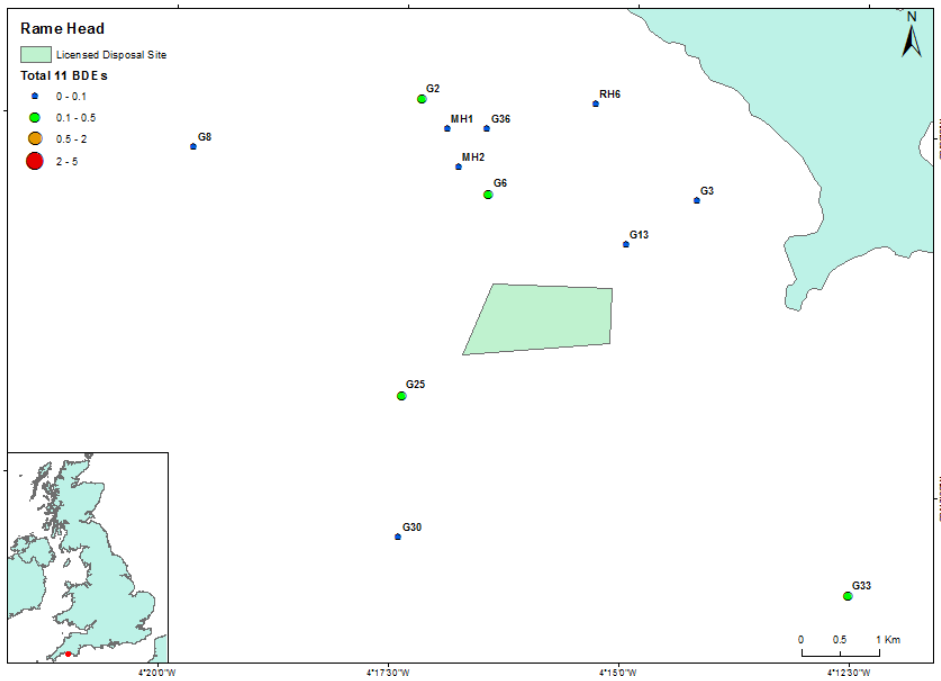


Figure A1.4.8. Summed 11 BDEs concentrations for the stations sampled at Rame Head South, 2016.

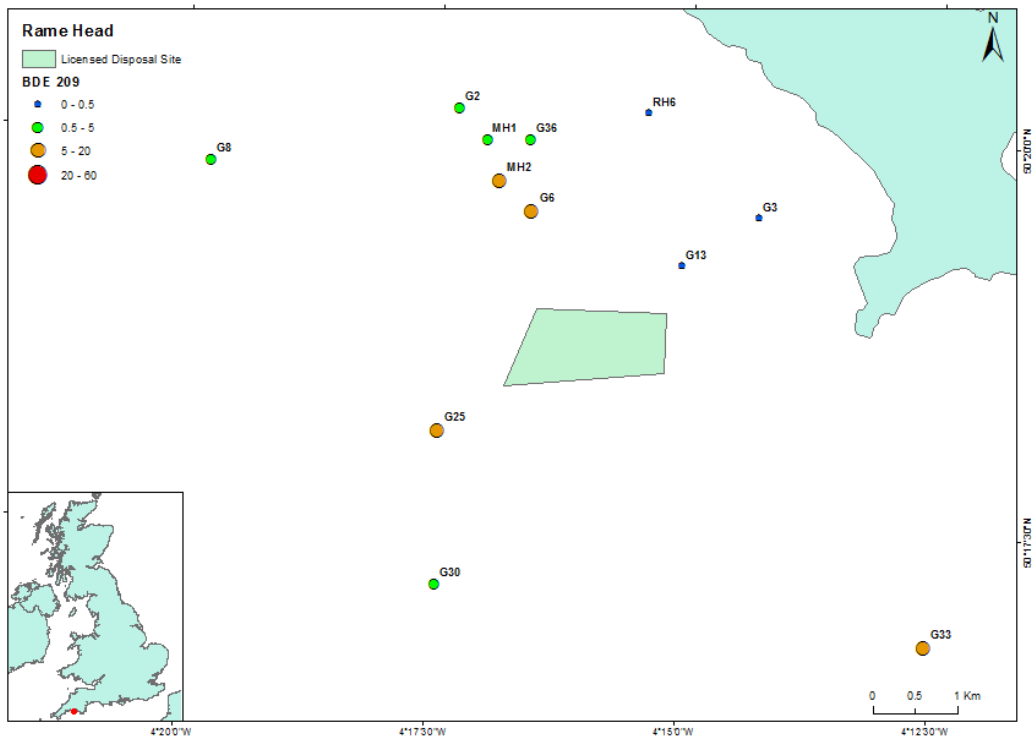


Figure A1.4.9. BDE209 concentrations for the stations sampled at Rame Head South, 2016.

Organochlorine pesticides (OCPs) were detected at every station except G13, RH6 and G3; the three stations where BDE209 was below LOD. $\sum_6$DDTs concentrations ranged from <0.14-1.81 µg/kg dw, with the highest

values at G2 (1.81 µg/kg dw), G33 (0.98 µg/kg dw) and G6 (0.86 µg/kg dw). Dieldrin was detected at only seven out of 12 stations (range <0.05-0.219 µg/kg dw) with the highest values at G2 (0.22 µg/kg dw), MH2 (0.20 µg/kg dw) and G30 (0.20 µg/kg dw).

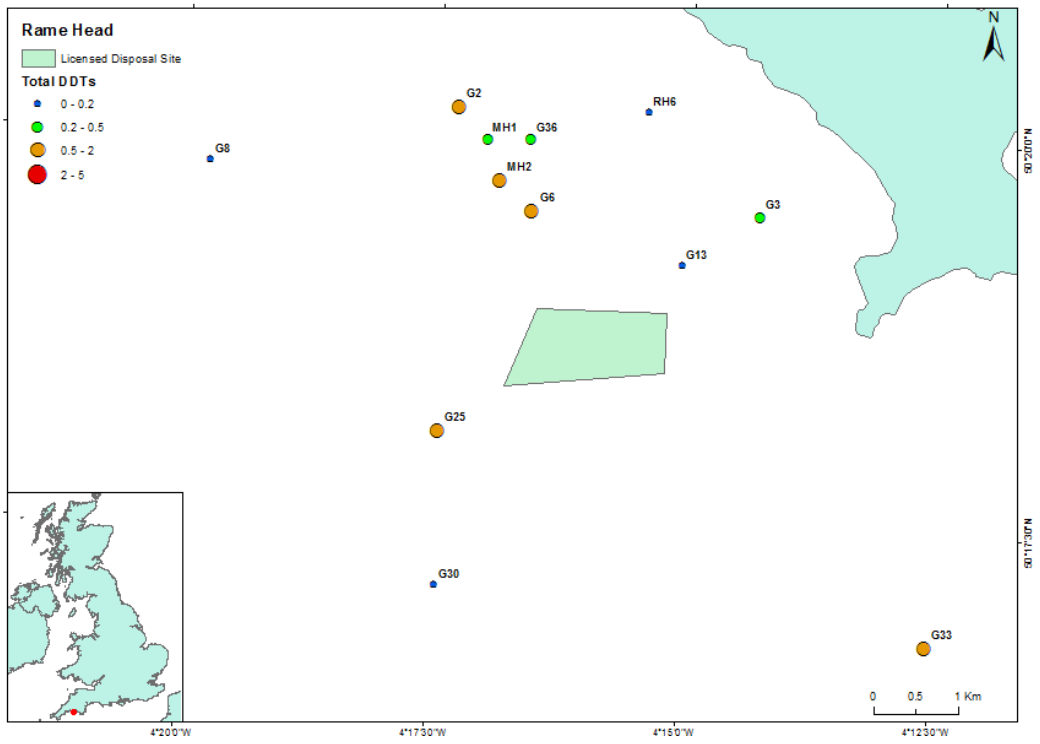


Figure A1.4.10. Total DDT concentrations for the stations sampled at Rame Head South, 2016.

Concentrations of CBs and dieldrin at all stations were below Cefas AL 1. ∑ 6DDTs concentrations were above Cefas AL 1 at one out of the 12 stations (G2), while no Cefas ALs exist for BDEs and BDE209. According to the OSPAR guidelines, stations G8 and RH6 had 'good' environmental status for all ICES 7 CBs, and 'good' status overall. The other 10 stations had 'bad' environmental status for CB118, but 'good' status overall. The sediment at Rame Head South has a very low total organic carbon content, so although PCB concentrations are generally low, once normalised to 2.5% TOC, concentrations increase closer to EAC thresholds. No OSPAR guidelines exist for BDEs and OCPs at present.

In 2015, the Rame Head South disposal site received eighteen hundred tonnes of maintenance dredged material (Figure A1.4.2), which is very low compared to previous years. Looking at temporal trends in contaminant levels (Table A1.4.3), ∑ICES7 CB concentrations were lower in most stations in 2016 than they were in 2014. The exceptions were G33, G25 and G2, but levels at these stations were within the range or close to concentrations previously obtained.

Table A1.4.3. Temporal trends (2002-2016) of ∑ICES 7 CBs concentration (in µg/kg) for the stations sampled at Rame Head South.

Station	∑ICES 7 CBs concentration (in µg/kg)											
	2002	2003	2004	2005	2006	2007	2008	2009	~	2014	~	2016
G34		*0.7*		*0.7*	*0.7*	2.1	*0.7*	*0.7*		*0.7*		
G50							*0.7*	*0.7*		0.89		
G33	*0.7*	14.2	7.67	2.37	4.08	4.26	7.87	2.46		2.19		4.83
G28	64.6	57.9	4.78	8.55	10.2	9.86	71.9	10.2		4.59		
G30						3.69	*0.7*	1.27		*0.7*		0.68
G25	23.9	19.7			2.07		2.6	1.83		1.44		3.04
G21	28.4	12.3				5.42	4.76					
G18	81.9	90.8	62.5	6.7	7.11		18.8					
KH1						40.6	1.37					
G20						1.8	6.6					
G19	194	15.9	202	24.7	1.43	1.34	13.1					
G16										1.18		
G13	*0.7*	*0.7*	1.47	*0.7*	*0.7*	384	1.83	*0.7*		1.34		0.56
G3	*0.7*	*0.7*			*0.7*	0.95	*0.7*	*0.7*		*0.7*		0.36
RH7		*0.7*		*0.7*		*0.7*	*0.7*	*0.7*		*0.7*		
G37		*0.7*			1.33	0.89	*0.7*	*0.7*		*0.7*		
RH6		*0.7*		*0.7*		*0.7*	*0.7*	*0.7*		*0.7*		0.21
G6					2.75	3.85	0.82	3.26		2.53		2.38
MH2												1.95
G36		*0.7*				1.8	1.82	2.79		1.55		1.56
G2	*0.7*	5.1				1.19	1.58	*0.7*		1.78		2.76
MH1												1.59
G8	5.2	7.4	0.86	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*		*0.7*		0.27

Concentrations in italic represent estimates of concentrations for samples where all ICES 7 congener concentrations were below LODs.

Concentrations of ∑11 BDEs at Rame Head South have always been close to LOD since 2003, and the 2016 results are in accordance with this observation (Table A1.4.4). Improved limits of detection result in lower measured concentrations in most stations, with the exception of G25 which showed an increase.

Table A1.4.4. Temporal trends (2002-2016) of ∑11 BDEs concentration (in µg/kg) for the stations sampled at Rame Head South.

Station	∑11 BDEs concentration (in µg/kg)										
	2003	~	2005	2006	2007	2008	2009	~	2014	~	2016
G34	*0.69*		*0.69*	*0.69*	*0.69*	*0.11*	*0.11*		*0.11*		
G50					*0.69*	0.13	*0.11*		*0.11*		
G33			*0.69*	0.69	*0.69*	*0.11*	0.12		0.18		0.14
G28	*0.69*		*0.69*	*0.69*	*0.69*	0.18	0.12		0.14		
G30					*0.69*	*0.11*	0.12		0.13		*0.075*
G25	0.79			0.88		*0.11*	0.13		0.13		0.40
G21	0.80				*0.69*	0.12					
G18	1.18		*0.69*	0.84		*0.11*					
KH1					*0.69*	*0.11*					
G20					*0.69*	*0.11*					
G19	0.74		*0.69*	0.78	*0.69*	0.12					
G16									*0.11*		
G13	0.81		*0.69*	0.77	*0.69*	*0.11*	*0.11*		*0.11*		*0.075*
G3	0.79			0.82	*0.69*	*0.11*	*0.11*		0.13		*0.075*
RH7	0.73		*0.69*		*0.69*	0.12	*0.11*		*0.11*		
G37	0.75			0.76	*0.69*		*0.11*		*0.11*		
RH6	*0.69*		*0.69*		*0.69*	0.13	*0.11*		*0.11*		*0.075*
G6				0.96	*0.69*	0.53	0.12		0.23		0.11
MH2											*0.075*
G36	1.27				*0.69*	*0.11*	0.12		0.40		0.094
G2	0.72				*0.69*	0.51	0.49		0.36		0.13
MH1											*0.075*
G8	0.79		*0.69*	0.94	*0.69*	0.23	0.12		0.19		*0.075*

Concentrations in italic represent estimates of concentrations for samples where all 11 BDE congener concentrations were below LODs. Limits of detection for BDEs improved between 2007 and 2008 and therefore values assigned to congeners below LOD are lower in 2008 and 2009, resulting in a step decrease in ∑11 BDEs concentration for samples with congeners below LODs.

BDE209 has only previously been analysed in the sediments at Rame Head South for three years (Table A1.1.5). Concentrations in 2016 at most stations were very similar to those observed in 2014, which were higher (except for G28 and G30) than those from 2008-09. Station G6 to the north of the disposal site displayed the highest increase in BDE209 in 2016 with 10.5 µg/kg, and G25, to the southwest of the site, continues to exhibit relatively high concentrations.

Table A1.1.5. Temporal trends (2008-2016) of BDE209 concentration (in µg/kg) for the stations sampled at Rame Head South.

Station	BDE209 concentration (in µg/kg)					
	2008	2009	~	2014	~	2016
G34	*0.05*	*0.05*		0.28		
G50	1.05	2.16		2.71		
G33	2.55	0.65		6.22		5.90
G28	1.22	5.25		2.34		
G30	0.62	1.82		0.56		0.61
G25	5.31	1.89		8.87		8.17
G21	5.42					
G18	3.25					
KH1	2.96					
G20	4.21					
G19	0.77					
G16				0.29		
G13	*0.05*	*0.05*		0.17		*0.05*
G3	0.10	*0.05*		0.22		*0.05*
RH7	*0.05*	*0.05*		0.28		
G37		*0.05*		0.23		
RH6	*0.05*	*0.05*		*0.05*		*0.05*
G6		3.83		3.95		10.5
MH2						7.77
G36	1.05	1.53		2.17		3.16
G2	1.10	0.94		3.47		2.82
MH1						3.26
G8	*0.05*	*0.05*		0.49		0.50

1.4.3.3.3 Trace metals

Levels of enrichment for Rame Head South stations using OSPAR BAC and regional baseline assessment concentration (or RAC) (West Channel) values are represented in Figure A1.4.11. Assessment of metals enrichment shows that sediments at all stations were found to be slightly enriched regarding lead (Pb) for most stations, and moderate for station G25, when using the OSPAR BAC method. No station, however, showed lead enrichment when assessed using the RAC approach (Figure A1.4.11).

Cadmium (Cd) levels are mostly slightly enriched using the OSPAR BAC approach, with station MH2 showing moderate enrichment. Assessment using the RAC approach gives greater enrichment, with all stations depicting values 2-5 times higher than the baseline value for Cd. This is due to Cd baseline value for the West Channel area being lower than that of the OSPAR BAC value.

Levels of copper (Cu) and chromium (Cr) ranged from not enriched to slightly enriched with the OSPAR BAC approach, although assessment based on the RAC approach gave a less noticeable enrichment in these elements. No enrichment was observed for arsenic (As), nickel (Ni) and zinc (Zn) for all stations when the RAC method was applied, however enrichment is slightly more pronounced (i.e. 1-2 times) when assessed against the OSPAR BAC approach for stations G8 and G25.

Regional variability is even more marked for mercury (Hg) as the derived regional baseline value is 10 times that of the OSPAR BAC for the West Channel (Table A2.3.1), resulting in an important difference in enrichment factors between the two assessment approaches. While most stations were found to be either between 2-5 times and >5 times the OSPAR BAC value, all stations were found to be lower than the baseline value (Figure A1.4.11).

Since stations within the Rame Head South disposal site have not been sampled since 2009, Figure A1.4.12 only shows temporal trace metals data for stations located outside the disposal site. Overall, no specific temporal trend is observed for most elements, except for Zn where a slight decrease can be seen and Pb continues to display a notable decrease from 2006 to 2016.

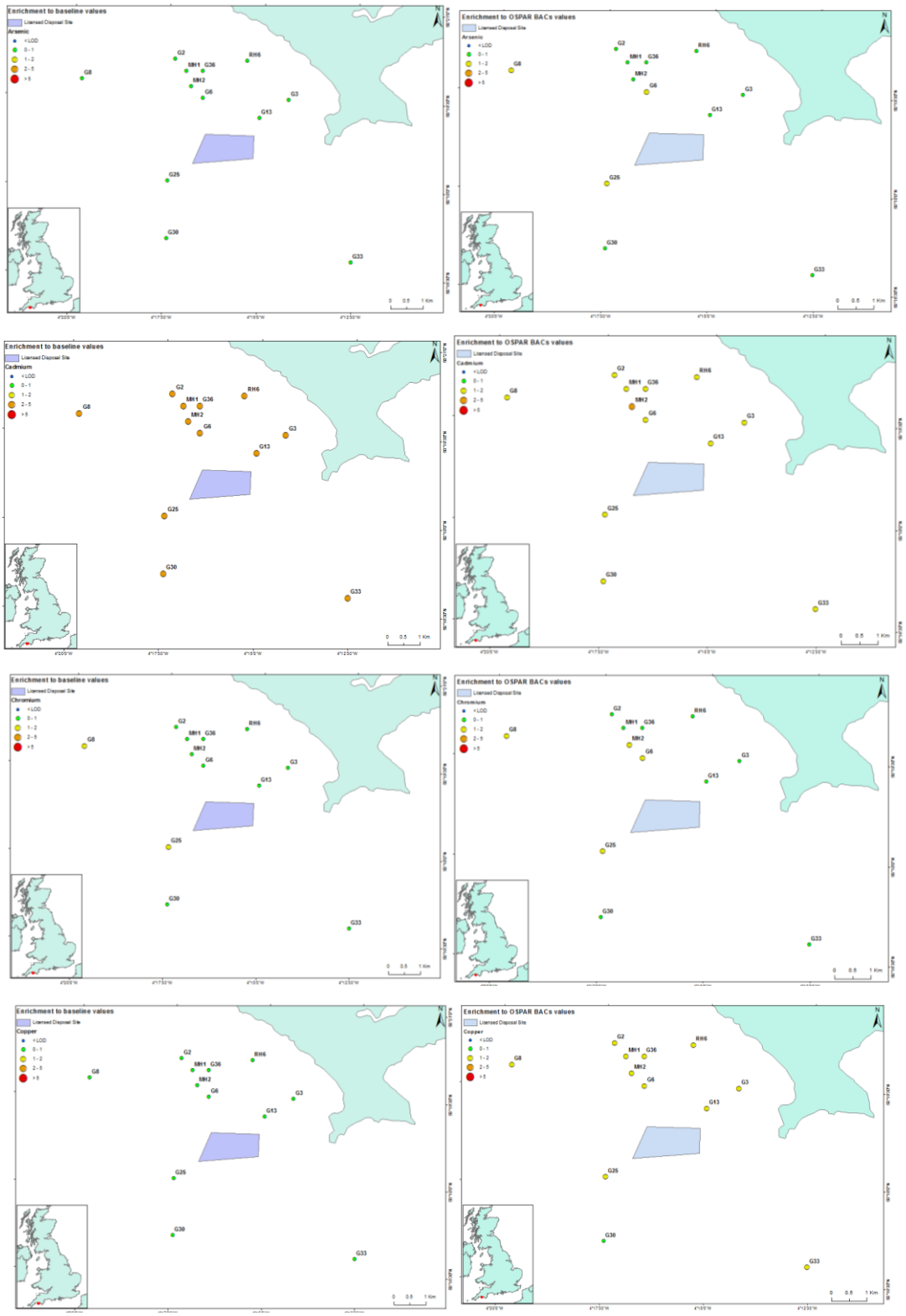


Figure A1.4.11. Enrichment of regional baseline (left) and OSPAR BACs (right) for trace metals sampled at Rame Head South in 2016.

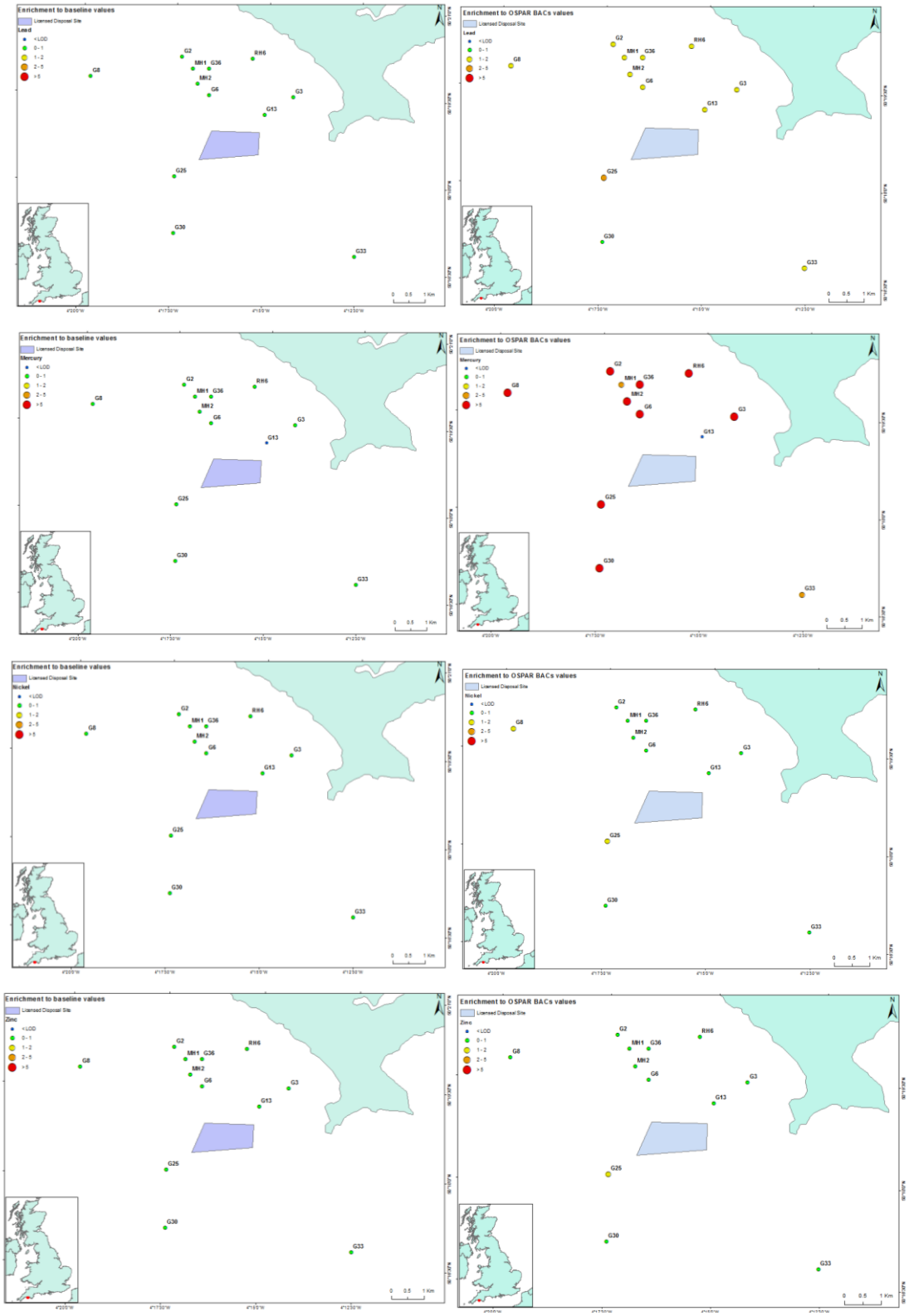


Figure A1.4.11. Continued.

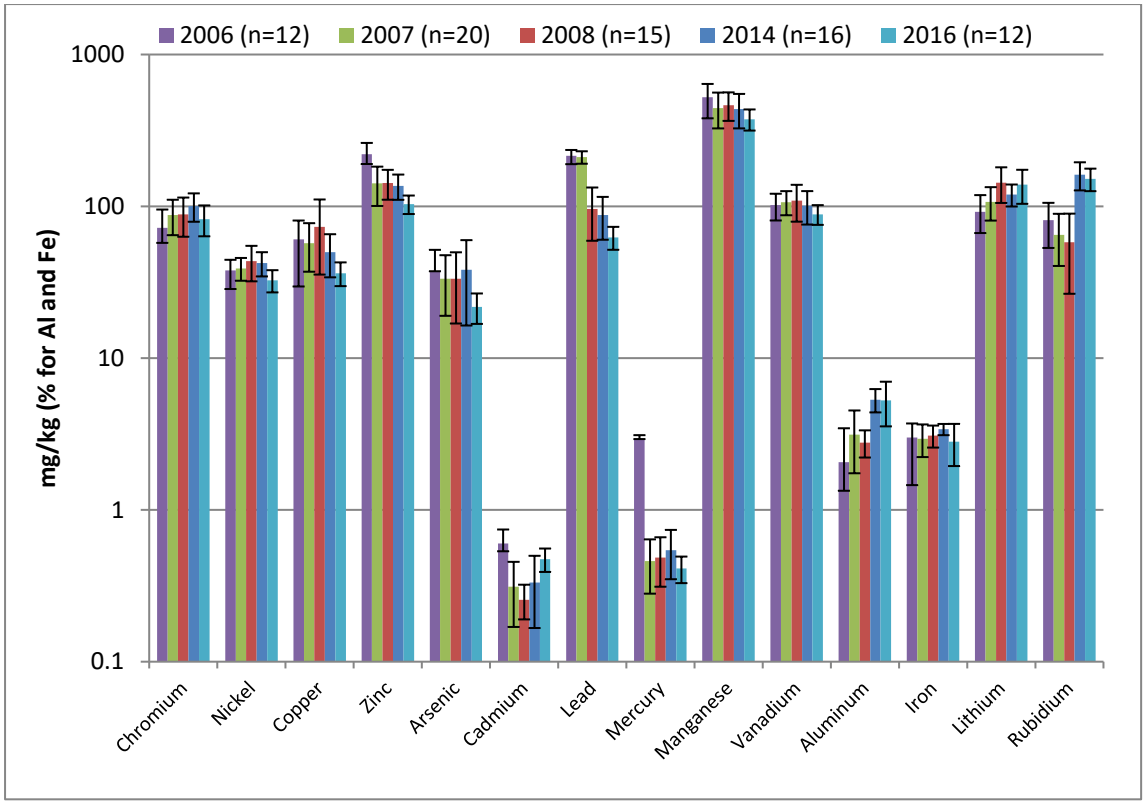


Figure A1.4.12. Temporal data of the trace metals concentrations for the stations sampled around the Rame Head South disposal site, 2006-2016.

1.4.3.4 Macrofaunal assemblages

The macrofauna survey conducted at Rame Head South in 2016 consisted of 14 stations surrounding the licenced dredge disposal site. Three replicate macrofaunal samples were collected from most stations except for G16 and G28, which yielded one and two samples respectively. To aid with the interpretation of the faunal assemblage data, stations were categorised by depth into one of three categories; less than 20 m, 20 – 30 m and greater than 40 m, and by distance from the disposal site boundary; less than 1 km, 1 – 2 km, 2- 3 km and greater than 4 km. Depth and distance from disposal site values were extracted for each station using the Defra Elevation Model (Astrium, 2011) and the 'Near' tool in ArcMap 10.1®. It should be noted that this classification does not account for the effect of tides on the ultimate fate of the disposed material and thus may not be the most appropriate way to detect spatial trends in community structure (Bolam et al., 2011a; Okada et al., 2009).

1.4.3.4.1 Multivariate analyses

Multivariate tests were performed using PRIMER V6 (Clarke and Warwick, 1994) on square root-transformed abundance data. There was generally high within-station similarity, relative to between-station similarity as is evident in the clustering dendrogram showing group average similarity within replicates of the same station (Figure 13). A non-parametric multi-dimensional scaling ordination of the transformed abundance data indicates that shallow stations have a similar faunal community (Figure A1.4.14). RH06 and G03 can be distinguished by the presence of polychaetes of the *Magelona* genus and the gammarid shrimp *Bathyporeia elegans*. These two

taxa are absent from the deepest stations and have an average abundance less than 0.06 in stations from the 20 – 30 m depth range.

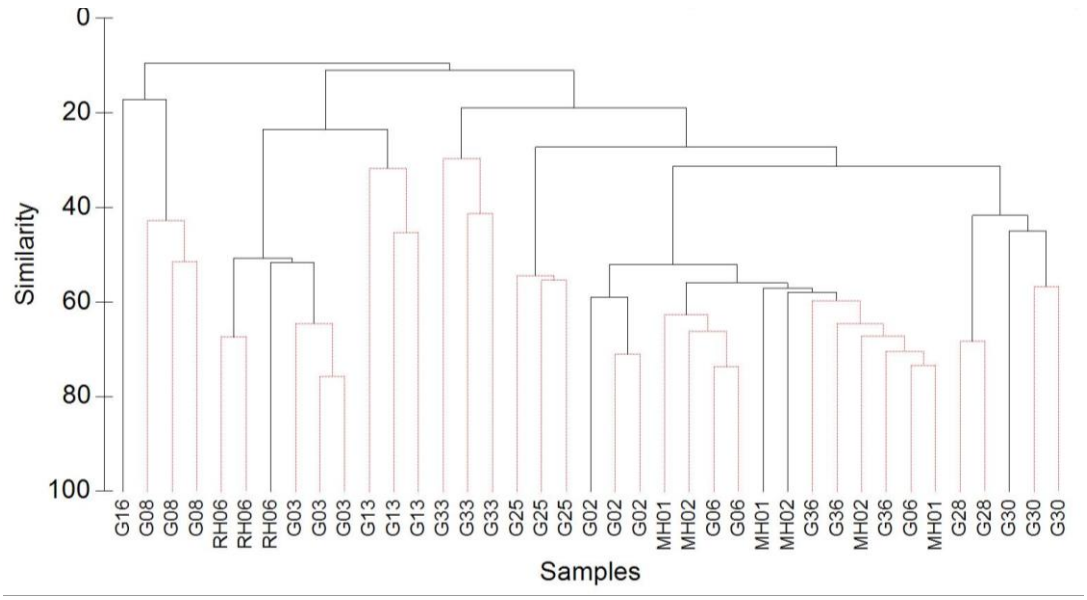


Figure A1.4.13. Clustering dendrogram, p = 0.05.

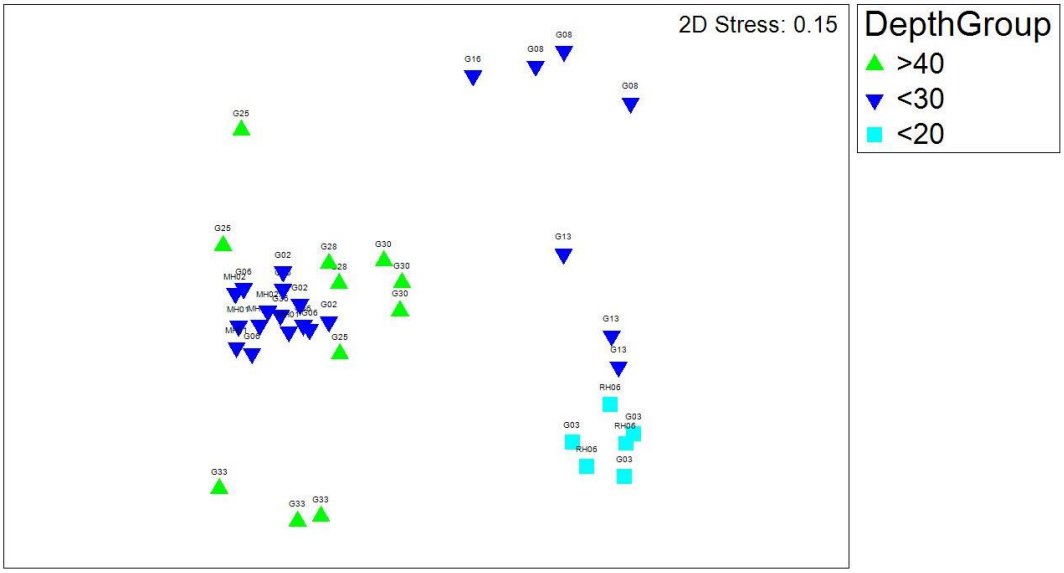


Figure A1.4.14. NMDS ordination plot of the sampling stations (with replicates) at Rame Head South in 2016. Based on square root-transformed abundance data, stations classed by depth group.

1.4.3.4.2 Univariate analysis

A total of 265 taxa (23 colonial and 242 solitary organisms) were identified from the 39 successful samples; 86% of taxa represented to genus or species level. The remaining taxa were identified to family level or below, following taxonomic distinction guidelines and best practices (Worsfold et al., 2010). However, the number of taxa present in a single replicate ranged from a minimum of 12 (station G25) to a maximum of 60 (station G30) and was on average 32 (± 12 s.d.). The most diverse taxonomic group was annelids which accounted for 44% of the species identified. Arthropoda, Mollusca and Echinodermata contributed 43% (18%, 19% and 5% respectively) and the remaining 13% consisted of ten major phyla; Cnidaria, Platyhelminthes, Nemertea, Entoprocta, Chaetognatha, Sipuncula, Bryozoa, Phoronida, Hemichordata and Chordata.

There was no relationship between number of taxa (S) within a sample and the interaction between station depth and distance away from the disposal site. Similarly, there was no relationship between abundance of individuals (N) or Hill's diversity metric (N1) or total biomass (g) and the interaction between station depth and distance away from the disposal site (Table A1.4.3.A1.4.3).

Table A1.4.3. Linear model results showing no significant relationship between the variables tested [number of taxa (S), abundance of individuals (N), Hill's diversity metric (N1), total biomass (g)] and the interaction between depth and distance away from the disposal site.

Variable	F statistic (df = 2, 36)	Adjusted R squared	P value
Number of taxa (S)	2.1	0.06	0.14
Abundance of individuals (N)	1.2	0.01	0.31
Hill's diversity metric (N1)	1.7	0.04	0.19
Total biomass (g)	0.4	-0.03	0.65

Boxplots showing the number of taxa (S), abundance of individuals (N), Hill's diversity metric (N1) and total biomass (g) for each station are presented by 'depth' categories in Figure A1.4.15.A1.4.15-A1.4.18. Colonials were excluded from the latter two metrics. There is no overall association between variables and depth. Stations G03 and RH06, from the shallowest depth category, have similar numbers of taxa (S), (20 and 21 respectively). However, total abundance (N) and biomass (g) was much lower in RH06 than in G03. The difference in abundance was due to the higher abundance of polychaetes of the *Magelona* genus at station G03. Furthermore, one large bivalve, *Mactra sultorum*, and fragments of an echinoderm from the Spatangoida family were present in the replicate samples taken at G03 which accounts for the difference in biomass observed.

Station G28 possessed an elevated number of individuals which, upon further investigation of the raw data, can be attributed to having the highest mean number of taxa (S) and an abundance of the polychaete *Scalibregma inflatum*, (119 and 113 in the two replicates). *S. inflatum* has been shown to increase abundance as a result of

organic input however it regularly occurs in high numbers in sediment samples from around the UK and can be locally common (Hiscock et al., 2004).

1.4.3.4.3 Temporal analyses

A comprehensive analysis of the macrofaunal community at Rame Head South to determine any temporal changes in community structure is not within the scope of this report (see Bolam et al., 2011a). A preliminary assessment of seven stations, common to the three most recent surveys carried out at Rame Head South, was conducted to augment the analysis of the 2016 survey data. In addition, due to the lack of information from within the licenced area, it is felt that a description of the variability of the general area is beneficial.

Three replicate macrofauna samples were collected at each station during monitoring surveys in 2008, 2009 and 2016 (except for station G28 which yielded two replicates in 2016). Abundance data from replicate samples were averaged prior to square root-transformation. Multivariate analysis was performed using a suite of routines available in PRIMER, V6 (Clarke and Warwick, 1994). Community structure was generally similar within stations at each survey event. However, the community at station G33 in 2016 was not as similar as that found in 2008 and 2009 (Figure). This can be attributed to a few notable absences from the 2016 dataset e.g. the mean abundance of the polychaete *Lumbrinereis* sp. at station G33 in 2008 and 2009 was 88 and 63 respectively. However, only three individuals were present at G33 in 2016. Furthermore, there were no gammarid shrimps (*Ampelisca* spp.) identified in 2016 while they were present in high numbers during the previous surveys (37 and 21 in 2008 and 2009 respectively). Station G13 also showed relatively high temporal variability (Figure A1.4.19). Taxa responsible for this difference include the bivalve mollusc *Phaxus pellucidus*, which was only found during the 2016 survey; the highly mobile brittle star *Ophiothrix fragilis*, which was present only in 2008 (and with high abundance in one of the replicate samples); and the interstitial polychaete *Polygordius*, which was absent in the 2016 survey.

Boxplots showing the variability of the number of taxa (S), number of individuals (N), Hill's diversity index (N1) and total biomass (wet weight g) between survey years for each station demonstrate the variability of each metric over time at a fixed location (Figure **A1.4.20.**A1.4.20 - Figure A1.4.26A1.4.26). This variation is also evident in the sediment characteristics of these stations (Section A1.4.3.1, and Bolam et al., 2011b, 2009).

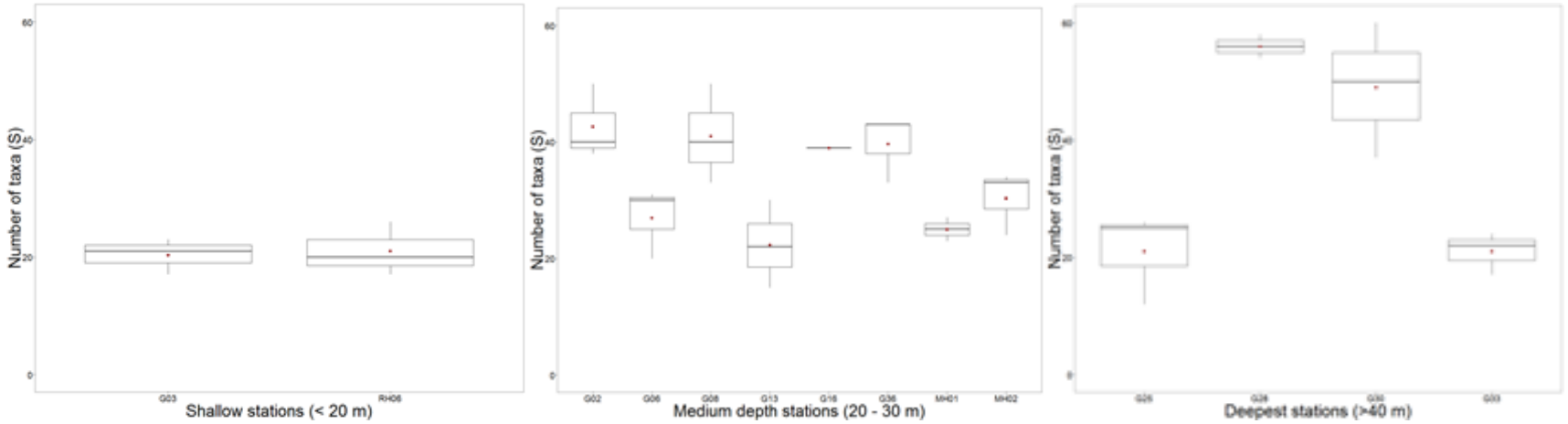


Figure A1.4.15. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (S) at each station for shallow (top left), mid-depth (top right) and deep (bottom) groups. The mean value is represented as a closed circle.

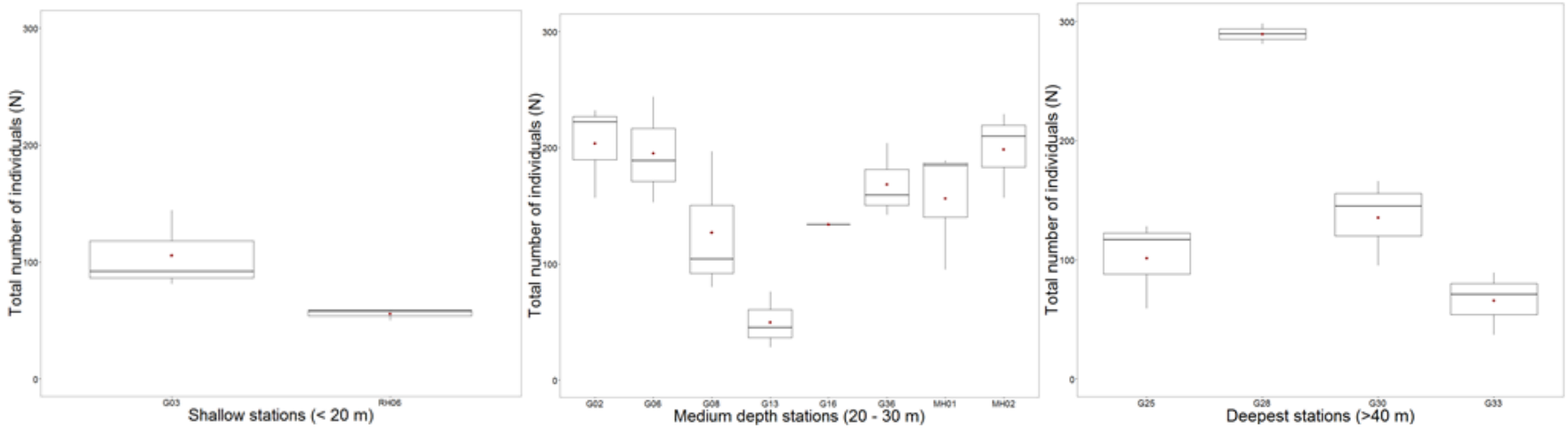


Figure A1.4.16. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of individuals (N) at each station for shallow (top left), mid-depth (top right) and deep (bottom) groups. The mean value is represented as a closed circle.

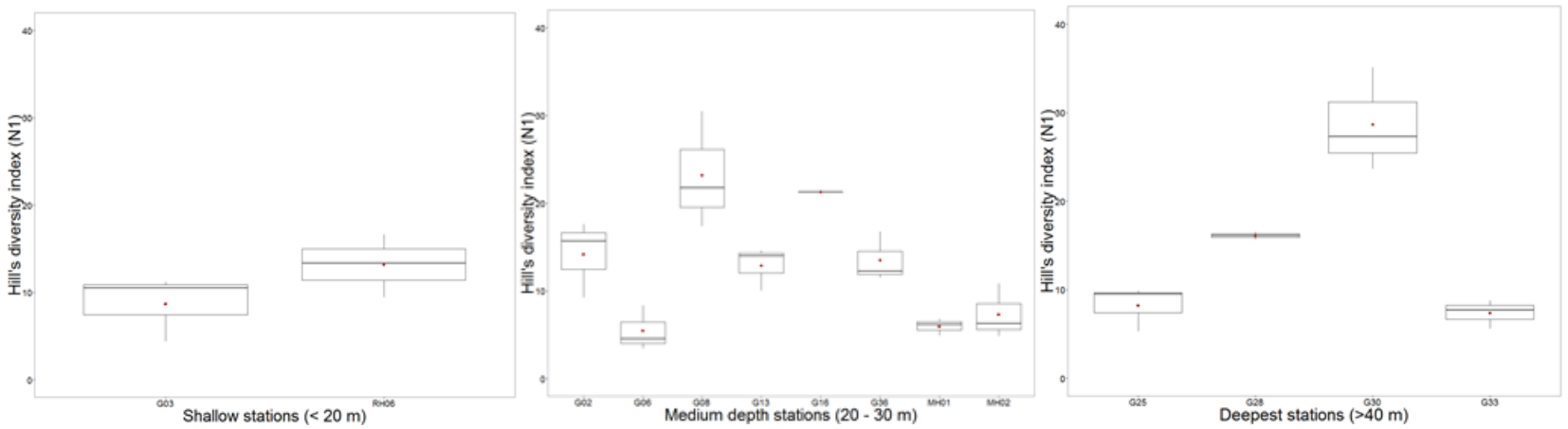


Figure A1.4.17. Boxplots showing the median, interquartile range and 95 % confidence intervals of Hill's diversity index (N1) at each station for shallow (top left), mid-depth (top right) and deep (bottom) groups. The mean value is represented as a closed circle.

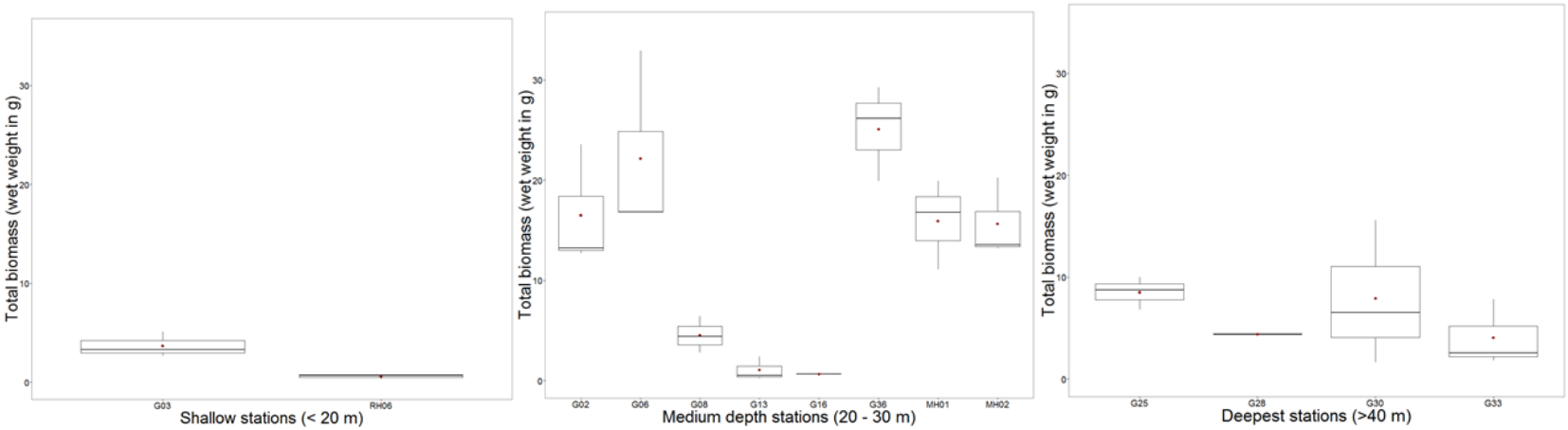


Figure A1.4.18. Boxplots showing the median, interquartile range and 95 % confidence intervals of the total biomass (g) at each station for shallow (top left), mid-depth (top right) and deep (bottom) groups. The mean value is represented as a closed circle.

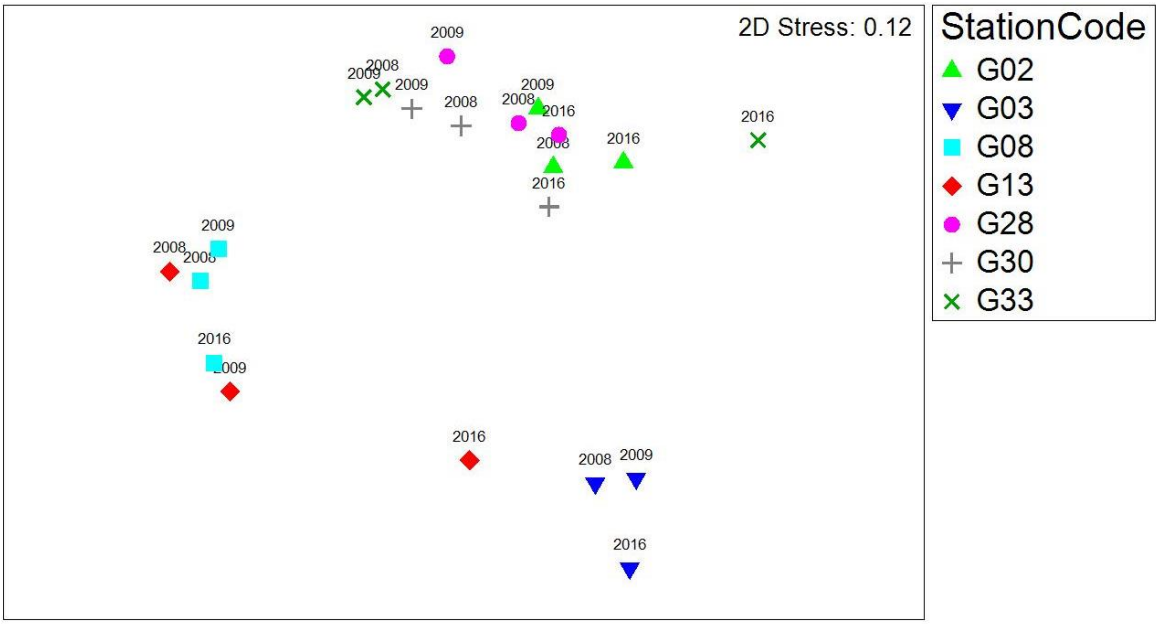


Figure A1.4.19. Two-dimensional representation of the nMDS ordination of the square root-transformed mean taxon abundance data showing the (dis)similarity of benthic community within stations surveyed on the three most recent surveys of Rame Head South (2008, 2009, 2016).

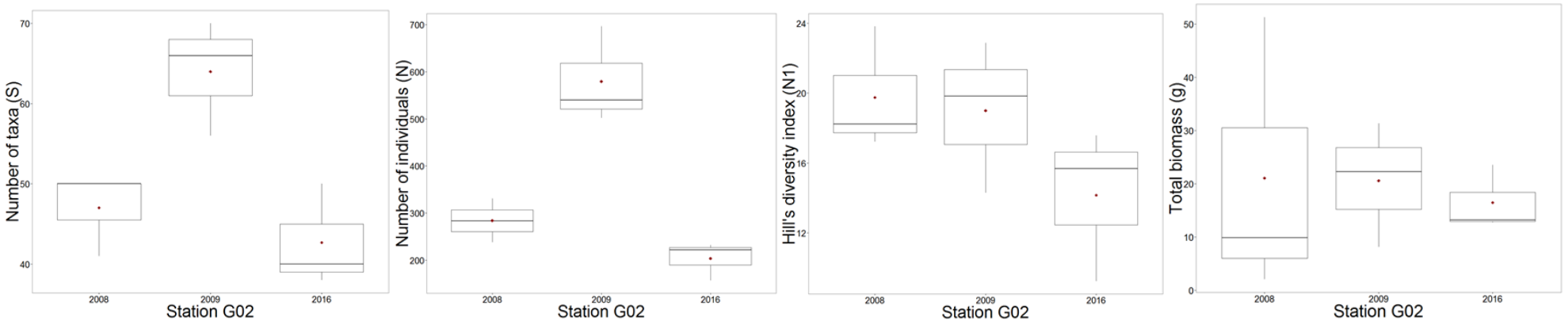


Figure A1.4.20. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G02 during 2008, 2009 and 2016.

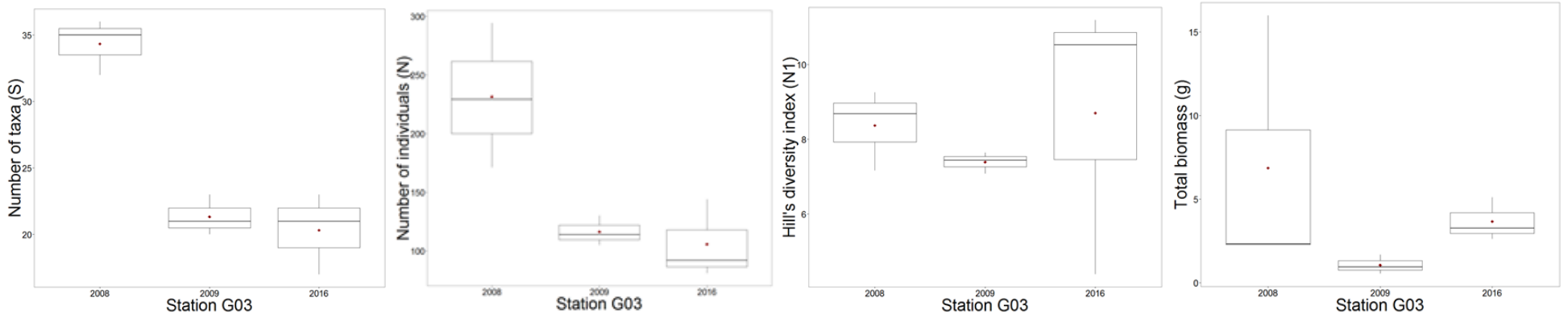


Figure A1.4.21. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G03 during 2008, 2009 and 2016.

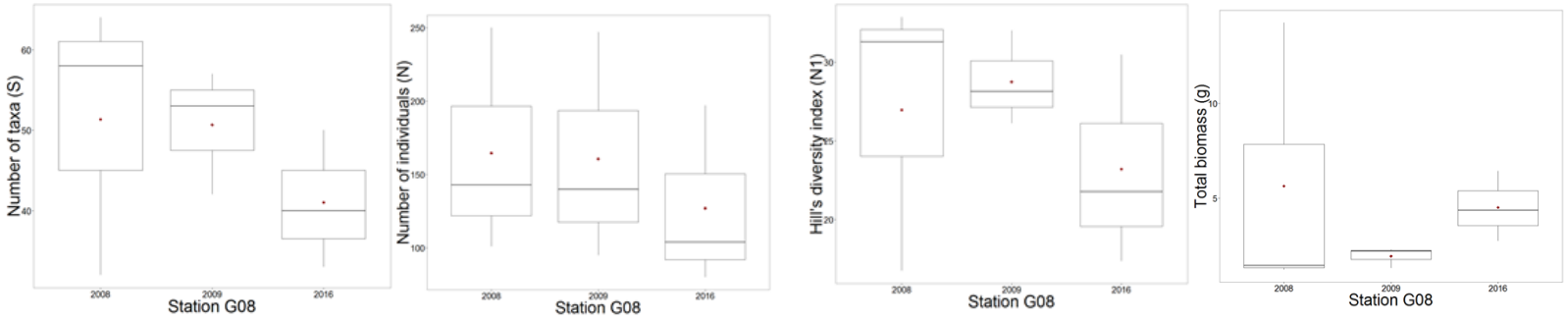


Figure A1.4.22. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G08 during 2008, 2009 and 2016.

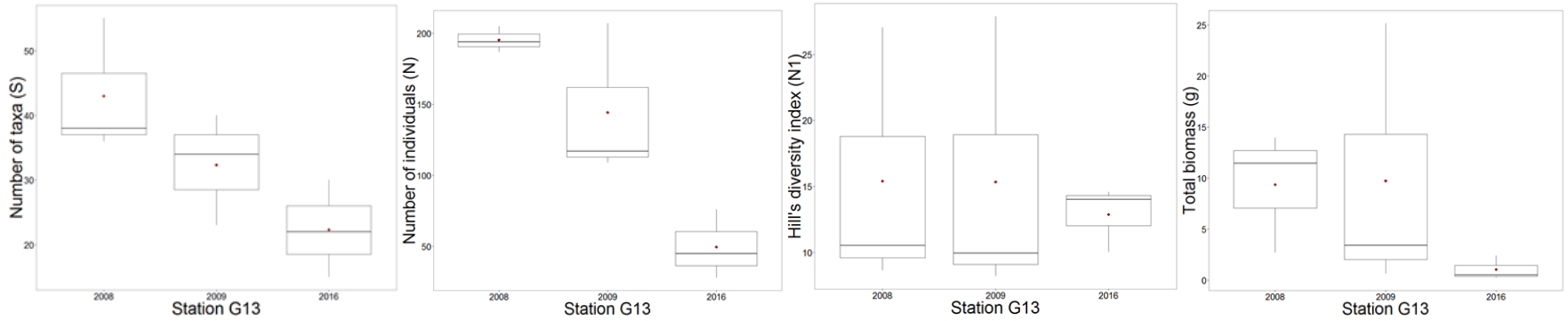


Figure A1.4.23. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G13 during 2008, 2009 and 2016.

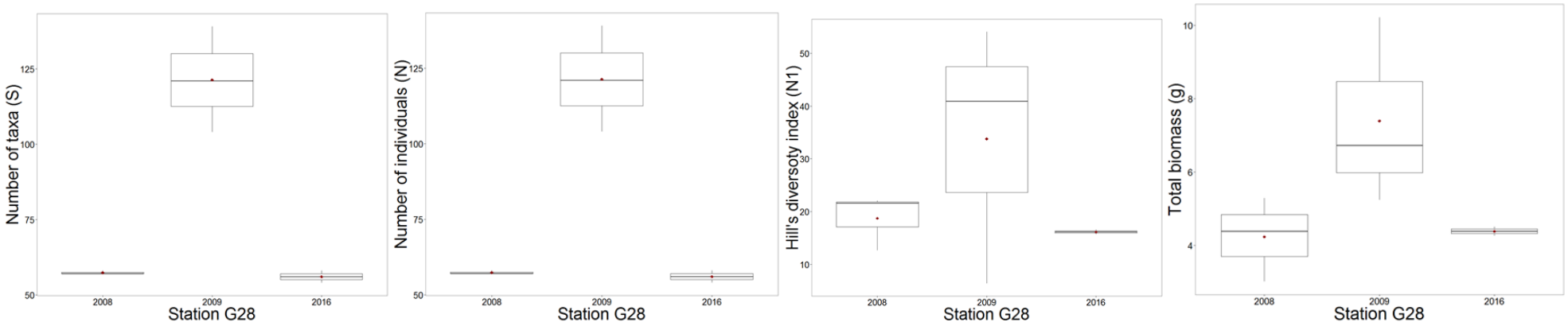


Figure A1.4.24. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G28 during 2008, 2009 and 2016.

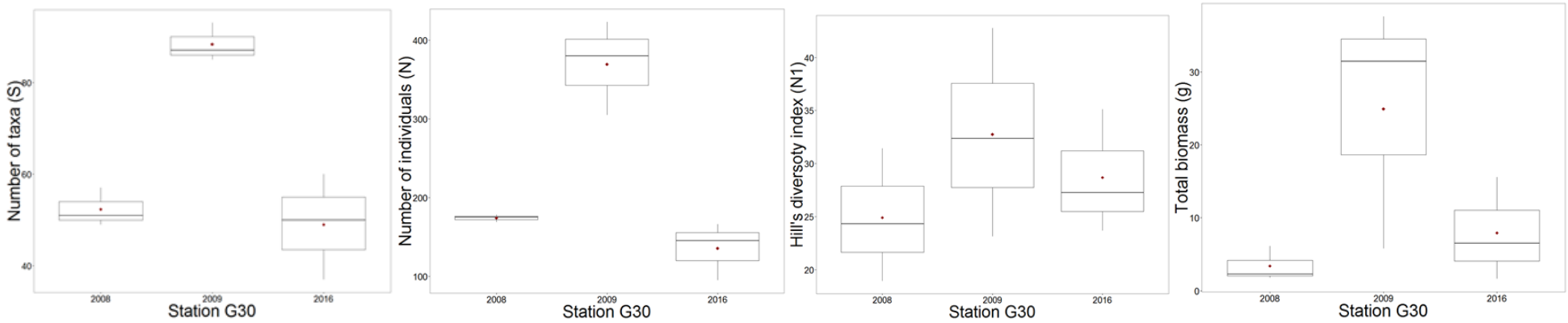


Figure A1.4.25. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G30 during 2008, 2009 and 2016.

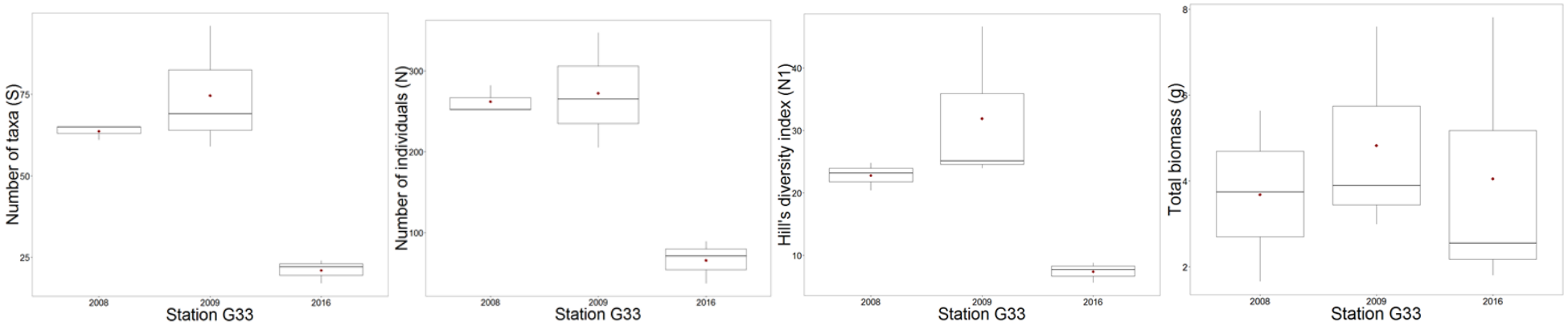


Figure A1.4.26. Boxplots showing the median, interquartile range and 95 % confidence intervals of the number of taxa (top left), number of individuals (top right), Hill's diversity index (bottom left) and total biomass (bottom right) at station G33 during 2008, 2009 and 2017.

1.5 Lantic Bay

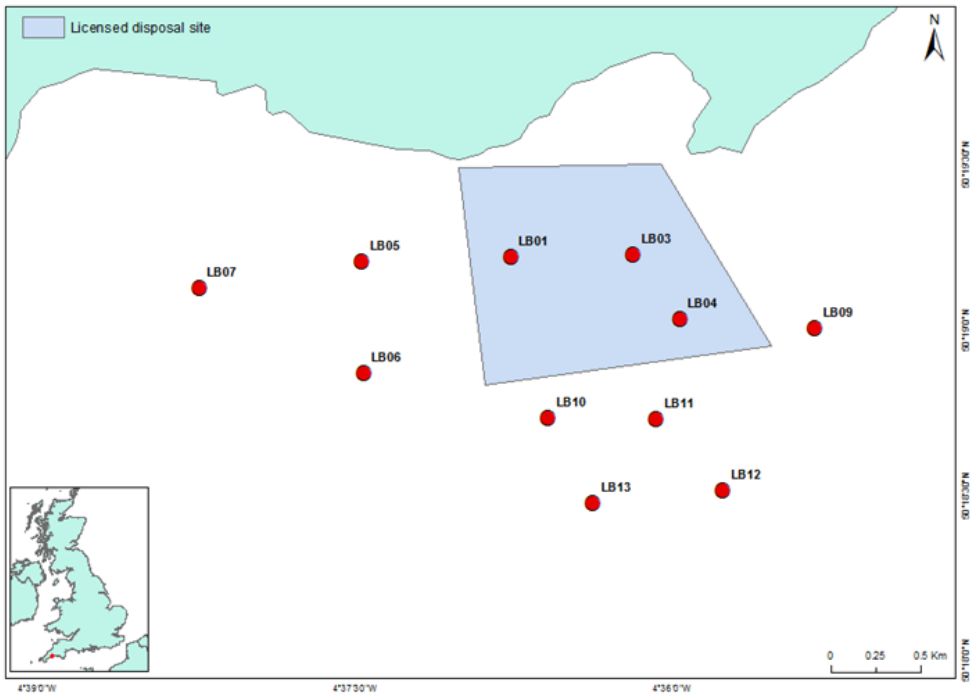


Figure A1.5.1. Location of the 11 stations for which samples were successfully collected during June 2016.

1.5.1 Background

Lantic Bay PL060 (Figure A1.5.1) is located close to the rocky shore just east of the entrance to the Fowey Ria system, Cornwall, the mouth of which is represents a deep inlet surrounded by a steep-sided catchment. The disposal site, which is exposed to long-period Atlantic swell waves from a southwesterly direction, is comparatively little-used, being used for the disposal of maintenance material, and very occasionally capital material, resulting from dredging within the River Fowey and the nearby Par Harbour. Dredging within the Fowey is conducted to maintain the deep water required to allow anchorage of cruise ships and to provide safe navigation of the vessels used to transport china clay mined from the local area. Quantities of material deposited to Lantic Bay average approximately 66,000 wet tonnes per annum since the early 1980s, although larger quantities, circa 160,000 wet tonnes were disposed there during 1985, 1987 and 1993 (Figure A1.5.2).

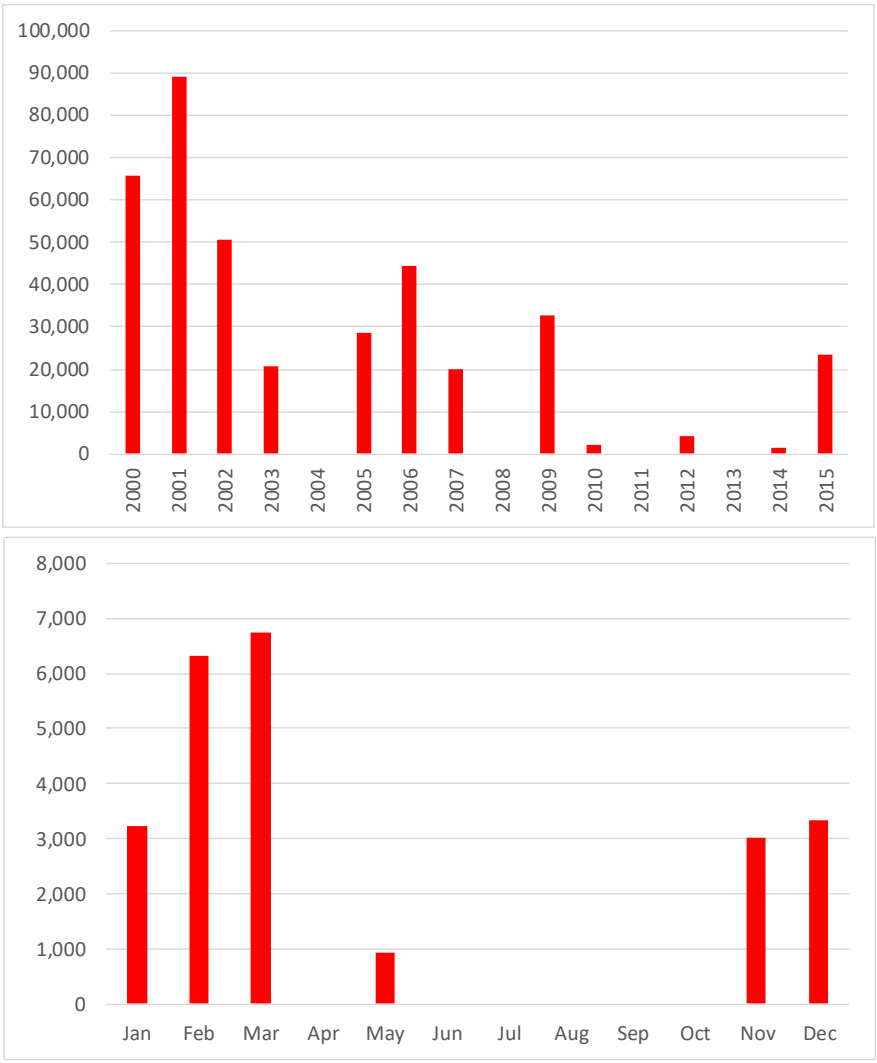


Figure A1.5.2. Disposal returns (wet tonnes) for material annually disposed of to Lantic Bay 2000-2015 (top) and for each month during 2015 (bottom).

During the winter of 2015-16, maintenance dredged material from Corporation Wharf, Plymouth, which is normally disposed of at Rame Head South, was deposited at Lantic Bay (data not available at time of writing for inclusion within Figure A1.5.2). As this material originates from a different system (the Tamar catchment), the MMO considered it prudent, in view of no data hitherto, to undertake seabed sampling at Lantic Bay to ascertain the present spatial variability in sediment granulometry and contaminants concentrations. Under the auspices of C6794, Cefas sampled a small number of stations within and outside the disposal site (Figure A1.5.1). The survey was not conducted to assess impacts at this site resulting from the recent disposal of material from the Tamar, partly as there is no reason to believe that this material will result in alterations to the area beyond those resulting from disposal of material from Fowey. The data acquired from sampling in 2016 are used to determine

the present spatial variability in sediment granulometry and contaminants concentrations in this area in view of a current absence of any such data.

1.5.2 Parameters monitored

Sediment particle size

Sediment organic carbon

Sediment contaminants (PAHs, organohalogens, trace metals)

1.5.3 Results

1.5.3.1 Sediment particle size

The sediments at the stations sampled at Lantic Bay were predominantly gravelly sands, sandy gravels and gravels with some muddy sands/ sandy muds (Table A1.5.1).

Table A1.5.1 Sediment summary statistics and descriptions for each sample at Lantic Bay in 2016.

Station	Gravel (%)	Sand (%)	Silt/clay (%)	Folk symbol	EUNIS sediment description
LB01	27.56	71.89	0.55	gS	coarse sediment
LB03	44.10	54.88	1.03	sG	coarse sediment
LB04	28.54	70.64	0.82	gS	coarse sediment
LB05	69.41	30.28	0.30	sG	coarse sediment
LB06	30.37	68.68	0.95	sG	coarse sediment
LB07	83.71	14.74	1.56	G	coarse sediment
LB09	8.23	90.59	1.18	gS	coarse sediment
LB10	1.00	19.57	79.43	sM	mud and sandy mud
LB11	0.48	66.02	33.51	mS	mud and sandy mud
LB12	0.45	35.13	64.42	sM	mud and sandy mud
LB13	0.51	57.76	41.73	mS	mud and sandy mud

The spatial variation in the proportional representation of gravel, sand and silt/clay for each sampling station in 2016 is shown in Figure A1.5.3 and the percentages of silt/clay content in Figure A1.5.4. The data revealed generally coarser sediments inshore, including sediments within the disposal site, with muddy sands/ sandy muds present further offshore. Indeed, silt/clay was only present in the four stations offshore of (or to the south of) the disposal site (Figure A1.5.4).

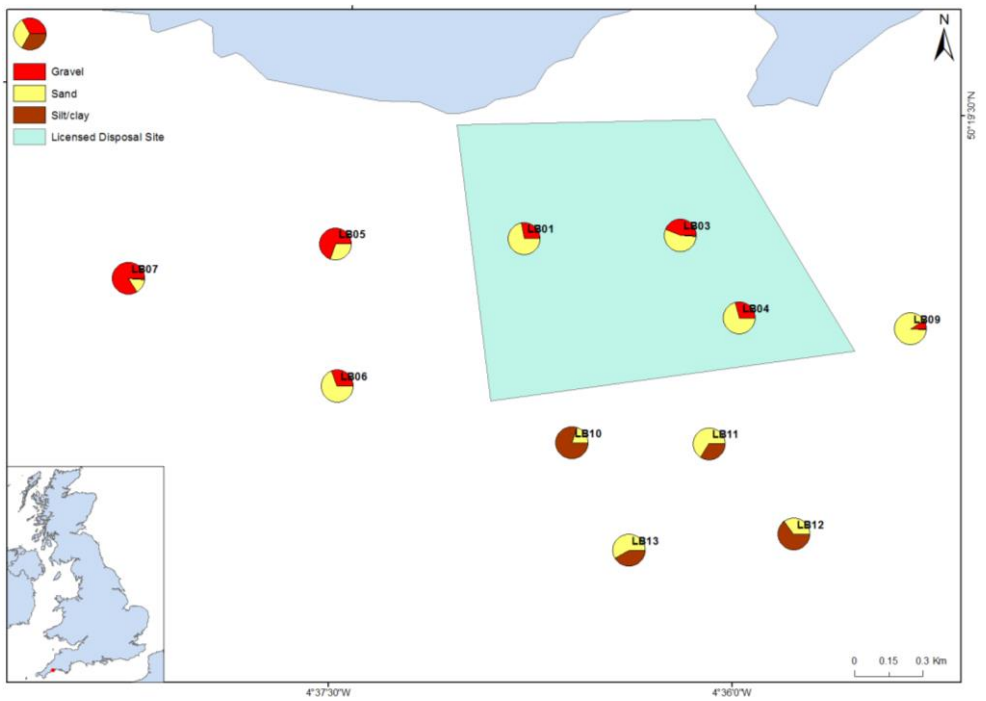


Figure A1.5.3. Pie charts of gravel, sand and silt/clay of the sediments sampled at Lantic Bay in 2016.

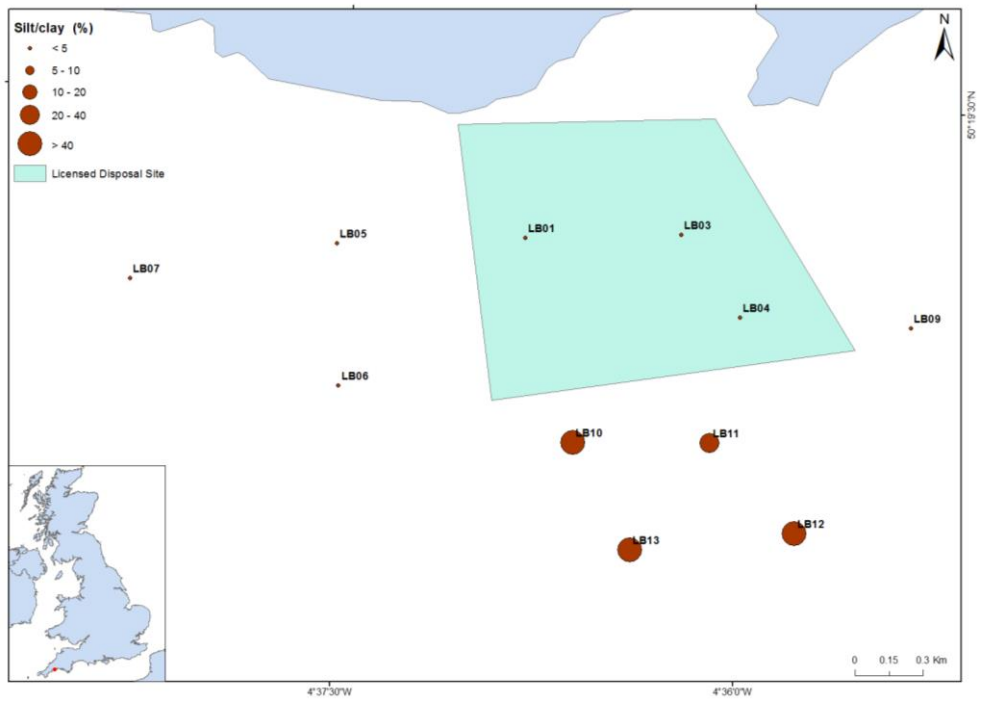


Figure A1.5.4. Sediment silt/clay content (%) of the stations sampled at Lantic Bay in 2016.

1.5.3.2 Sediment organic carbon

Sediment organic carbon values in the <2mm sediment fraction range from 0.11 to 2.32%, while those in the <63µm sediment fraction range from 1.58 to 2.08 % (Figure A1.5.5). Stations LB01, LB03, LB05, LB06 and LB09

all had low silt/clay content (<2% silt/clay) and so it was not possible to measure the organic carbon on this fraction.

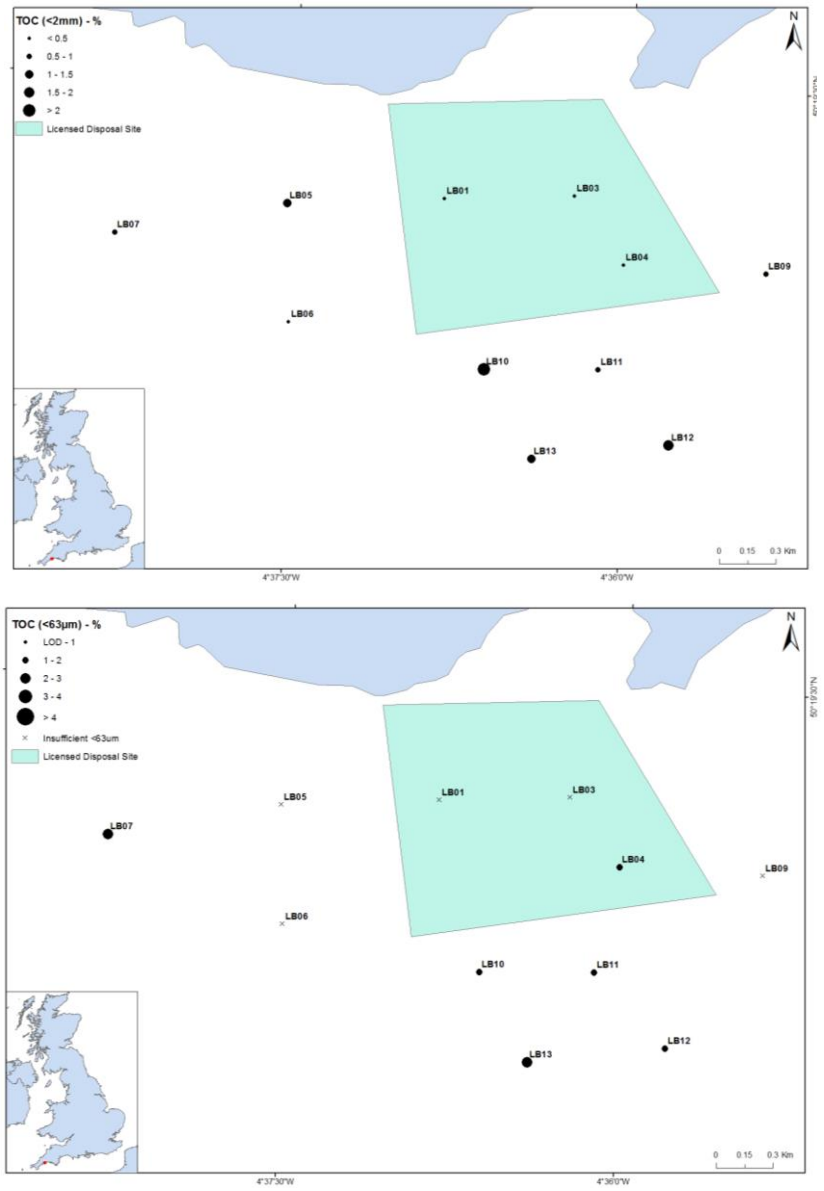


Figure A1.5.5. Sediment organic carbon (%) in the <2mm fraction (top) and the <63µm sediment fraction (bottom) at Lantic Bay in 2016.

1.5.3.3 Sediment contaminants

1.5.3.3.1 PAHs

The highest summed PAH (ΣPAH) concentration at Lantic Bay in 2016 was 3,380 µg kg^{-1} dry weight found at LB10, approximately 0.3Km south of the disposal site (Figure A1.5.6). The second highest concentration observed was 2,170 µg kg^{-1} dry weight at LB12 which similarly lies to the south of the disposal site.

In contrast, the lowest ΣPAH concentration was 133 µg kg^{-1} dry weight was measured to the west of the disposal site at LB06, and a low concentration of 261 µg kg^{-1} dry weight was sampled at LB09 approximately, 0.3 km east of the southern edge of the disposal site. Low ΣPAH concentrations were also present at two of the three stations within the disposal site (282 µg kg^{-1} dry weight at LB01 and 448 µg kg^{-1} dry weight at LB04; Figure A1.5.6).

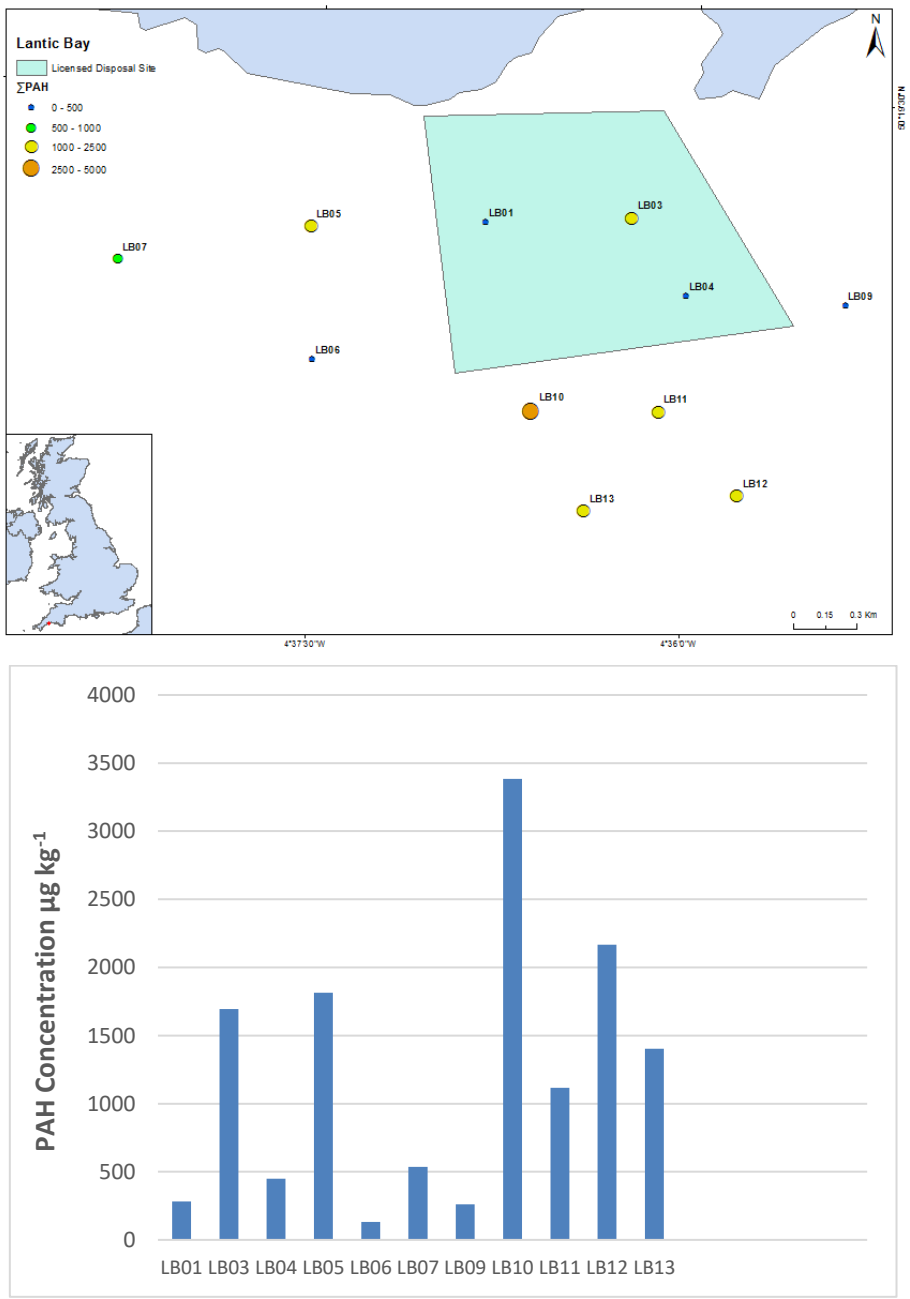


Figure A1.5.6. Map (top) and histogram (bottom) displaying summed PAH concentrations (µg kg^{-1} dry weight) for stations sampled at Lantic Bay in 2016.

None of the sediments sampled from the 11 stations in 2016 exceeded the ERL or ERM for low molecular weight (LMW) or high molecular weight (HMW) PAHs. Evaluation of the PAH data indicated that the source in the sediment samples LB01-09 were of mixed sources, with approximately 40% of the PAH content arising from oily sources and approximately 60% from combustion sources. However, for the four remaining stations (LB10-13) which are located south of the disposal site, PAH data evaluation indicated that the mixed source in the sediment samples was approximately 70% oily and 30% combustion sources with the highest percentage found at LB10 at 71%.

Summed PAH values found at Lantic Bay in 2016 are similar to those found at other disposal sites in the southwest of England, and directly comparable to those found at Rame Head South during 2016. These levels are low compared to those found at other disposal sites around UK waters, with values ten times higher being observed at sites off the northeast coast of England.

1.5.3.3.2 Organohalogens

∑ICES7 CBs concentrations at Lantic Bay range from 0.11-2.3 µg/kg dw. All of the 11 stations showed ∑ICES 7 CB concentrations above LOD, with the highest concentration (2.3 µg/kg dw) being measured at LB10 to the south of the disposal site (Figure A1.5.7). The next two highest values (1.47 and 0.859 µg/kg dw at LB12 and LB13 respectively), were also located south of the disposal site. The stations whose sediments where highest in silt/clay fractions, therefore, not only displayed the greatest summed PAH concentrations but also the most elevated ∑ICES7 CB concentrations. The lowest ∑ICES 7 CB results of 0.11, 0.13 and 0.14 µg/kg dw were found at LB05, LB04 and LB06, respectively.

BDE concentrations at Lantic Bay are low, generally at or below LOD (∑11 BDEs range <0.075-0.15 µg/kg dw). All BDE congeners were below LOD at eight of the 11 stations (Figure A1.5.8). The three stations to the south of the disposal site (i.e. LB10, LB12 and LB13) contained the highest ∑11 BDEs concentrations (0.15, 0.11 and 0.083 µg/kg dw, respectively), although these can be considered as very low.

BDE209 was detected at nine of the 11 stations (the exceptions were LB01 (inside the disposal site) and LB06 (west of the site)) and was at higher concentrations than the other measured organohalogens (range <0.1-22.2 µg/kg dw) (Figure A1.5.9). The highest concentration of 22.2 µg/kg dw was measured at LB10 to the south of the disposal site, with 5.9, 5.3 and 1.8 µg/kg dw being measured at LB12, LB13 and LB11, respectively, also south of the site. BDE209 concentrations measured for all other stations were <1 µg/kg dw, which is low for coastal sediments sampled in UK waters.

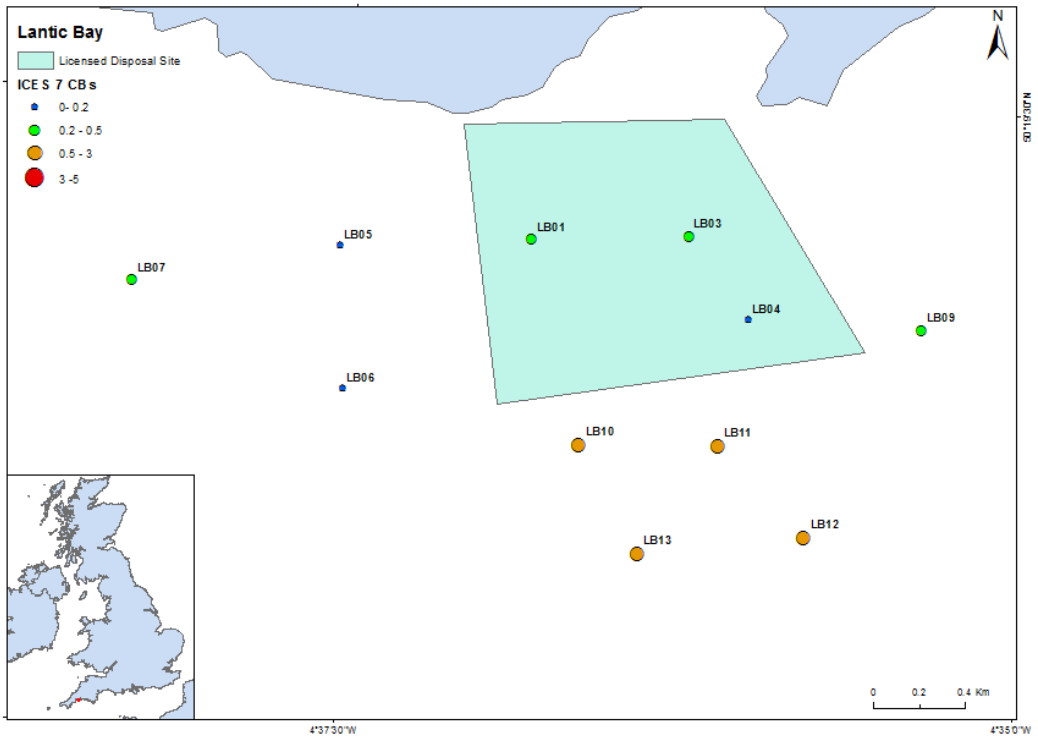


Figure A1.5.7. Summed ICES7 CB concentrations for the stations sampled at Lantic Bay in 2016.

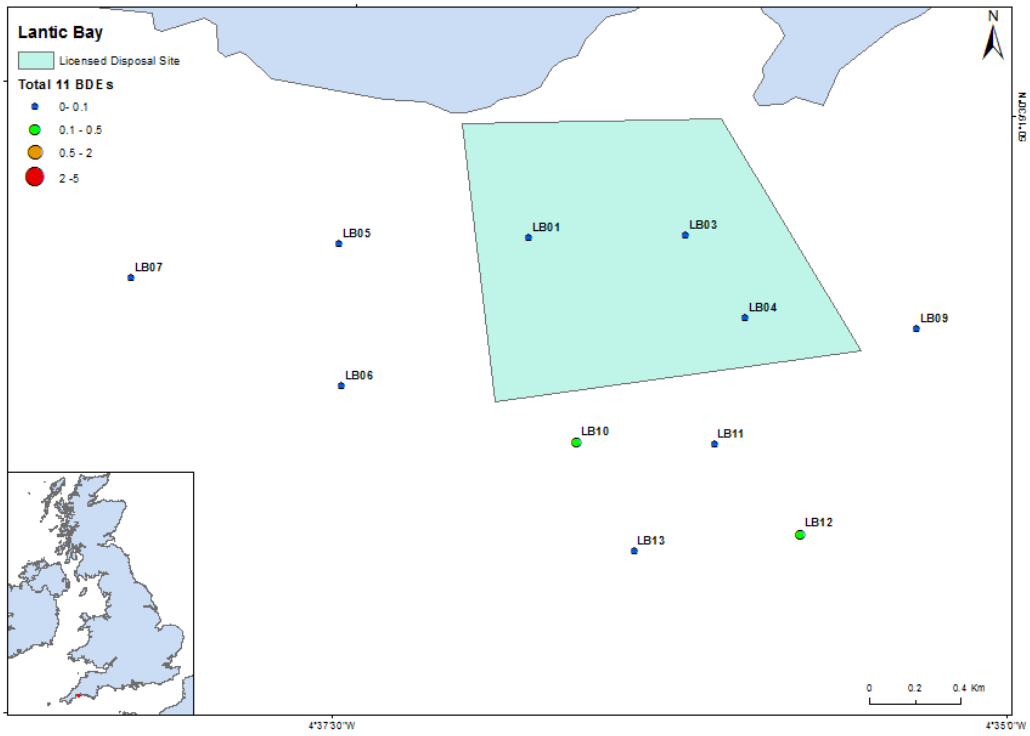


Figure A1.5.8. Summed 11 BDEs concentrations for the stations sampled at Lantic Bay Stations in 2016.

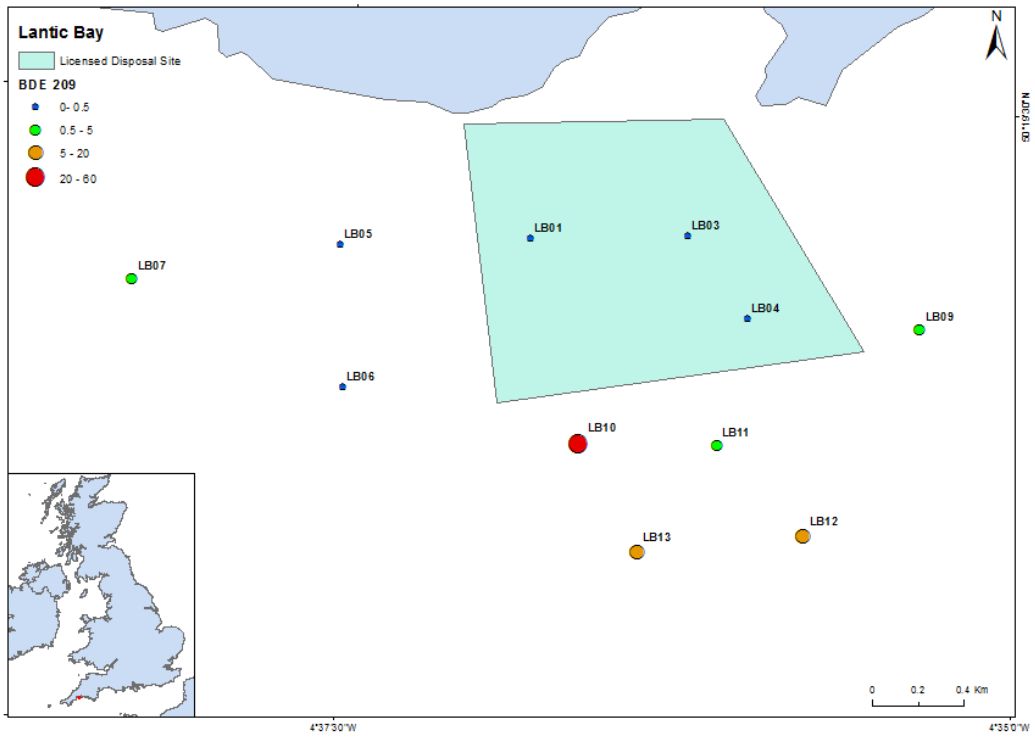


Figure A1.5.9. BDE209 concentrations for the stations sampled at Lantic Bay in 2016.

OCPs were detected at 10 out of 11 stations, though DDTs were only detected at six stations. ∑ $_6$DDTs concentrations ranged from <0.14-0.84 µg/kg dw, with the highest values south of the disposal site at LB10 (0.84 µg/kg dw), LB12 (0.53 µg/kg dw) and LB13 (0.36 µg/kg dw) (Figure A1.5.10). Dieldrin was detected at 10 out of 11 stations (range <0.05-0.31 µg/kg dw), with the highest values again at LB10 (0.31 µg/kg dw), LB11 (0.23 µg/kg dw) and LB12 (0.22 µg/kg dw).

Concentrations of CBs, dieldrin and ∑ 6DDTs at all stations were below Cefas AL 1. No Cefas action levels exist for BDEs and BDE209. According to the OSPAR guidelines, all stations bar LB01 (inside the disposal site) had 'good' environmental status for all ICES 7 CBs, and 'good' status overall. Station LB01 had 'bad' environmental status for CB118, but 'good' status overall. No OSPAR guidelines exist for BDEs and OCPs at present.

There is no previous data from Lantic Bay with which to compare the 2016 results for any temporal trends. In comparison with the nearby Rame Head South disposal site, Lantic Bay generally has lower CB concentrations.

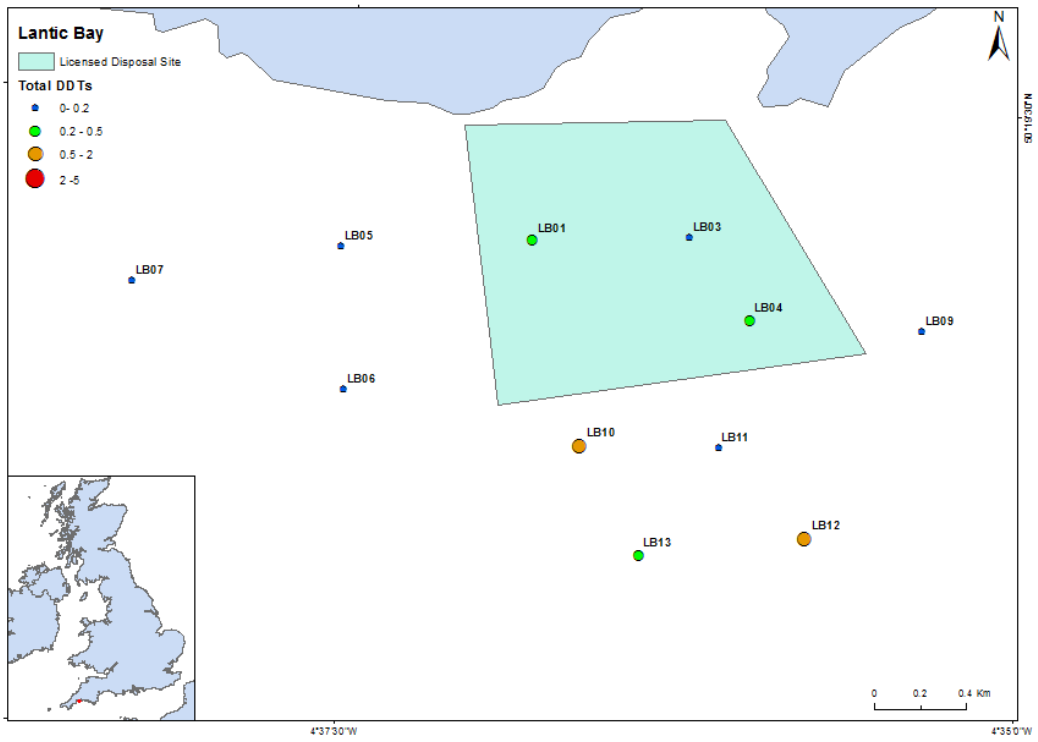


Figure A1.5.10. Total DDT concentrations for the stations sampled at Lantic Bay in 2016.

1.5.3.3.3 Trace metals

Levels of enrichment for Rame Head stations using OSPAR BAC and regional baseline (West Channel) values are represented in Figure A1.5.11. With the OSPAR assessment method, copper (Cu) concentrations are slightly enriched for most stations, with LB01 (situated within the disposal site) being moderately enriched. However, no station was found to be enriched when the data was compared to the baseline value. Similar observations were found for arsenic (As) where no enrichment was recorded when the baseline numerical method was used as enrichment assessment, however the enrichment is slightly more pronounced when assessed against the OSPAR BAC values.

No station was found to be enriched for chromium (Cr) and nickel (Ni) according to either assessment approach. The majority of stations are slightly enriched for Zn, except at LB05 where enrichment was moderate (i.e. 2-5 times the baseline values) when assessment was carried out using the baseline numerical approach. The enrichment for Zn is more pronounced with the OSPAR approach, with the majority of northern-most stations (including the stations within the disposal site) being slightly or moderately enriched. Levels of Zn for stations located south of the disposal site remain below the OSPAR BAC value.

The majority of the mercury (Hg) concentrations sampled were below the limit of detection, only one station (LB09) recorded moderate enrichment with the OSPAR approach whereas no enrichment was observed when assessed against the baseline values. Lead (Pb) enrichment was moderately enriched for all stations when assessing against OSPAR BAC: this enrichment is not present with the baseline value approach. In contrast, cadmium (Cd) enrichment was moderate for all stations when assessed against the baseline values yet enrichment was less pronounced using the OSPAR approach. This, of course, reflects the fact that the Cd baseline value is lower that the OSPAR BAC value (Table A2.3.1).

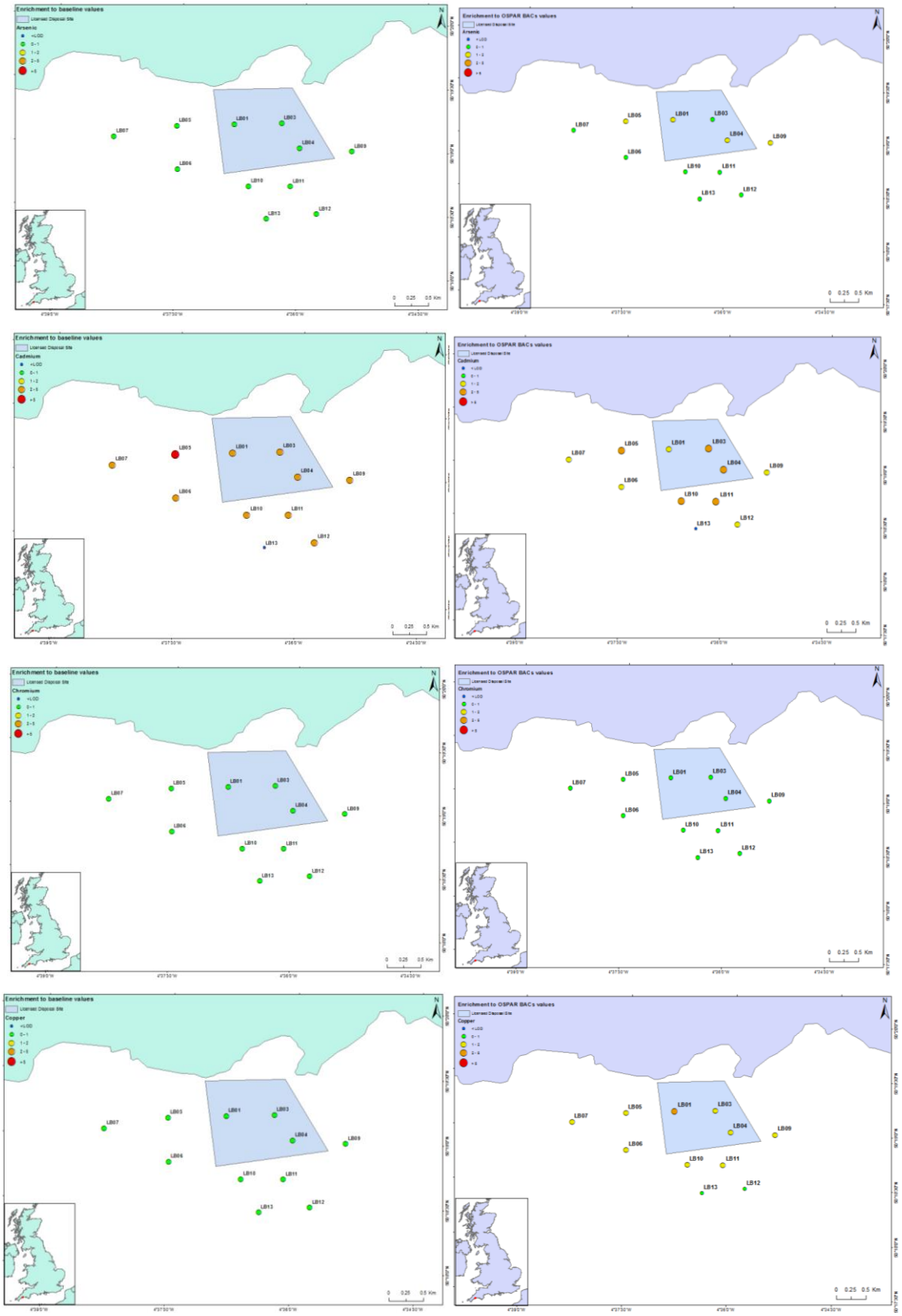


Figure A1.5.11. Enrichment of regional baseline (left) and OSPAR BACs (right) for trace metals sampled at Lantic Bay in 2016.

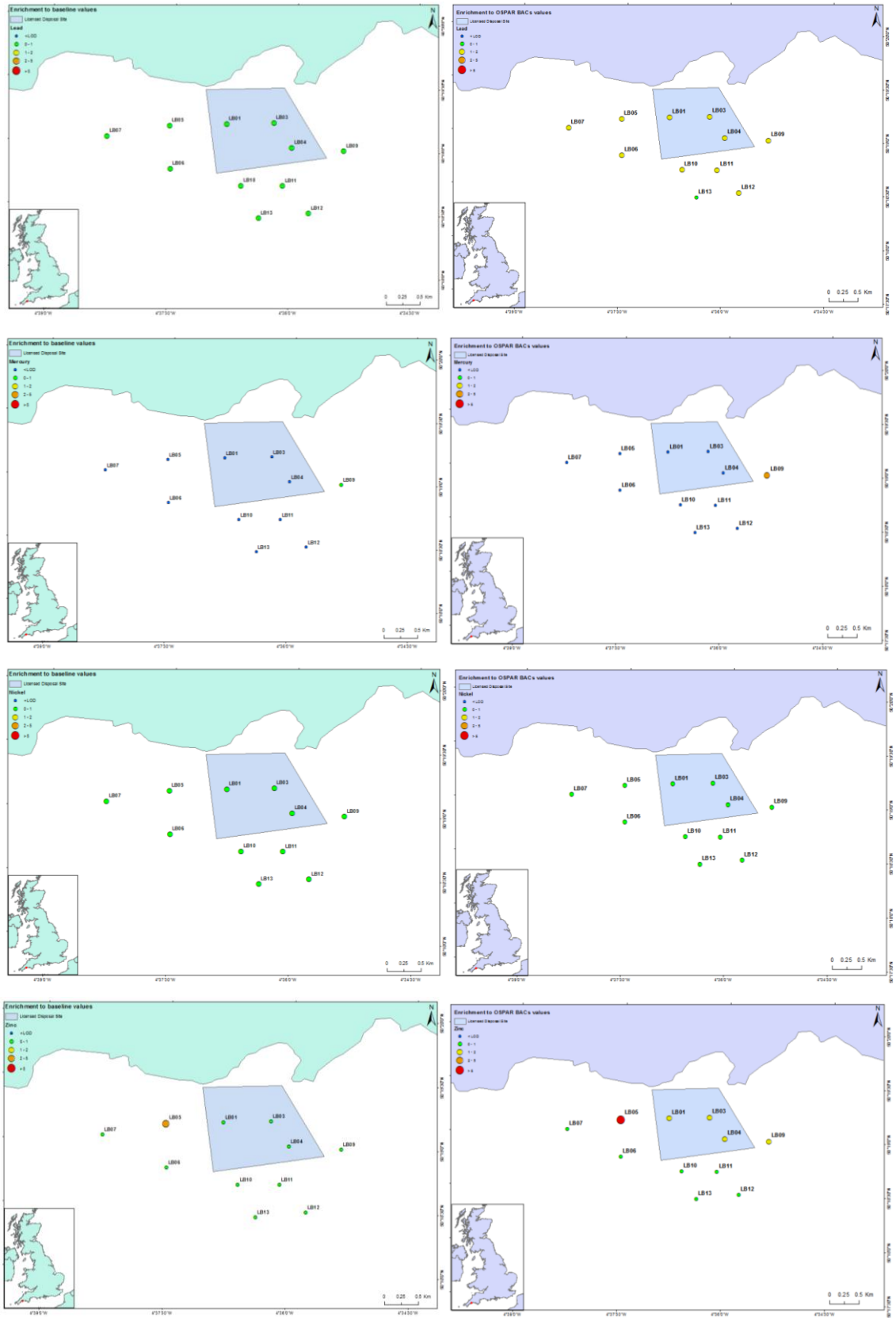


Figure A1.5.11. Continued.

Appendix 2. Assessment methods for sediment contaminants

2.1 PAHs

2.1.1 Methodology

Sediment samples, collected in glass jars, were frozen immediately after collection and not defrosted until required for analysis. Each homogenised wet sediment sample was extracted using alkaline saponification followed by liquid/liquid extraction. A sample of sediment was taken for a total solids determination as all results are reported on a dry weight (DW) basis. The sample extract was then passed through an alumina chromatography column in order to remove polar compounds, concentrated to 1 ml and sealed in a vial. A suite of alkylated and parent PAH were then determined using coupled gas chromatography/mass spectrometry (GC/MS). Quantification was by means of deuterated internal standards added prior to digestion, with analytical quality control samples being run within each sample batch. Full details can be found in Kelly et al. (2000).

2.1.2 Method used for assessment

Cefas currently has action level limits for contaminants such as trace elements and PCBs but none currently exist for PAHs. Reviews of what has been investigated in other countries has indicated that the most promising of the currently available co-occurrence methods is the Effects Range Low/Effects Range Median (ERL/ERM) methodology which is founded on a large database of sediment toxicity and benthic community information (Long et al., 1998).

The ERL/ERM methodology derives SQGs representing, respectively, the 10th and 50th percentiles of the effects dataset and can be derived for individual PAH compounds. In a regulatory context, where SQGs are to be used as informal (non-regulatory) benchmarks to aid in the interpretation of sediment chemistry (Long et al., 1998), this becomes complicated where a large number for individual PAH are determined, as is usually the case. This has led to separate ERL/ERM derived SQGs being set for “Low molecular weight PAHs” and “High molecular weight PAHs”. In this context;

LMW PAHs include 2- and 3-ring PAH compounds;

- Naphthalene
- monomethyl naphthalenes
- acenaphthene
- acenaphthylene
- fluorine
- phenanthrene
- anthracene

HMW PAHs include the 4- and 5-ring PAH compounds;

- fluoranthene
- pyrene
- benz[*a*]anthracene
- chrysene
- benzo[*a*]pyrene
- dibenz[*a,h*]anthracene

Although a wider suite of PAH is determined routinely for both licensing and monitoring purposes, these can be considered as toxicity markers for the PAH as a whole. The ERL and ERM concentrations applied are given in Table A2.1.1.

Table A2.1.1. ERL and ERM concentrations for LMW and HMW PAHs in sediments. The limits for LMW PAH are lower than those for HMW PAH as they carry a higher acute toxicity.

PAH compounds	**ERL** (µg kg^{-1} DW)	**ERM** (µg kg^{-1} DW)
LMW PAH	552	3,160
HMW PAH	1,700	9,600

2.2 Organohalogens

2.2.1 Sample extraction

Sediment samples were air dried and sieved (<2mm) in a controlled environment. 10 g of dried sediment were mixed with sodium sulphate, transferred to a glass Soxhlet thimble and topped with 1 cm of sodium sulphate. $^{13}C_{12}$-labelled BDE209, HCB, alpha-HCH, gamma-HCH, *p,p'*-DDT, CB28, CB52, CB101, CB118, CB138, CB153 and CB180 was added as internal recovery standard to all samples prior to the extraction step. Samples were extracted over a 6 h period using 50:50 iso-hexane:acetone, with an average of 9 - 10 cycles h^{-1}. Sulphur residues were removed at this stage with copper filings.

2.2.2 Sample extract clean-up

An aliquot of the Soxhlet extract was cleaned up and using alumina (5% deactivated) columns. The elute contained polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs) and polybrominated diphenylethers (PBDEs).

2.2.3 Analysis of PCBs and OCPs by GC-MS/MS

After addition of internal standard CB53 and CB112, PCB and OCP concentrations were determined with an Agilent 7890A GC coupled with 7000 QQQ-MS/MS in positive electron impact mode (ESI+). The separation of analytes was performed using two 25.0 m × 200 µm, 0.33-µm-film-thickness DB-5 capillary columns (J&W) with a backflush system installed. The carrier gas and collision gas were helium (1.4ml/min) and nitrogen (1.5ml/min), respectively. The initial oven temperature was 90°C, held for 2.00min, then increased to 165°C at 15°C/min, to 285°C at 2°C/min, to 310°C at 40°C/min and finally held for 10 min, with the column backflush instigated when the oven reached 285°C (total run time 71.7 mins). The injector temperature, ion source and quadrupole temperatures were 270°C, 280°C and 150°C, respectively. A 1-µl extract was injected in pulsed-splitless mode with a purge time of 2 min.

2.2.4 Analysis of PBDEs by GC-MS/MS

After addition of internal standard CB200, PBDE concentrations were determined with a Shimadzu 2010plus GC with TQ8030 QQQ-MS/MS in positive electron impact mode (ESI+). The separation of analytes was performed on a 15.0 m × 250 µm, 0.15-µm-film-thickness Rtx-1614 capillary column (Restek). The carrier gas was helium (1.28ml/min) and the collision gas was argon. The initial oven temperature was 120°C, held for 1.00min, then increased to 275°C at 15°C/min, to 300°C at 50°C/min, and finally held for 5 min. The injector temperature and source temperature was 340°C and 230°C, respectively. A 2-µl extract was injected in pulsed-splitless mode with a purge time of 2 min.

2.2.5 Analysis of BDE209 by GC-MS

BDE209 concentrations were determined with an Agilent 6890 GC with 5973 MS in NCI mode. The separation of analytes was performed on a 15.0 m x 250 µm, 0.1-µm-film-thickness DB-1 capillary column (J&W). The carrier gas was helium (1.3ml/min constant flow, average velocity 59 cm/s) and the reagent gas was methane (40 psi). The initial oven temperature was 90°C, held for 1.00min, then increased to 200°C at 25°C/min, to 295°C at 10°C/min, and finally held for 20 min. The injector temperature and detector temperature was 250°C and 200°C, respectively. A 2-µl extract was injected in pulsed splitless mode with a 20psi pulse until 1 min and a purge time of 2 min.

2.2.6 Quantitation methods

The identification of PCBs and OCPs was based on the retention time of individual standards in the calibration mixtures. Quantitation was performed using internal standards and 9 calibration levels (range 0.1 – 200 ng/ml). The combined PCB and OCP standard solutions contained the following 41 compounds in iso-octane: Hexachlorobenzene; hexachlorobutadiene, alpha-HCH, beta-HCH, gamma-HCH, *p,p'*-DDE, *p,p'*-TDE, *p,p'*-DDT, *o,p'*-DDE, *o,p'*-TDE, *o,p'*-DDT, dieldrin, heptachlor, heptachlor epoxide, endosulfan-I, endosulfan-II, endosulfan sulfate; IUPAC CB101; IUPAC CB105; IUPAC CB110; IUPAC CB118; IUPAC CB128; IUPAC CB138; IUPAC CB141; IUPAC CB149; IUPAC CB151; IUPAC CB153; IUPAC CB156; IUPAC CB158; IUPAC CB170; IUPAC CB18; IUPAC

CB180; IUPAC CB183; IUPAC CB187; IUPAC CB194; IUPAC CB28; IUPAC CB31; IUPAC CB44; IUPAC CB47; IUPAC CB49; IUPAC CB52; IUPAC CB66. Concentrations were corrected for the recovery of the $^{13}C_{12}$ labelled recovery standards.

Quantitation for PBDEs was performed using internal standards and 10 calibration levels (range 0.05 – 100 ng/ml). The PBDE standard solutions contained the following 11 compounds in iso-octane: IUPAC BDE17; IUPAC BDE28; IUPAC BDE47; IUPAC BDE66; IUPAC BDE100; IUPAC BDE99; IUPAC BDE85; IUPAC BDE154; IUPAC BDE153; IUPAC BDE138; IUPAC BDE183; plus an additional 13 compounds: IUPAC BDE3; IUPAC BDE7; IUPAC BDE15; IUPAC BDE49; IUPAC BDE71; IUPAC BDE77; IUPAC BDE119; IUPAC BDE126; IUPAC BDE156; IUPAC BDE184; IUPAC BDE191; IUPAC BDE196; IUPAC BDE197; together with the internal standard IUPAC CB200 and recovery standards F-BDE69 and F-BDE-160. Concentrations were corrected for the recovery of the F-BDE recovery standards.

Quantitation of BDE209 was performed using an internal standard and 7 calibration levels (range 0.5 – 500 ng/ml). The BDE209 standard solutions contained IUPAC BDE209 in iso-octane, plus an additional 3 compounds IUPAC BDE206; IUPAC BDE207; IUPAC BDE208; together with the internal standard $^{13}C_{12}$- labelled IUPAC BDE209.

2.2.7 Quality assurance/ quality control procedures

AQC procedures included reagents purification, method blanks, and use of control charts created from repeated analysis of the NIST-1944 Certified Reference Material (CRM) and Quasimeme CEMP-245 materials.

2.2.8 Method used for assessment

PCB, OCP and BDE concentrations were determined in the sediments and reported on a dry weight basis. The ∑ICES 7 CBs (CB28, CB52, CB118, CB153, CB138, CB170, CB183), and the sum of all 25 measured CBs (∑CBs) were calculated, together with ∑DDTs (*p,p'*-DDE, *p,p'*-TDE, *p,p'*-DDT, *o,p'*-DDE, *o,p'*-TDE, *o,p'*-DDT). Where individual congener concentrations were below the limit of detection (LOD) of 0.01 µg/kg, a value of half the LOD was inserted for calculation of summed concentrations. The ∑11 BDEs were calculated. Where individual congener concentrations were below the LOD of 0.02 µg/kg, a value of half the LOD was inserted for calculation of summed concentrations. For samples analysed prior to 2015, a different LOD applied, resulting in higher values substituted for congeners below LODs. The congener patterns were evaluated, with BDE183 a marker constituent of the octa-BDE technical mix, and the other BDEs constituents of the penta-BDE technical mix. Additionally, BDE209 ("Deca BDE") concentrations were calculated. Where BDE209 concentrations were below the LOD of 0.1 µg/kg, a value of half the LOD was inserted.

The Total Organic Carbon (TOC) content in the <2 mm fraction determined at a number of representative sampling stations was used to additionally calculate the contaminant concentration normalised to 2.5% TOC

content. The TOC data from the representative stations was used to estimate the TOC content at adjacent stations for which this value was lacking.

Concentrations of PCBs and OCPs in the sediment were compared with various action limits, to investigate whether any adverse effects in benthic biota were likely to expected as a consequence of their presence. There are no action limits available to compare PBDE concentrations with at the present. Concentrations are expressed on a dry weight basis unless otherwise stated.

The current Cefas action limits for dredge disposal are: PCBs Action level 1 if ∑ICES7 CBs > 10 µg/kg or ∑CBs > 20 µg/kg and action levels 2 if ∑CBs > 200 µg/kg; OCPs Action level 1 if ∑DDTs > 1 µg/kg, dieldrin > 1 µg/kg, no Action level 2 for either ∑DDTs or dieldrin. Concentrations are expressed on a dry weight basis.

OSPAR in Charting Progress2 (CP2) have set criteria for Background Assessment Concentrations (BAC) and Environmental Assessment Concentrations (EAC) for the ICES7 CBs in sediments (see Table A2.2.1). Concentrations are expressed in µg/kg dry weight normalised to 2.5% organic carbon. Concentrations below BACs would be considered to have high environmental status. Concentrations significantly below EACs could be considered to have good environmental status and those above, bad environmental status. The station is deemed to have 'bad' environmental status if 'bad' status occurs for more than one ICES7 CB congener.

Table A2.2.1. OSPAR assessment criteria for CBs in sediment from CP2.

Sediment (µg/kg dry weight, normalised to 2.5% TOC)		
Compound	**BAC**	**EAC**
CB28	0.22	1.7
CB52	0.12	2.7
CB101	0.14	3.0
CB118	0.17	0.6
CB138	0.15	7.9
CB153	0.19	40
CB180	0.10	12

2.3 Trace Metals

2.3.1 Methodology

The sediment samples were collected in plastic bags and were frozen immediately after collection. The samples were collected for PSA and metal analyses on the <63µm fraction. Details on obtaining the <63µm sediment fraction can be found in the Particle Size Analysis technical report.

The sample is digested in a mixture of hydrofluoric, hydrochloric and nitric acids using enclosed vessel microwave, the digest is made up in 1% nitric acid and further diluted prior to analysis by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma-Mass Spectroscopy (ICP-AES). Quantification of Al, As, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Rb and Zn is done using external calibration with Indium as internal standard. A certified reference material is run within each sample batch for quality control. Results are reported in mg kg^{-1} (ppm).

Some samples contained insufficient silt/clay (<63µm) for trace metals determination. Values lower than the detection limits were omitted from the dataset. This is because several detection limits were higher than real values, causing spurious elevations.

2.3.2 Numerical assessments

2.3.2.1 Raw data

Two approaches were carried out on the raw data:

1. Data comparison between the stations located inside the disposal sites and those that are situated outside the disposal site. The average concentration is obtained over a number of years and sites to allow data comparison. This data is averaged and so might not reflect the true observed trend for individual stations.
2. Temporal trend is also assessed for stations within the disposal sites and outside the disposal site. The average concentration is calculated for each year to carry out temporal trend analysis.

2.3.2.2 Enrichment factors

In order to assess relative level of trace metal contamination for a sampled station, enrichment to a baseline is required. This report presents two assessment methods; (i) comparisons with OSPAR Background Assessment Concentrations (BACs) as in previous reports, and (ii) comparisons with regional baseline concentrations.

Enrichment ratio is defined as:

$$\frac{\text{Metal raw value}}{\text{OSPAR BAC or proposed baseline value}}$$

Enrichment is arbitrary defined in 4 levels:

0-1: no enrichment

1-2: slight enrichment

2-5: moderate enrichment

>5: high enrichment

The two assessment methods are detailed below (but refer to Cefas (2011) for a fuller explanation).

2.3.2.2.1 OSPAR BACs

OSPAR (BACs) are defined for Clean Seas Environment Monitoring Programme (CSEMP) assessment to determine temporal trends in concentrations (OSPAR, 2008). They are derived from Background Concentrations (BCs) which are based on concentrations recorded in 'pristine' areas.

Normalisation of metal concentrations is required to account for differences caused by different sediment types present in the area surveyed. Normalisation of the metal concentrations to 5% aluminium using a pivot point is completed to derive the OSPAR BACs, using pivot point data defined in the assessment manual for contaminants in sediment and biota (OSPAR, 2008). Aluminium and lithium are both commonly used to normalise metal concentrations. Correlations between all trace metals, at each site, were completed to determine the best normaliser to use.

For most sites, there were no clear correlations between the trace metals and correlations values of aluminium and lithium indicate that the relationship between the normaliser and trace metals was not strong enough to endorse the use of Al or Li for normalisation.

As trace metal concentrations used for in this study were measured on the fine fraction of sediment (<63µm), normalisation to some extent has already been completed, therefore all enrichment calculation were based on the raw data.

2.3.2.2.2 Regional baselines

The above-mentioned Background Concentrations (BCs) are based on concentrations recorded in 'pristine' areas. There is only one set of values assigned by OSPAR for the whole North Atlantic (http://www.ospar.org). However, trace metal concentrations are known to show regional variation in the UK, largely related to the variable geology around the coast and historical industrial activity in the early 19th Century which has caused localised elevated levels (Ridgeway et al, 2003; Rowlatt and Lovell, 1994; Cefas, 2005). Therefore, for assessing enrichments at disposal sites, Cefas have developed regional baselines utilising various spatial datasets around

England and Wales. Recently, an extensive study was carried out on 8 regions defined in the Clean Seas and Environment Programme (CSEMP) (Figure A2.3.1) and the proposed metals baselines concentration derived from this study have additionally been used in this report as a validation tool to i) compare with OSPAR BACs values, and ii) to assess the credibility of using those proposed baselines values instead of the OSPAR BACs values when studying for metals enrichment. The proposed baselines for the areas are given in Table A2.3.1, along with the corresponding OSPAR BACs values for each metal (OSPAR, 2006).

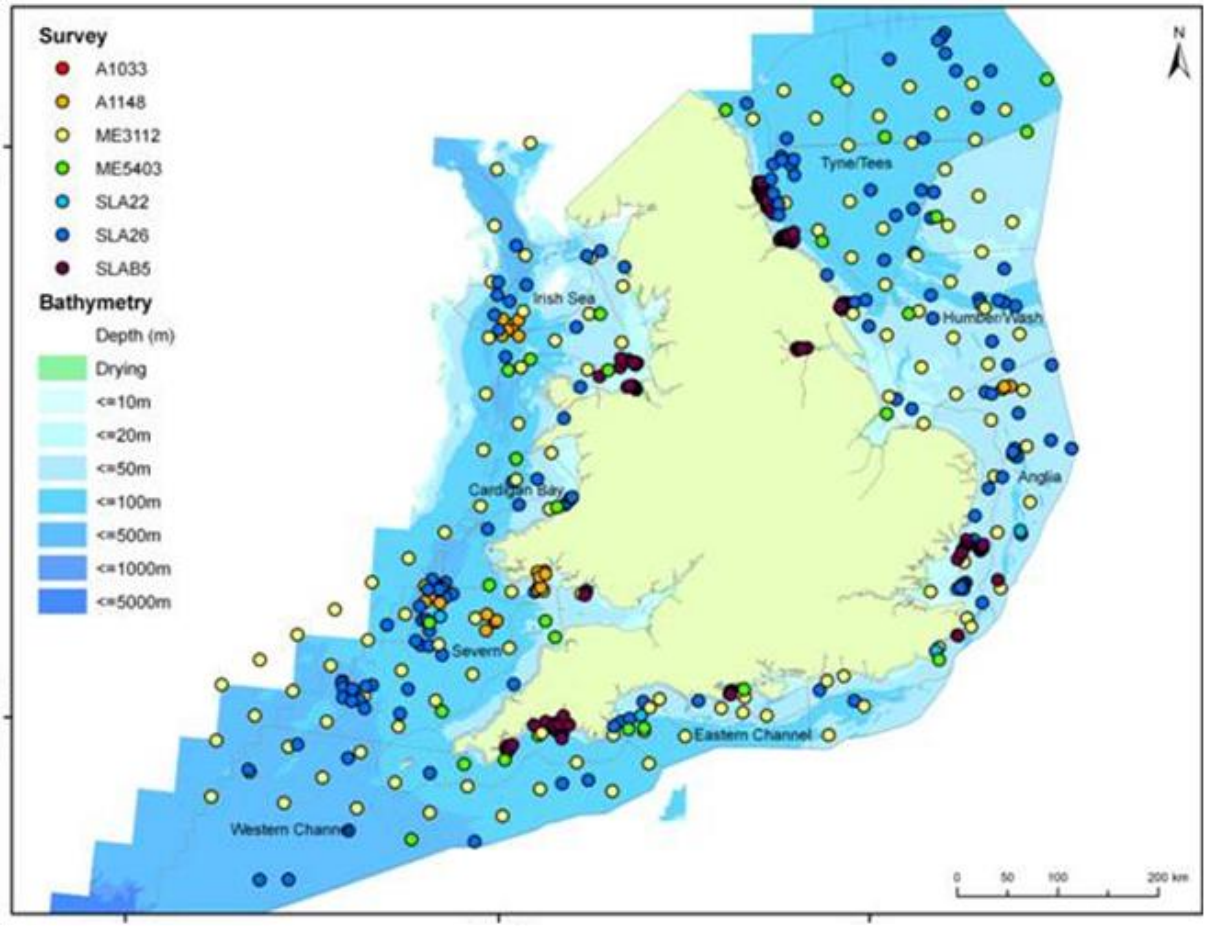


Figure A2.3.1. Location of stations sampled to provide metals data as part of the regional baseline approach.

Table A2.3.1. OSPAR BACs (in red) with proposed baselines for regions covered in disposal site assessment under C6794.

	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Anglia	33	0.2	115	40	0.16	56	46	130
Cardigan Bay	26	0.29	103	26	0.12	44	73	145
Eastern Channel	23	0.18	90	26	0.12	31	45	107
Humber Wash	30	0.17	109	31	0.21	44	67	129
Irish Sea	21	0.29	115	38	0.43	47	77	240
Severn	21	0.2	81	27	0.1	36	47	135
Tyne/Tees	27	0.31	135	29	0.35	55	131	171
West Channel	34	0.19	105	72	0.77	50	108	153
OSPAC BAC	25	0.31	81	27	0.07	36	38	122

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