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Dredged Material Disposal Site Monitoring Round the Coast of England: Results of Sampling (2017-18)

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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 1.2) project (C6794 hereafter) round the coast of England during 2017-18.
- 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. none site-specific) level.
- Five disposal sites were targeted for assessment during 2017; Harwich Haven (Greater Thames Estuary), North Edinburgh Channel in the Outer Thames Estuary, Nab Tower off the Isle of Wight, Plymouth Deep (southwest) and Barrow-in-Furness (northwest).

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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' Science for Sustainable Marine Management (SSMM) 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 currently 173 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 project 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' SSMM team and case licensing officers within the MMO. The scientific outcomes of the work undertaken within C6794 are circulated to the Cefas SSMM 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 2017-18, is the 9th in the series. The previous reports 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 2017-18 are listed in Table 1.1. These sites were identified following consultation between Cefas' SSMM 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 2017-18.

Disposal site	**Geographical location off English coast**	**Code**
Harwich Haven	East	TH027
North Edinburgh Channel	Southeast	TH080
Nab Tower	South	WI060
Plymouth Deep	Southwest	PL035
Barrow-in-Furness	Northwest	IS205

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' SSMM 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 2017-18 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 2017-18 results with those of previous years to provide a temporal assessment (see Bolam et al., 2009; 2011a; 2012a; 2012b; 2014b; 2015a; 2015b; 2016b and 2017 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; 2015a; 2015b; 2016b; 2017), the conclusions regarding each site are contained within Section 2 (below). More detailed scientific data (e.g., acoustic, sediment particle size, organic carbon, macrofauna, contaminants) for each site, together with their interpretation, are presented in Appendix 1. For background information regarding each disposal site monitored, the reader is directed towards this appendix.

2 Conclusions and implications for further monitoring

The main findings of the monitoring undertaken during 2017-18 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 Harwich Haven (TH027)

Harwich Haven (TH027) is a new disposal site, recently characterised by the Harwich Haven Authority (HHA), designated as 'open' on a trial basis by the MMO. The site lies off the entrance to the main navigation channel to the ports of Harwich and Felixstowe, 9 km further inshore than the existing Inner Gabbard disposal site (TH052).

The MMO recently granted HHA a marine licence (L/2013/00392/3) to undertake two trial disposals at Harwich Haven during June 2016 (470,786 m^3) and August 2016 (455,761 m^3) of dredged material arising from maintenance dredging at Harwich and Felixstowe Harbour. As part of the licence condition, HHA was required to conduct monitoring during and after these disposal campaigns for turbidity/suspended sediment concentrations, seabed sediment deposition using bathymetry and sediment traps, and benthic sampling for benthic community impacts (HRW, 2017). Cefas monitoring at this site under C6794 during 2017 aimed to acquire data to provide an independent assessment of the acoustic and macrofaunal monitoring conducted on behalf of HHA.

A comparison of the September 2016 bathymetric data acquired on behalf of HHA with those of Cefas, acquired during July 2017, showed great concordance. The range in depth across the site was 20.66 to 22.65m (CD). It was possible to infer that there are regions that appear deeper in 2016 than in 2017, however, these were within errors associated with data acquisition and are, therefore, likely to be inconsequential and/or artefactual.

The Cefas 2017 backscatter data revealed a discrete, elongate patch of higher intensity reflection is present across the centre of the surveyed area, orientated southwest to northeast. This patch of stronger reflectivity is associated with a 'trough-like' depression revealed by the bathymetric data. Lower intensity reflections are noted to the west and east of the central trough, with two discrete patches of very low intensity reflection located to the north of the surveyed area. These areas of lower intensity reflectivity are associated with small bedforms (ripples) oriented southwest to northeast.

The macrofaunal communities were assessed based on 20 grab stations (in triplicate) located both inside the disposal site and across the wider area. The assemblages of all stations were dominated by polychaetes, followed by crustaceans and bivalves. Total abundance and biodiversity (species richness, Margalef diversity, and species evenness) of macrofauna within the disposal site were within the ranges observed for the wider area. Macrofaunal communities at three of the four stations within the dredge disposal site clustered together (i.e., share common taxa as evidenced by multivariate numerical techniques) with communities sampled at stations distributed across most of the surveyed area. The fourth station within the disposal site clustered with a different group of stations, which differed from the former cluster mainly in that the latter had lower abundances of the reef-forming polychaete *Sabellaria spinulosa*. These observations do not indicate any clear effects of dredge disposal on benthic communities and are consistent with the findings of previous surveys of the site conducted on behalf of HHA.

2.2 North Edinburgh Channel (TH080)

The North Edinburgh Channel disposal site is located along a relatively narrow, shallow channel in the Thames Estuary, north of Ramsgate. The site was opened in 2004 with the first dredged material being disposed in 2006 (125,663 wet tonnes), followed by a relatively large amount in 2007 (1,340,454 wet tonnes) and finally the most recent disposal being carried out in 2008 (277,684 wet tonnes). There have been issues raised regarding the shallowing of this site; a particular concern as the channel offers a viable passage from the Essex estuaries to the north Kent coast for leisure yacht and motor-cruisers.

Presently, the MMO are processing a marine licence application from the Port of London Authority (PLA) for the disposal of approximately 6.23 Mt (wet) of dredged material from Knock John, West Oaze and Black Deep for possible disposal to TH080. This would represent a 10-year licence for the dredging and disposal of maintenance material for the site which has not received material since 2008. In view of this, the MMO required Cefas to undertake a baseline survey of the bathymetric characteristics of the site and its immediate environs from which any subsequent physical changes associated with this potential licence may be assessed.

When compared with previous data and published charts, the Cefas data indicate that the North Edinburgh Channel has been subject to significant bathymetric change over the last 20 years. This change is manifested by marked shifts north-eastwards of the main channel, which are distinct over periods of ten years. In the shorter term (i.e. 2015 to 2017), small shifts southwards of the main channel contours are detectable, although these changes are within accuracy tolerances of the comparison process. A notable expansion in area within the 15 m contour (i.e. the central deep section of the channel) has been identified as a result of a significant shift westwards of the 15 m contour. These findings may be used to inform decisions regarding the potential need to revise the exact location of the boundary of the dredged material disposal licenced area. Furthermore, these data form a valuable baseline from which any bathymetric changes associated with potential increased depositions of (capital) material may be assessed.

2.3 Nab Tower (WI060)

Nab Tower is a well-used disposal site in 30 to 40 m water depth and approximately 13 km southeast of Bembridge, Isle of Wight. The site is the main recipient of both maintenance and capital material from ports, harbours, berths and navigational channels in Southampton, Portsmouth and the Isle of Wight. In recent years there have been several licences granted for large volumes of capital material at this site. Notably, a licence for the deepening of the Portsmouth approach channel permitted up to approximately 6 million tonnes (wet weight) of clay, gravel, sand and silt material to be deposited at the site between 2015 and 2017.

Cefas last surveyed Nab Tower in 2014, when a significantly large capital dredge and disposal camping was underway. The 2014 acoustic survey of the area was complemented with macrofauna samples from within and around the disposal area (Bolam et al. 2015; Bolam et al. 2016). The 2014 survey results showed that dredge material remained on the seabed within the disposal area (from the acoustic survey) and negatively impacted the benthic community within the disposal area, although there was no evidence impacts were apparent beyond the disposal boundary. The 2017 Cefas survey reported here, wherein macrofaunal assemblages for 18 stations within and surrounding the disposal site were assessed, was conducted towards the end of the disposal of the recent capital campaign. These data aim to characterise the area to describe the breadth and scale of impact associated with that campaign.

The most abundant taxon sampled across the whole survey area was the crustacean *Ampelisca diadema* (1438 individuals from all samples), however this species was unevenly distributed, only occurring in nine samples with the vast majority being from the three samples at one station. The second most abundant taxon (1107 individuals), the bivalve *Abra alba,* was more ubiquitous occurring in 30 samples, however almost half of this abundance was accounted for from the three samples at one station. The most commonly encountered taxon was the polychaete species *Lumbrineris cingulata*, found in 43 samples at an average abundance of six individuals per ($0.1m^2$) sample. In general, there was a clear trend of lower species number, abundance and biomass at the stations within and close to the disposal site.

Multivariate analyses based on taxonomic abundance (transformed) data revealed that the assemblages of the 18 stations could be significantly delineated into six distinct faunal assemblage clusters. The assemblage clusters of the stations inside the licenced boundary were generally distinct from the more diverse and more densely-populated assemblages outside the site. The benthic assemblages observed in the 2017 were generally similar to those in 2014. Additionally, the stations from within the disposal site for both 2014 and 2017 grouped close to each other on a multivariate ordination plot of all stations, demonstrating that the benthic community present at the disposal site has remained taxonomically-similar over this period.

The 2017 data acquired under C6794 provide a valuable dataset of the assemblages within Nab Tower at the end of a large capital disposal campaign. Unlike those of disposal sites which predominantly receive maintenance material on a year-on-year basis, temporal changes in the assemblages of Nab Tower are less predictable as relatively few studies have focussed on recovery from large capital deposits. In this respect, we would regard future sampling at the same stations sampled in 2014 and 2017 at Nab Tower in subsequent years justifiable. The data acquired and intelligence gleaned from this would offer advances in our predictive capability of the recovery following such large deposits.

2.4 Plymouth Deep (PL035)

Plymouth Deep is a recently-designated dredged material disposal site that was characterised to provide a sustainable location for receiving material resulting from dredging operations within the River Tamar and Plymouth Sound area. The 1.5 km by 1 km site, located in 49 to 50 m (Ordnance Datum Newlyn, or ODN) of water, is located south of Plymouth and the entrance to the Tamar Estuary, around 9 km southwest of the Plymouth breakwater.

In situ observations of the suspended solids concentrations (or SSC) resulting from the disposal of dredged material at Plymouth Deep during May 2017 and relevant modelling approaches were combined to provide a better understanding of the potential impacts of disposal at the site, particularly at the Western Channel Observatory (WCO) pelagic monitoring station (also known as ‘L4’). Through conducting relevant comparisons with the model, the observational data were used to provide a better understanding of the modelling and, therefore, assess whether the model represents a reliable basis regarding predictions of future impacts and, as such, as a valid tool for setting disposal limits for the site.

The observations showed a response to the discharge and an increase in SSC; the modelling predicted the level of peak surface concentration (4 mg/l) to be 80 % of that observed (5 mg/l).

Thus, the modelling broadly predicted peak concentrations of suspended sediment. Some discrepancies, for example the duration of the increased suspended load, between the model prediction and observational data remain which are currently difficult to resolve. Natural variations in salinity and SSC in this region, which result from fluctuations in freshwater input from the Tamar, represent a particular problem to resolving issues associated with the capacity of the model to accurately predict these aspects of the sediment movement.

It is recommended that assessments of satellite imagery during periods of disposal and high SSC events at L4 should be conducted in future. This relatively low-cost approach, when coupled with ongoing monitoring conducted at L4, would enable a better understanding of the SSC recorded at the station and help afford a better estimate of likely acceptable maximum disposal volumes.

In addition to testing the accuracy of the predictive model for the site, full replicate (four) macrofaunal sample processing was conducted for fourteen sampling periods during 2016 and 2017 (seven in each year). These samples were acquired through the regular (more-or-less bimonthly) and ongoing monitoring programme of benthic assemblages at L4 conducted by Plymouth Marine Laboratory (PML) for the WCO. These data were used to assess potential macrofaunal impacts at the L4 benthic station resulting from the May 2017 disposal campaign.

Based on a number of univariate metrics of community structure, and abundance- and biomass-based multivariate analyses, there was no indication that the macrofaunal assemblages sampled at L4 during 2017 showed any deviation from those sampled in 2016. However, this assessment inherently pertained solely to the detection of potential impacts resulting from the disposal campaign conducted during May 2017; it cannot be used to provide an assessment of potential effects of ongoing disposals associated with the longer-term use of the site. On the assumption that Plymouth Deep is to be the recipient of routine material from the Plymouth region, it would seem prudent to sanction further comparable assessments of longer temporal periods (depending on the realised disposal regime).

2.5 Barrow-in-Furness (IS205)

The Barrow-in-Furness (IS205) dredged material disposal site is situated off Morecambe Bay on the northwest coast of England at an approximate depth of 20 m. Barrow-in-Furness was commissioned during 1991 in response to the need to dispose of a large volume (8 MT in total) of mixed capital material resulting from the lengthening and deepening of the access channel to Barrow Docks (Ware et al., 2010). The material was largely comprised of silt from the docks and dock entrances along with sand, gravel and clay from the approach channel. During subsequent years, this site has continued to receive small amounts of maintenance dredged material and, occasionally, small amounts of capital material (Ware et al., 2010).

The MMO have recently received a variation to an existing marine licence to grant the disposal of approximately 400,000 m^3 from Anchorsholme; Barrow-in-Furness offers the most suitable site for receiving this material. As this quantity represents a notable increase in capital material compared to recent years, the MMO considered it judicious to monitor possible impacts resulting from the disposal campaign. In 2017, sampling under C6794 targeted five stations which have previously been selected for comparable monitoring by Cefas during the 1990s and in 2007; two stations within the site and three along a transect to the west of the site. Triplicate samples for sediment particle size assessment and macrofaunal assemblages were sampled at each station.

The 2017 data revealed that the ongoing disposal of dredged material to Barrow-in-Furness appears to negatively impact the benthic assemblages within the disposal site. Assemblages are dominated by different taxa from those outside and exhibit lower abundance and numbers of species. The data imply that such impacts are not extended much further west (< 5 km) from the site (no data are acquired for other directions outside the site due to depth differences making such assessments problematic). This situation in 2017 concurs with the conclusions based on earlier data from the 1990s and from 2007. The 2017 data represent a suitable contemporary baseline from which the potential impacts resulting from any changes to the disposal regime at the site may be assessed. Specifically, continued sampling of macrofaunal assemblages following the large placement of capital material from Anchorsholme, if licenced, would appear prudent.

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Appendix 1: Results

1 Harwich Haven

1.1 Background

Harwich Haven (TH027) is a new disposal site, recently characterised by the Harwich Haven Authority (HHA) that has been designated as open on a trial basis by the MMO. The site lies off the entrance to the main navigation channel to the ports of Harwich and Felixstowe, 9 km further inshore than the existing Inner Gabbard disposal site (TH052). The MMO recently granted HHA a marine licence (L/2013/00392/3) to undertake two trial disposals during June 2016 (470,786 m^3) and August 2016 (455,761 m^3) of dredged material arising from maintenance dredging at Harwich and Felixstowe Harbour. As part of the licence condition, HHA was required to conduct monitoring during and after these campaigns for turbidity/suspended sediment concentrations, seabed sediment deposition using bathymetry and sediment traps and benthic sampling for the assessment of benthic community impacts (HRW, 2017). The aim of the monitoring was to provide the information necessary to inform the MMO's assessment of the suitability of the proposed new site for designation to receive future dredged material. The main findings were summarised as:

1. there was no evidence of any large-scale increase in suspended solids concentrations as a result of the disposal activity;
2. analysis of bathymetry showed very little evidence of seabed level changes in excess of 0.2 m (the quoted vertical accuracy of the MBES set-up used); and
3. there is no evidence of an increase in fine material resulting from the two trial disposal events. The disposal resulted in a change in the benthic invertebrate assemblages with an increase in opportunistic species. However, this change did not result in a departure from the previously-observed marine assemblage found on muddy sands and gravels in this region (HRW, 2017).

Monitoring at this site under C6794 during 2017 aimed to acquire data to allow validation of conclusions 2 and 3 above. To fulfil this, Cefas conducted a multibeam acoustic survey of the disposal site, with a small number of ground-truth samples, to allow the bathymetry and seabed sediments of the disposal site to be described. As the Cefas monitoring was undertaken during

July 2017, this information allows a comparison with that acquired by the HRW during September/October 2016 to determine the longer-term physical changes associated with the trial deposits. Additionally, a spatial survey of the macrofaunal assemblages (and associated sediment granulometry) within and at suitably-located stations surrounding the site (approx. 18 stations in total) was conducted.

1.2 Results

1.2.1 Sediment Particle Size

Sediments from Harwich Haven in 2017 were predominantly mixed sediments including gravelly mud and gravelly muddy sands, with some gravelly sands and muddy gravels (Table A1.1).

Table A1.1: Average sediment descriptions and statistics for each sediment group (using EntropyMax) at Harwich Haven, 2017.

Sediment group	Number of samples	Sample Type	Sediment description
Har1a	26	Polymodal, Very Poorly Sorted	Gravelly Mud
Har1b	5	Polymodal, Extremely Poorly Sorted	Muddy Gravel
Har1c	16	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand
Har2a	8	Trimodal, Very Poorly Sorted	Gravelly Sand
Har3a	5	Unimodal, Moderately Sorted	Gravelly Sand

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
Har1a	10.24	36.66	53.11	3.22	4.86	8.29	12.42	7.86
Har1b	34.05	26.59	39.36	4.11	4.43	5.53	7.17	5.35
Har1c	29.82	51.26	18.92	6.05	14.49	14.06	11.37	5.28
Har2a	29.27	65.07	5.66	2.62	11.17	35.99	13.80	1.49
Har3a	7.40	91.01	1.59	9.76	63.42	15.83	1.54	0.45

The spatial variation in the proportional representation (average of three replicates) of gravel, sand and silt/clay for each sampling station in 2017 is shown in Figure A1.1 and silt/clay content in Figure A1.2. In general, the pattern of sediment compositions was similar to that observed in the HRW characterisation report, although these are described as primarily "coarse sediments with mud" whereas the Cefas approach would be describe these as "mixed" to reflect the mud content. Although the silt/clay content shows a similar pattern to that reported in the HRW characterisation, the totals are higher with an average content of ~30 % compared with

11 %. This may, however, reflect the wider sampling grid and larger number of samples taken by HRW, although at D26 the silt/clay reported by HHA was ~25 % compared with 80 % in 2017. The same PSA methodology has been used as for the previous HRW survey. A detailed comparison has not been completed with datasets, and observations are based on visual assessment from report only.

Sample replicates for each sample code, ordered in position relative to disposal site, were assessed for variability by comparing sediment groups (Table A1.2) and silt/clay content (Figure A1.3). These show that generally for most stations sampled, replicates are in the same sediment group. Silt/clay content showed high variability between replicates at D25. Average standard deviation for replicates was ~8 %. This highlights the value of analysing all replicates for PSA at this site as opposed to basing all assessment on a single replicate.

Table A1.2: Sediment groups (derived using EntropyMax) for each sample code for replicates at Harwich Haven in 2017.

Position relative to disposal site	Sample code	2017_A	2017_B	2017_C
Inside	D08	Har1c	Har1a	Har1b
Inside	D10	Har1c	Har1b	Har1c
Inside	D11	Har1b	Har1c	Har1c
Inside	D12	Har1a	Har1a	Har1c
Near field	D24	Har1a	Har1a	Har1a
Near field	D25	Har1c	Har2a	Har1a
Near field	D26	Har1a	Har1a	Har1a
Near field	D27	Har3a	Har3a	Har3a
Near field	D28	Har1a	Har1a	Har1a
Near field	D29	Har1a	Har1a	Har1b
Intermediate north	D36	Har1a	Har1a	Har1a
Intermediate north	D37	Har1a	Har1a	Har1a
Intermediate north	D38	Har1c	Har1c	Har1c
Intermediate south	D39	Har2a	Har2a	Har2a
Intermediate south	D41	Har1a	Har2a	Har1a
Far field north	D42	Har1c	Har1c	Har1c
Far field north	D43	Har3a	Har3a	Har1c
Far field south	D45	Har1a	Har1c	Har1c
Far field south	D46	Har2a	Har2a	Har2a
Intermediate southeast	D58	Har1b	Har1a	Har1a

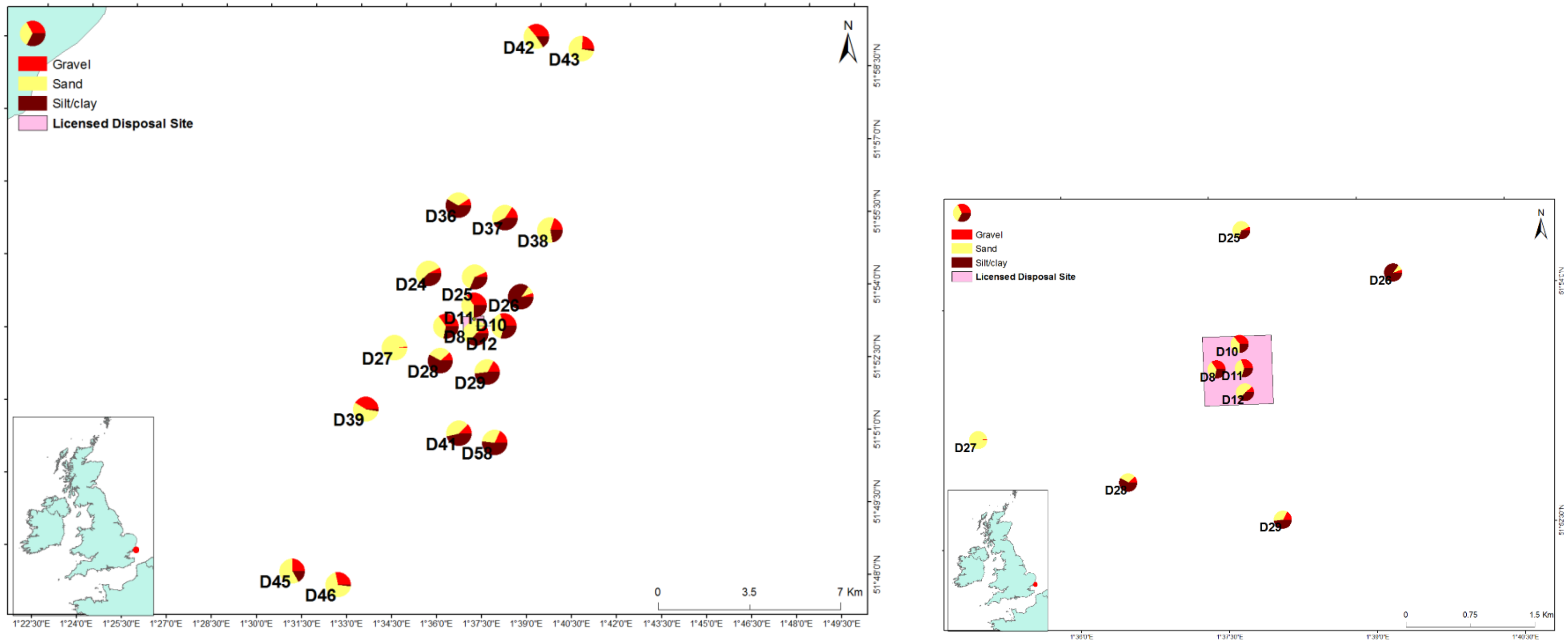
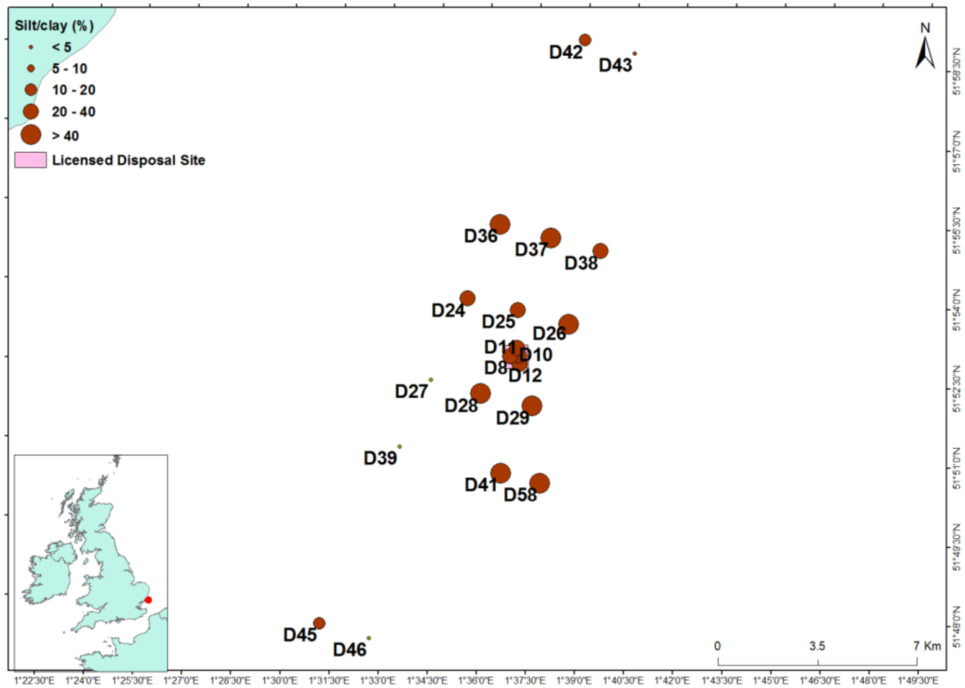


Figure A1.1: Pie charts of gravel, sand and silt/clay at Harwich Haven in 2017. Enlargement of disposal site area included as a separate map.



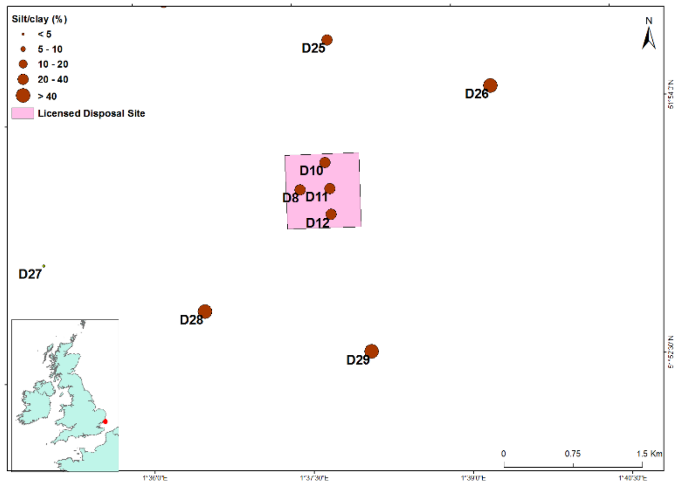


Figure A1.2: Silt/clay content (%) of sediments sampled at Harwich Haven in 2017. Enlargement of disposal site area included as a separate map.

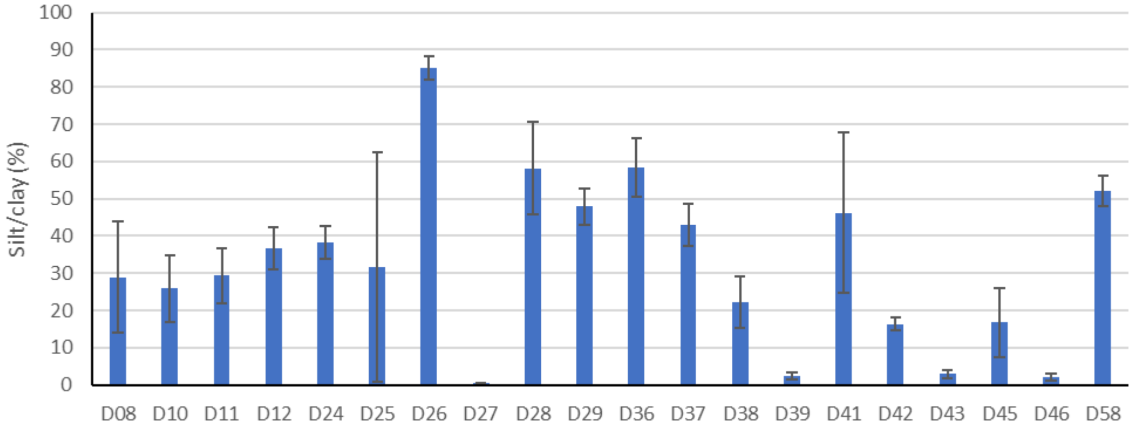


Figure A1.3: Silt/clay content (%) of sediments sampled at Harwich Haven in 2017. Error bars indicate standard deviation of replicates.

1.2.2 Multibeam bathymetry and backscatter

An acoustic survey of the Harwich Haven disposal site was undertaken using the vessel RV *Cefas Endeavour*. Multibeam echosounder (MBES) data were acquired using a Kongsberg EM2040 system. MBES bathymetry data were processed using CARIS HIPS and SIPS v9.08 to produce a cleaned bathymetric surface corrected to Chart Datum (Figure A1.4). The MBES backscatter data were processed using QPS Fledermaus Geocoder ToolBox v7.4.3 to produce a cleaned backscatter mosaic. Maps were then produced using ArcGIS v10.5. Sediment samples for Particle Size Analysis (PSA) were also taken from four locations within the licence area, which corresponded with previously surveyed locations (2012 and 2016; see previous section). The data acquired by Cefas were then compared with those obtained by HRW during their third survey (September 2016) of the monitoring conducted for the trial disposal campaign. The comparison of the two datasets was used to describe changes in seabed bathymetry and bed type within the disposal site.

1.2.2.1 Description of Current Bathymetry

The MBES bathymetric data acquired by Cefas cover an area (925 m x ~1,000 m) of seabed, thus providing 100 % coverage of the proposed licence area. Overall, a small variation in depth, from 20.5 m CD to 22.65 m CD, was observed across the surveyed area. These MBES data (Figure A1.4) indicate that the southwestern section of the disposal site shows the greatest depth

(~22.58 m CD). A depression extends throughout the centre of the site, shoaling to the northwest (Figure A1.4). The deeper 'trough-like' central section is between 22.49 m and 21.5 m CD deep and is surrounded by an area of raised bathymetry to the northwest with a gradual, shallow slope rising to depths of between 21.49 and 20.50 m CD. Indications of similar shoaling were observed to the northeast and southeast of the central section. A cross sectional depth profile of the site, from the northwest to the southeast corners, illustrates the trough and the low gradient of the bathymetric changes described (Figure A1.5).

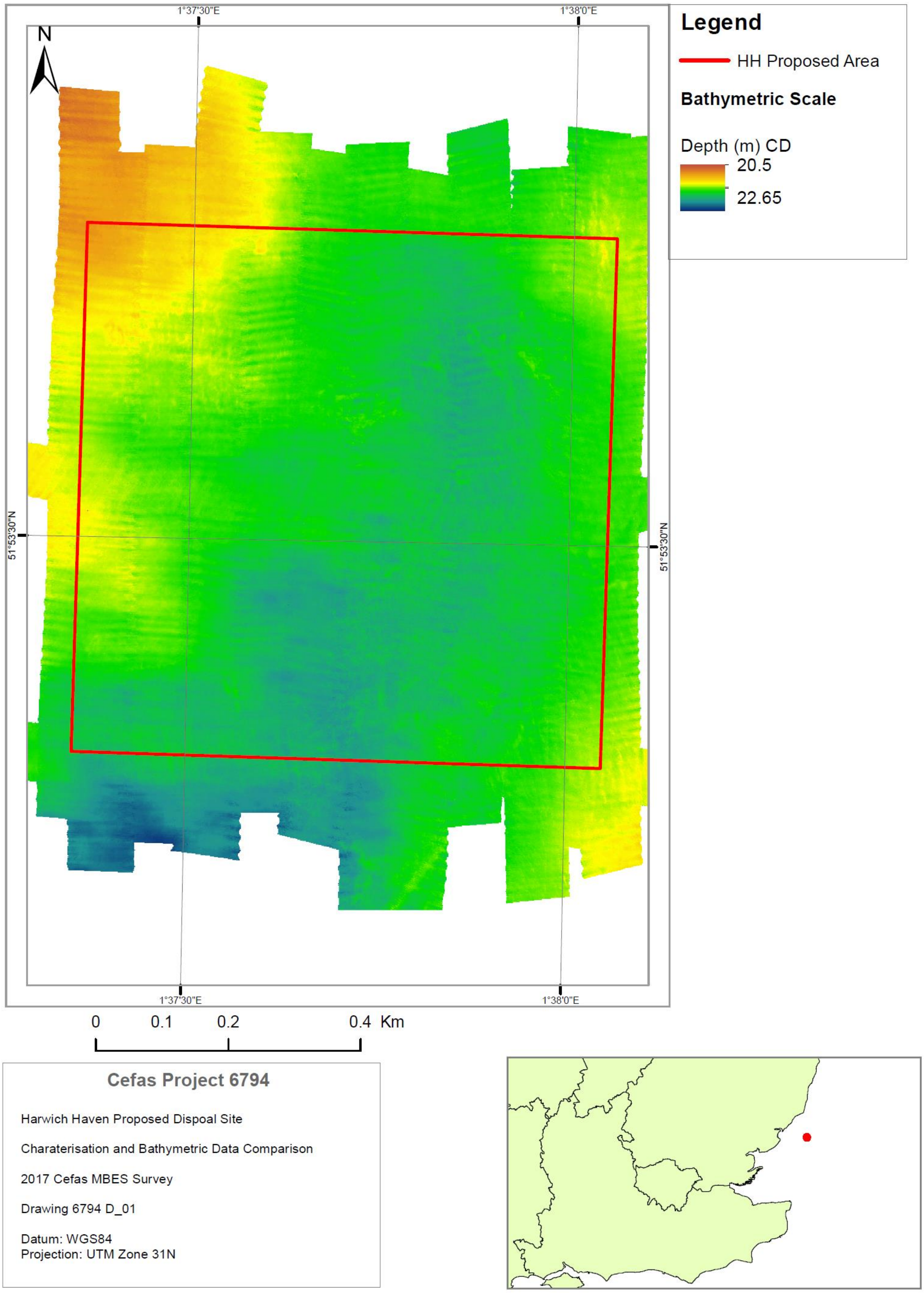


Figure A1.4: MBES bathymetry data acquired (2017) at Harwich Haven. Depth in meters relative to Chart Datum (CD).

Figure A1.5: Cross sectional bathymetric profile of Harwich Haven. The profile was run diagonally across the site, from the northwest corner to the southeast corner.

Slope calculation has been undertaken for the entire surveyed area (Figure A1.6, from northwest to southeast) using ArcMap 10.5. The western flank slope can be identified as ~800 m in length, with a depth change of 20.7 m CD to 22.03 m CD (i.e., - 1.33 m). As such, the average slope angle can be calculated as 0.733°, however, mapping of the slope variation (Figure A1.6) across the surveyed area indicates an increase in slope angles associated with the eastern flank of the central trough, with an average slope value of 1.16°.

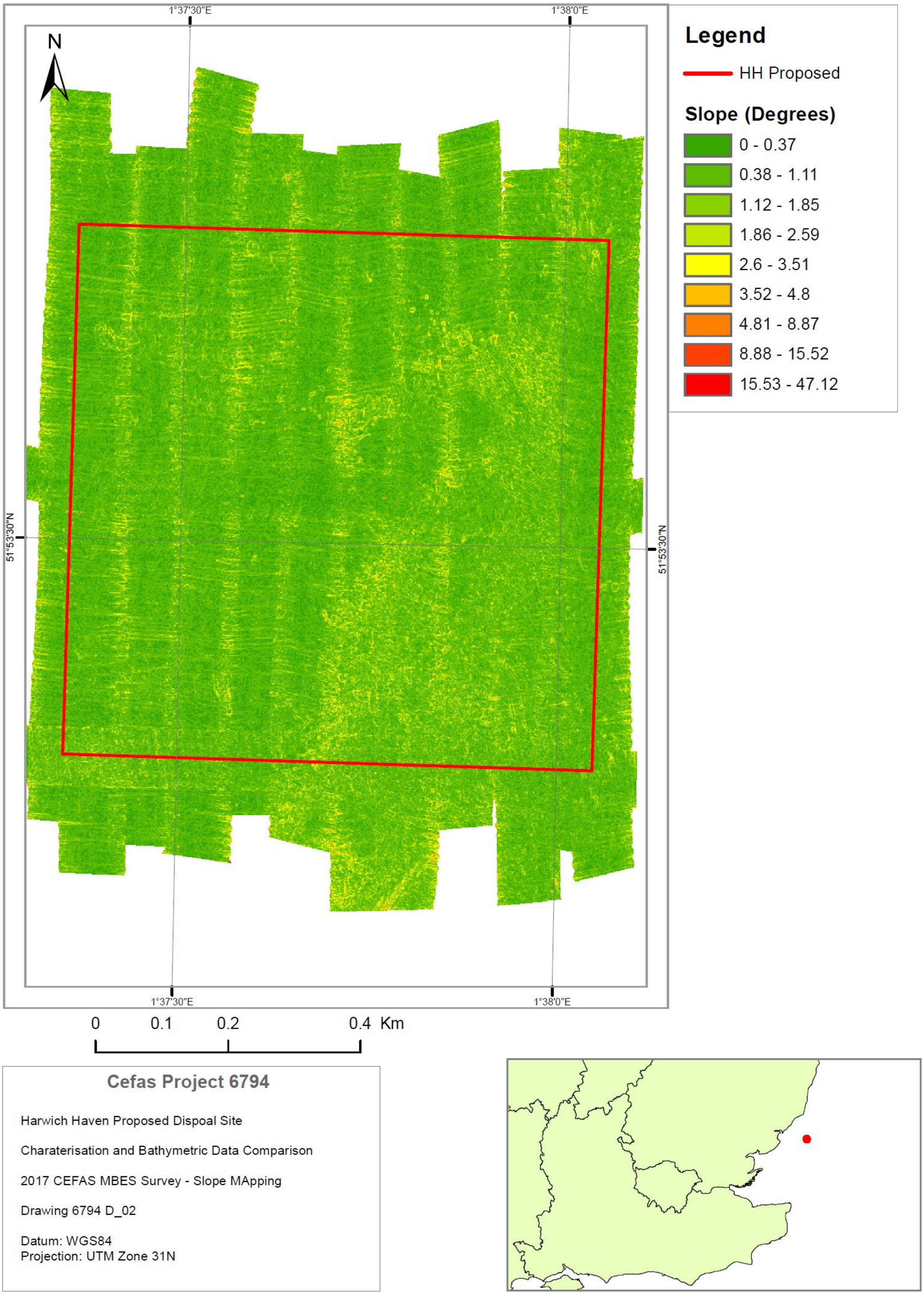


Figure A1.6: Slope profile map, showing slope in degrees across a diagonally orientated profile (NW to SE). These slope data are calculated from the Cefas 2017 MBES data acquired from the Harwich Haven disposal site.

1.2.2.2 Bathymetric data comparison

As previously mentioned, the Harwich Haven site was acoustically surveyed in September 2016 (HRW, 2017). The MBES data obtained are presented in Figure A1.7.

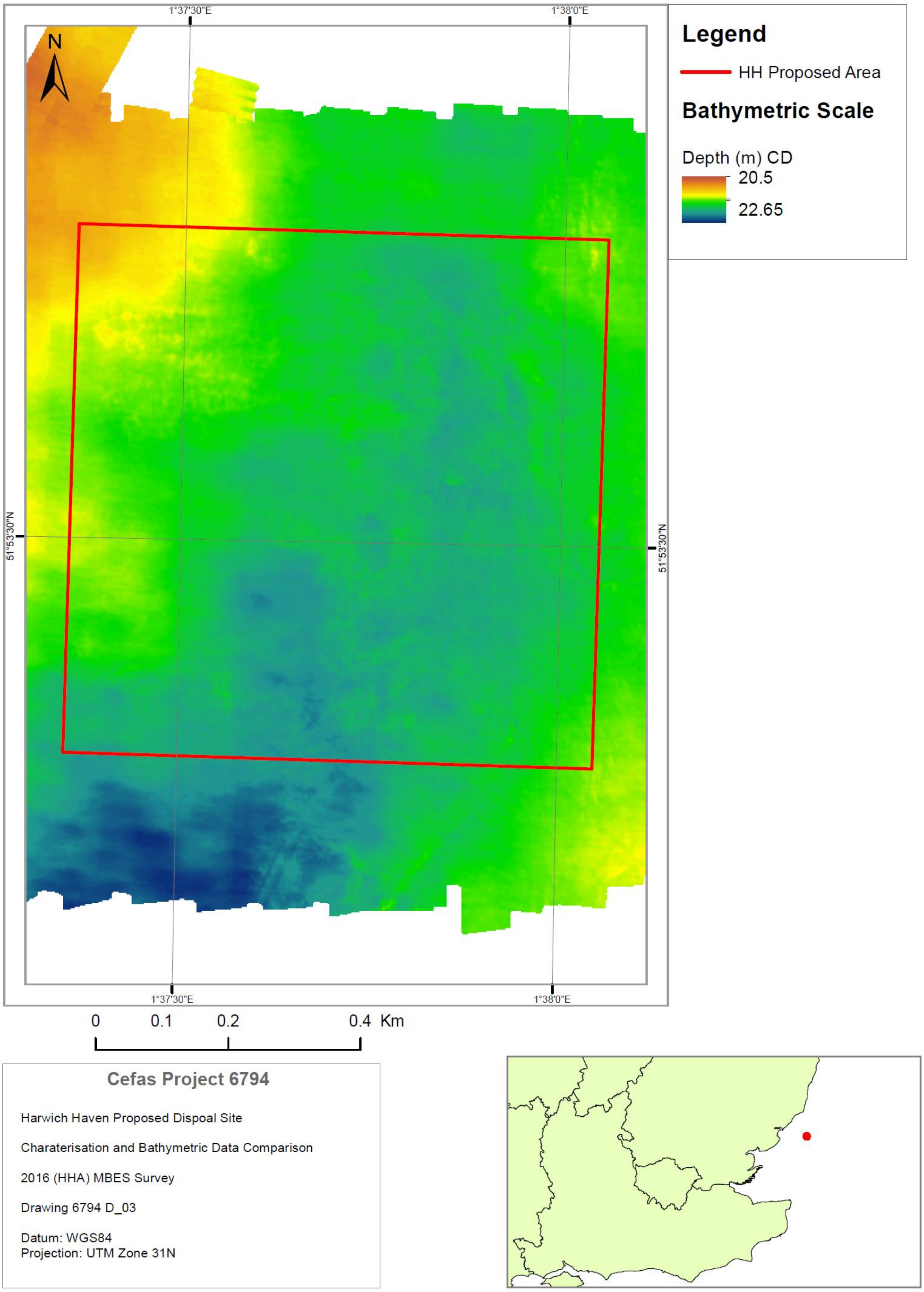
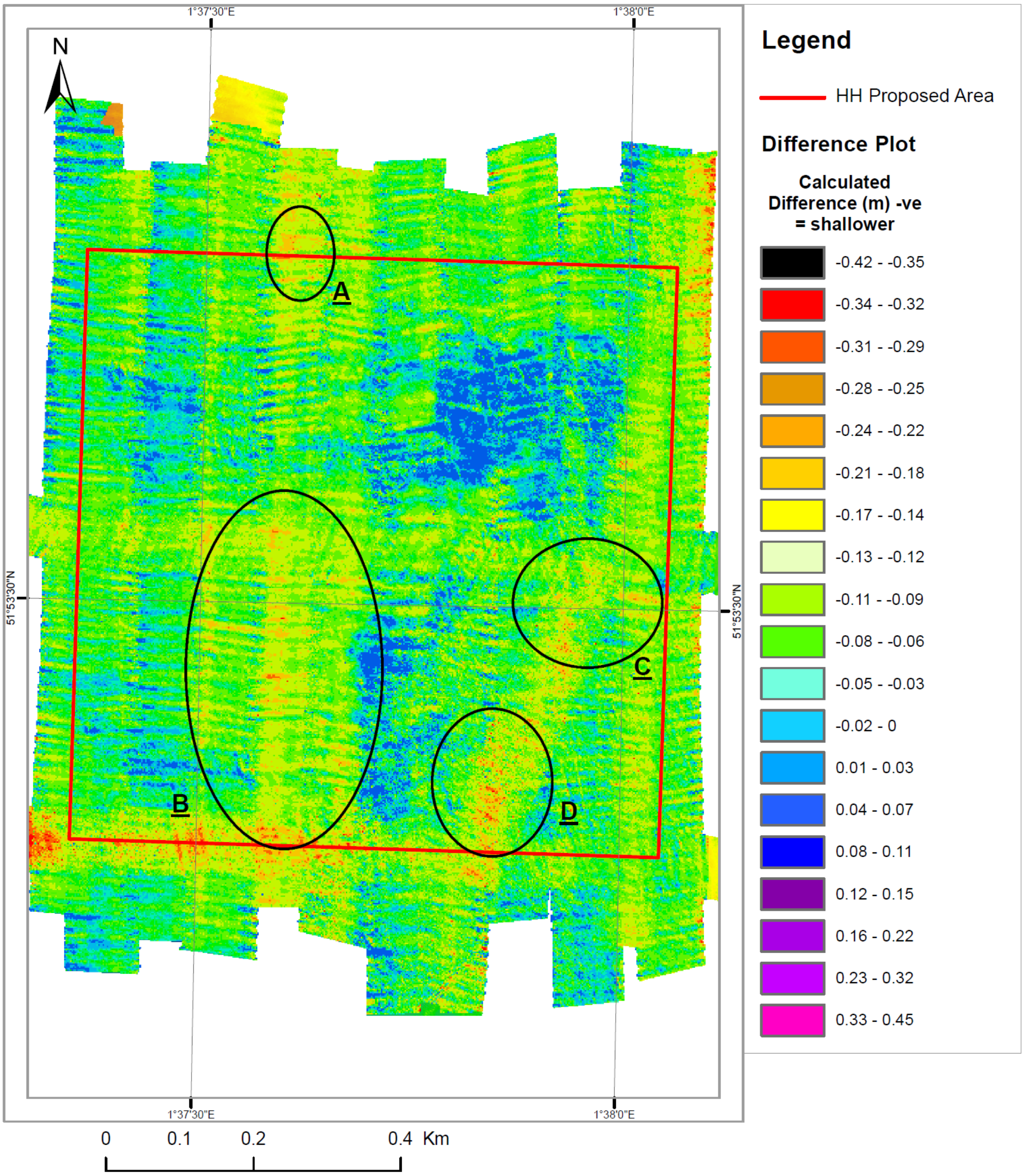


Figure A1.7: 2016 (September) acoustic data for Harwich Haven acquired by HR Wallingford (HRW, 2017).

These data show extensive similarities to those of Cefas, with a comparable (i.e. within total vertical uncertainty threshold) depth range of 20.66 to 22.65m (CD). The 2016 data have been compared with the data acquired in 2017. No large-scale bathymetric changes can be identified from visual comparison, however, it is possible to infer that there are regions that appear deeper in 2016 than in 2017.

Both datasets have been further compared using a raster difference calculation within ArcMap 10.5 (Figure A1.8). This data comparison indicates that the majority of site has undergone a slight change in depth (with negative values indicating an accrual) of between -0.06 and -0.18 m from September 2016 to July 2017. However, both values are less than the TVU (IHO Order 1a), i.e., they are not greater than the expected error. The difference map produced indicates that the maximum difference between the two datasets is -0.42 m. However, further review shows that no differences greater than -0.29 m are present within the licenced area, and that those values greater than -0.30 m are confined to the western end of a single survey line (highlighted in Figure A1.8), possibly due to spikes associated with data acquisition.



Cefas Project 6794

Harwich Haven Proposed Dispoal Site

Charaterisation and Bathymetric Data Comparison

2017 Cefas MBES Survey -
Difference mapping vs 2016 (HHA) MBES Survey

Drawing 6794 D_03

Datum: WGS84
Projection: UTM Zone 31N

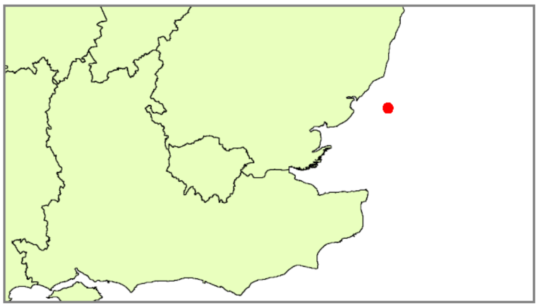


Figure A1.8: The calculated difference (in m) between the September 2016 MBES data (HRW, 2017) and the July 2017 Cefas MBES data.

Differences within the licenced area of greater than -0.18 m are confined to four areas (A, B, C and D in Figure A1.8). The data show some association between increased difference and survey line track, i.e. that greater differences are observed along certain acquisition lines. This may further indicate that the differences could be attributed to inherent error in MBES acquisition. For example, the increased frequency of elevated (>0.18 m) differences observed along the acquisition line at the extreme south of the survey area. However, Areas B and C illustrate a possible accrual of 10 – 20 cm of sediment between 2016 and 2017. This is in keeping with the indicative visual comparison discussed above.

1.2.2.3 Substrate Mapping

Backscatter data were acquired alongside the 2017 bathymetry data. These data (Figure A1.9) reveal areas of both higher and lower intensity reflections, indicative of a matrix of substrate types present within the licenced area.

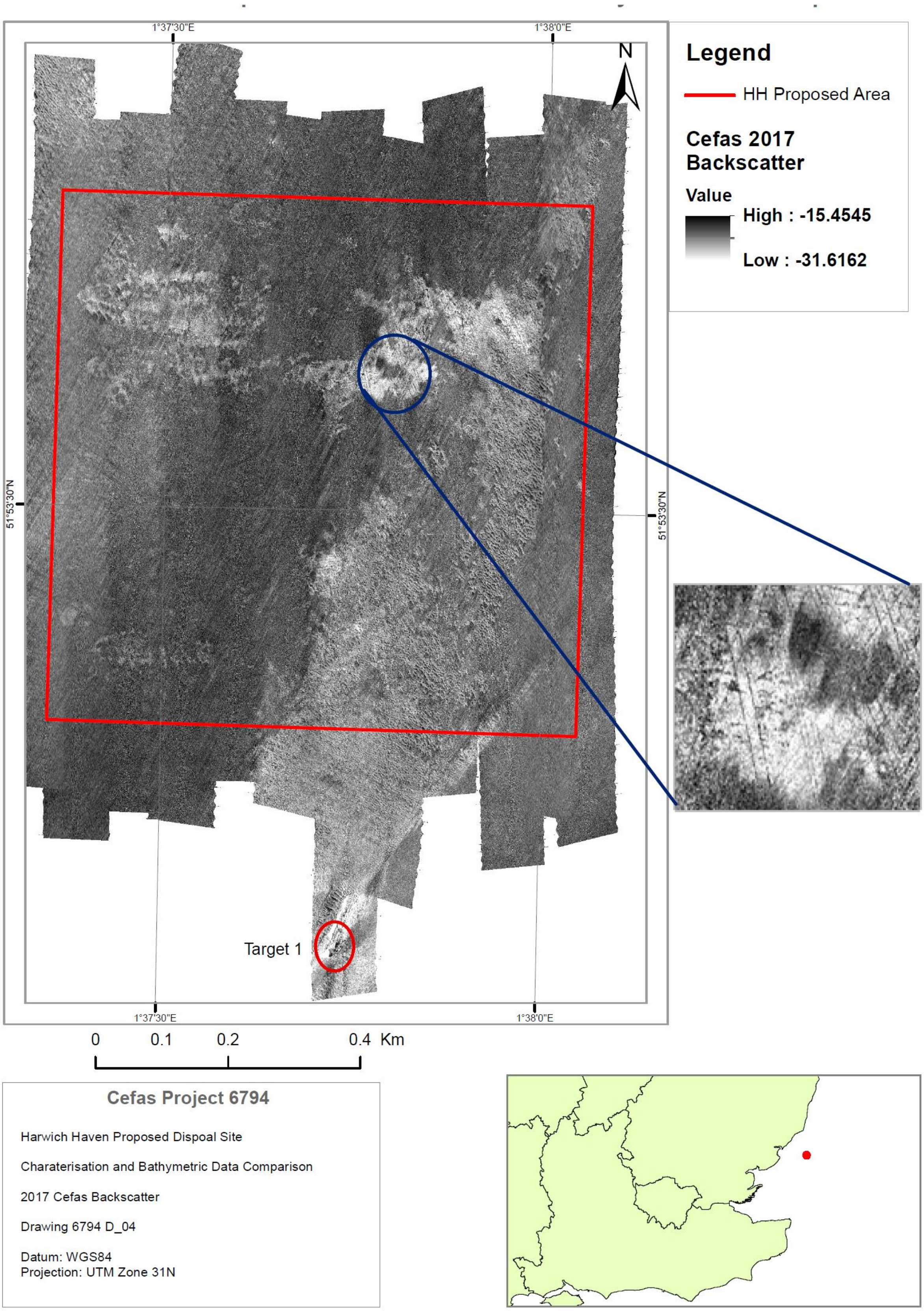


Figure A1.9: Map showing the backscatter data acquired during the 2017 Cefas survey.

A discrete, elongate patch of higher intensity reflection is observed across the centre of the surveyed are, orientated southwest to northeast. This area of stronger reflectivity is contiguous with the 'trough-like' depression discussed in the preceding section. Lower intensity reflections are noted to the west and east of the central trough, with two discrete patches of very low intensity reflection located to the north of the surveyed area. These areas of lower intensity reflectivity are associated with small bedforms (ripples) oriented southwest to northeast. Apparent scarring from bottom trawling activity is noted within the large patch of higher reflectivity substrate in the northeast of the licenced area. An identified anthropogenic structure (Target 1 in Figure A1.9) is observed on the seabed 342 m south of the licensed area: this is a charted wreck with approximate dimensions of 34 m in length and 13 m width.

The Cefas 2017 survey acquired PSA samples from four stations (three replicates at each) within the survey area (stations 49, 50, 51 and 52; see preceding section). The stations are located at sites monitored during previous HR Wallingford surveys (2012 and 2016 – bold and underlined labels in Figure A1.10). A single substrate sample was acquired in 2016, from station 11. This sample has been used to further confirm the substrate delineated using the 2017 data.

Locations and indicative substrate classifications have also been provided from the August 2012 survey (HRW, 2014). These data comprise graphical representations of substrate classification from nine benthic sediment sampling stations within the licence area. The areas of similar reflectance and depth have been mapped using manual delineation (Figure A1.10) using the substrate classes derived from the 2017 PSA data. The indicative substrate classifications, as inferred from the graphical presentation of the 2012 PSA data, have also been mapped for comparison and provide indicative substrate classification for a reflectance class (Ref-4) which was not ground-truthed in 2017.

Cefas

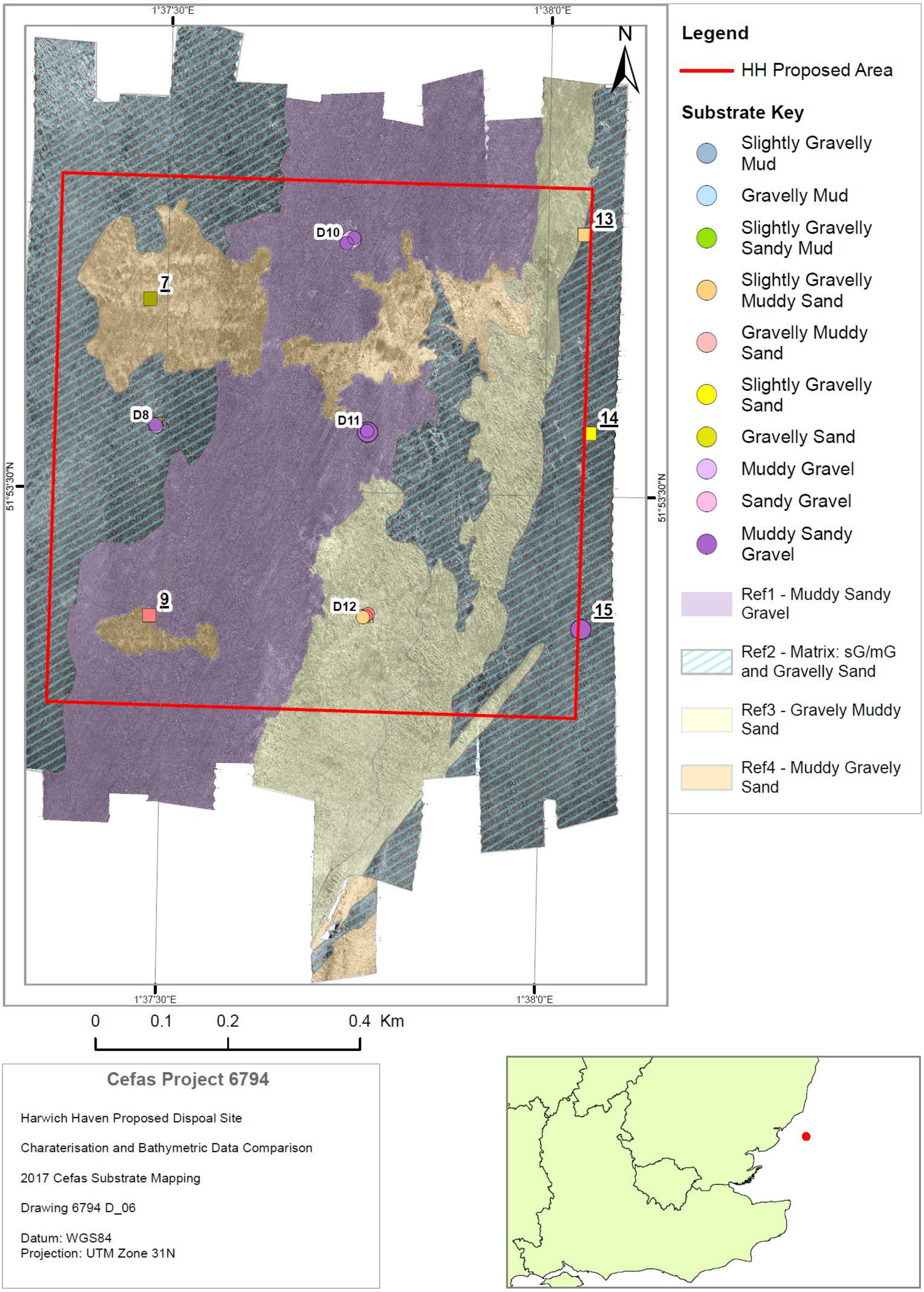


Figure A1.10: Map showing 2017 backscatter data (Cefas) with both 2017 (underlined) and 2012 (square symbols) sediment sampling stations and substrate mapping layers overlaid.

Substrate types were classified from the 2017 PSA samples using Gradistat (Blott and Pye, 2001), and the samples assigned textural groups which have been used here. These data have allowed for approximate calibration of the backscatter data. Intensity values of between -18 dB and -21 dB corresponded with the central trough area (reflectance area "Ref 1" in Figure A1.10), with the substrate classification of muddy sandy gravel derived from PSA stations 49, 51 and 11 (2016). Approximate intensities of between -20 dB and -25 dB ("Ref 3" in Figure A1.10) are associated with the gravelly muddy sand recorded at station 52 in 2017, and stations 12 and 13 in 2012.

A slightly lower intensity of reflection, of between -23 and -30 dB, was observed to be contiguous with stations 7 and 9 ("Ref 4" in Figure A1.10). This reflectance class was not sampled in 2017 or 2016, however the 2012 indicative class is muddy gravelly sand, perhaps with a higher proportion of mud than observed in reflectance class 3. The intensity of reflection varied considerably in the western and eastern extremes of the area, as too did recorded substrate types. The substrate data from station 50 (2017) and stations 8, 14 and 15 (2012) are indicative of a matrix of gravelly sand and sandy gravel/ muddy gravel. The substrate at station 14 is recorded from the 2012 survey as sand.

As only one data point with full PSA data was acquired from within the licence area during 2016 sampling (station ST / D11), the comparison between 2016 and 2017 data is inherently limited. Data provided from the PSA samples acquired in 2012 were qualitative only. As such, direct comparison between 2012 and 2017 data is not possible and 2012 textural groups have been included for reference only (providing indicative substrate information for those stations not sampled in 2016 or 2017).

A detailed temporal PSA comparison was only possible between samples taken at station 11 in 2016 (known as ST 11 in 2016) based solely on one replicate, and 2017 (from three replicates). Superficially, it appears that between 2016 and 2017 there was a slight fining of substrate at station 11, with less gravel and a higher contribution of silt fractions making up the substrate in 2017 (Figure A1.11). The textural group determined from the 2016 sample was muddy sandy gravel. In 2017, there is a significant amount of variability in composition observed between the three replicate samples, with the textural group varying between each replicate (muddy gravel, muddy sandy gravel and gravelly muddy sand). The trend for increasing fines is represented in each 2017 replicate, but to varying degrees.

With the lack of replicate samples acquired from the station in 2016, and given the inter-replicate heterogeneity seen in the 2017 samples, it is not possible to determine a definitive conclusion of fining within the licence area.

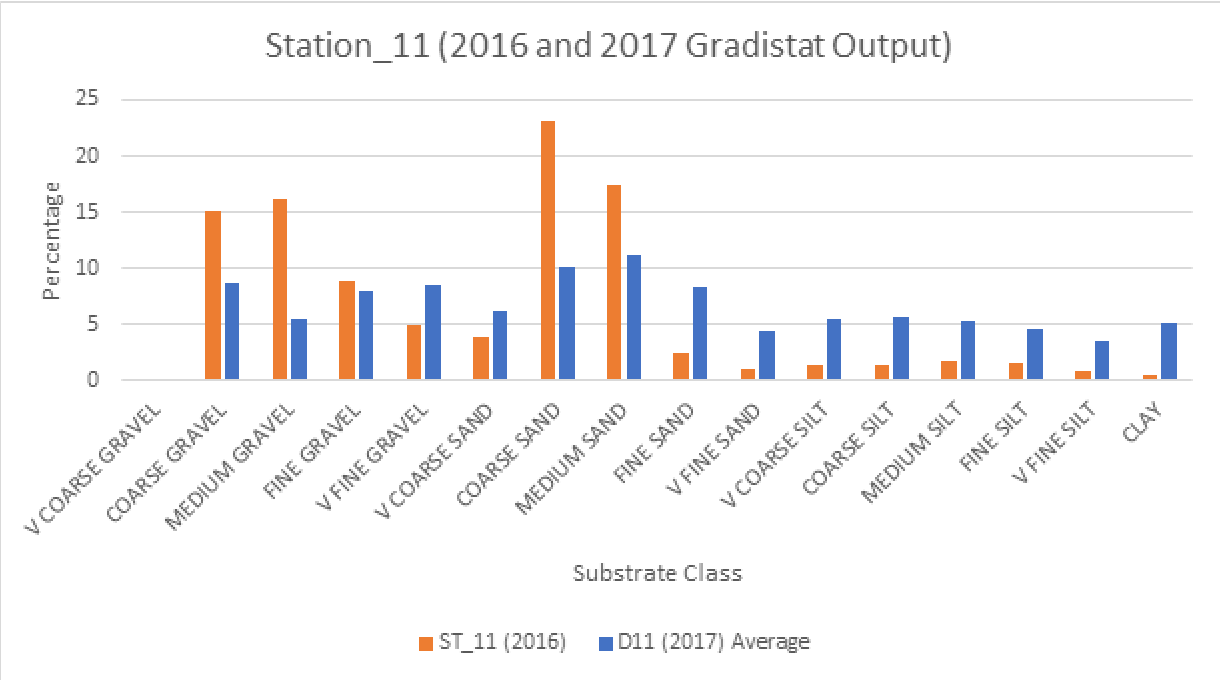


Figure A1.11: Sediment particle size comparison of station 11 in 2016 (based on one replicate) with that sampled in 2017 (average of three replicates).

1.2.3 Sediment macrofauna

Macrofauna were sampled at 20 stations (three replicate samples per station) during the Cefas survey of Harwich Haven in 2017 (Figure A1.12). The stations sampled represent a subset of those sampled by HR Wallingford as part of the monitoring of the impacts of the trial disposal campaign. Four of these stations were located inside the dredge disposal site, six were in the area immediately surrounding the disposal site (near field), another six were located at an 'intermediate' distance from the site (three to the north, three to the south), and four were located far afield (two to the north, two to the south). Samples were collected using a 0.1 m^2 mini Hamon grab, sieved over 1 mm mesh, and the retained animals identified to the lowest possible taxonomic level, enumerated, and weighed. The resulting taxon list was truncated to remove any animals that are not benthic invertebrates (e.g., fish) or were not complete animals (e.g., annelid fragments). Juveniles were retained and merged with adult records of the same taxon, where possible. However, if juveniles were recorded at a lower taxonomic resolution than adults then they were removed rather than reducing the resolution of adult records. Colonial animals, whose abundances could not be determined, were given an abundance of one.

Polychaetes were the most diverse and abundant group of benthic invertebrates at the four sampling stations within the dredge disposal site (52 % of the total number of species (S), 65 % of the total number of individuals (N)), followed by crustaceans (13 % of both total S and total N) and bivalves (10 % of total S, 20 % of total N) (Table A1.4). The numbers of cnidarian and bryozoan species were both slightly lower than the number of bivalve species (7 % each); however, individuals belonging to these colonial groups are not enumerated and thus their abundances could not be assessed (Table A1.4). Echinoderms were the least common of the major benthic invertebrate groups observed within the dredge disposal site (3 % of total S, 0.4 % of total N) (Table A1.4).

Similar patterns were observed when stations outside the dredge disposal site were also considered (Table A1.4). However, the dominance of polychaetes dropped somewhat while the dominance of crustaceans increased. There was little difference in the total number of bryozoan and cnidarian species at the four stations within the disposal site and the 20 stations sampled during the survey, suggesting that most representatives from these groups at Harwich Haven are present within the disposal site. Moreover, one bryozoan *Flustra foliacea* and one cnidarian *Alcyonium digitatum* were only observed inside the disposal site. The 'other' taxonomic group category (i.e. species that do not belong to any of the major groups) constituted a similar proportion of total abundance within the disposal site and throughout the wider area; however, many more species from this group were observed in the latter case (five vs 16 species).

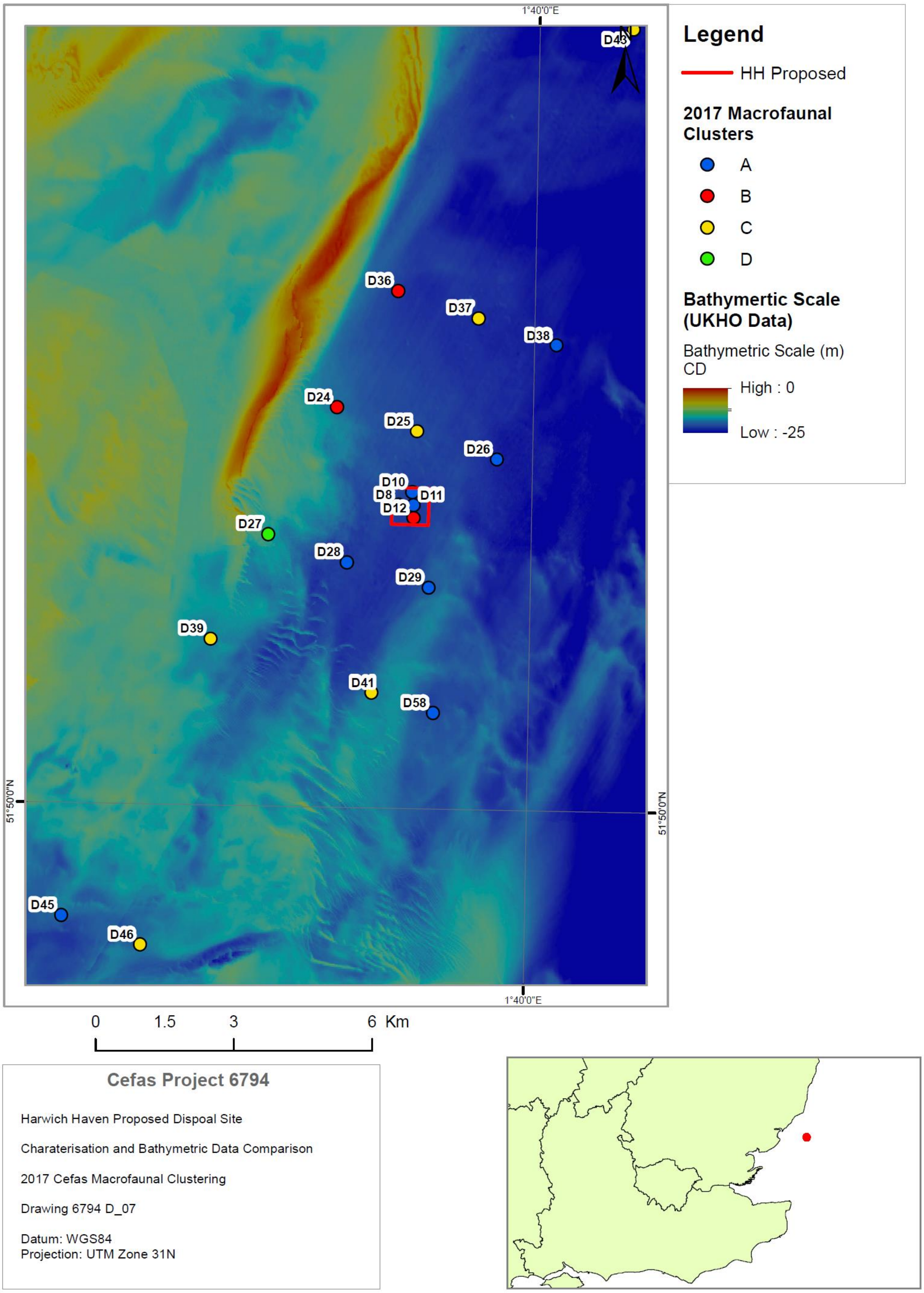


Figure A1.12: Locations of stations where macrofauna were sampled during the 2017 Cefas survey of the Harwich Haven dredge disposal site. The dredge disposal site is indicated by the red box (containing stations D08, D10, D11, and D12). Significantly different clusters ($p < 0.05$) are shown: ● = cluster A, ● = cluster B, ● = cluster C, and ● = cluster D. The taxa that characterise each cluster are shown in Table A1.3.

Table A1.4: Numbers of species (S) and individuals (N) from benthic invertebrate groups at four stations (three replicate grabs per station) in the Harwich Haven dredge disposal site boundary in 2017.

Phylum (sub-phylum or class)	**Number of species (S)**	**% of total S**	**Number of individuals (N)**	**% of total N**
Annelida (Polychaeta)	35	51.5	288	64.6
Arthropoda (Crustacea)	9	13.2	56	12.6
Mollusca (Bivalvia)	7	10.3	88	19.7
Echinodermata	2	2.9	2	0.4
Cnidaria (Hydrozoa)	5	7.4	-	-
Bryozoa	5	7.4	-	-
Other	5	7.4	12	2.7

Table A1.5: Numbers of species (S) and individuals (N) of benthic invertebrate groups recorded at 20 stations (three replicate grabs per station) in the Harwich Haven dredge disposal site and nearby areas in 2017.

Phylum (sub-phylum or class)	**Number of species (S)**	**% of total S**	**Number of individuals (N)**	**% of total N**
Annelida (Polychaeta)	66	47.8	1314	53.7
Arthropoda (Crustacea)	27	19.6	437	17.9
Mollusca (Bivalvia)	11	8.0	574	23.5
Echinodermata	5	3.6	44	1.8
Cnidaria (Hydrozoa)	6	4.3	3*	0.1
Bryozoa	7	5.1	-	-
Other	16	11.6	74	3.0

* Only one taxon within the Cnidaria (i.e., Actiniaria) could be enumerated.

Total abundance of macrofauna (individuals m^{-2}) at the dredge disposal site was within the range of total abundance observed across the full survey area, and its variability among stations within the disposal site was relatively low (Figure A1.13-A). The highest total abundance was recorded in the far field south area (station D45); however, the other station within this area (D46) had a lower total abundance than was recorded at any of the stations inside the disposal site (Figure A1.13-A). Largely the same patterns were observed for species richness (the total number of species across the three samples collected per station; Figure A1.13-B) and Margalef diversity (species richness in relation to the log of total abundance; Figure A1.13-C). The main exception is that one station within the disposal site (D12) was substantially less diverse than the others (Figure A1.13-B & C). Species evenness (Pielou's index) within the disposal site showed little variation between stations and was within the range of evenness observed at the near field stations, but was higher than observed at some stations in more distant areas (Figure A1.13-D). Evenness was particularly low at station D38 in the northern area at intermediate distance from the disposal site.

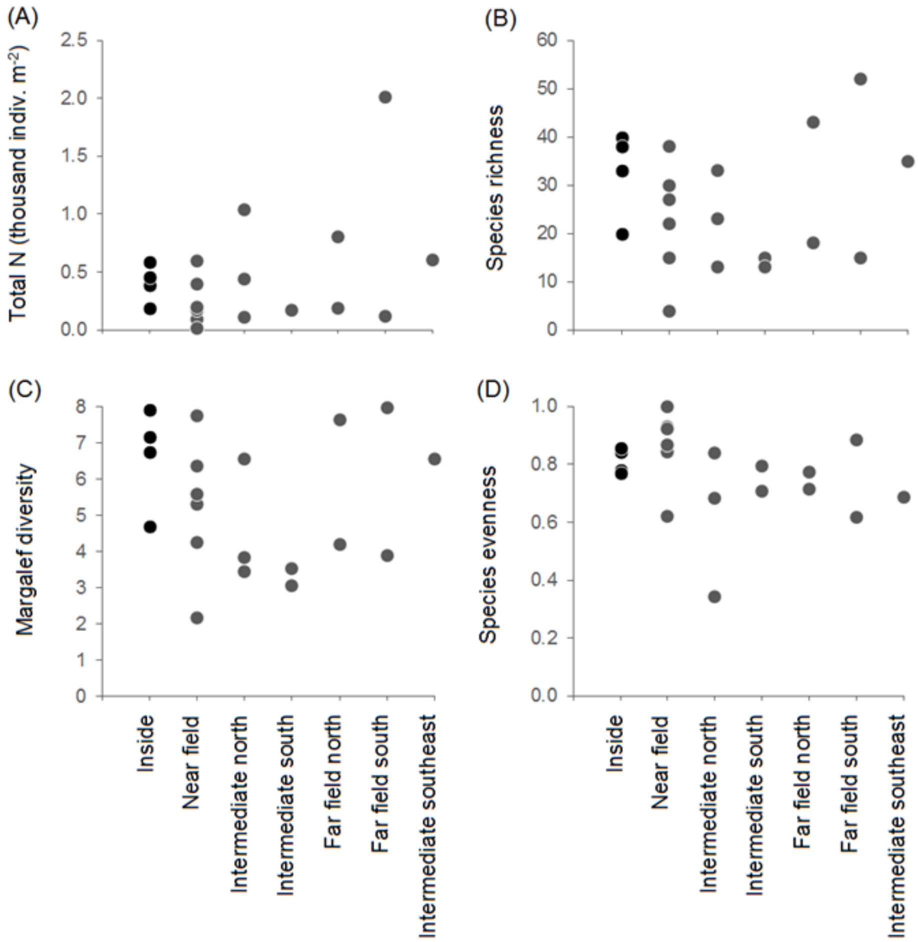


Figure A1.13: Variation in benthic macroinfaunal communities at sampling stations located inside the Harwich Haven dredge disposal site and in nearby areas in terms of (a) the total number of individuals (m^{-2}), (b) the number of species summed across three replicate samples (species richness), (c) Pielou's evenness index, and (d) the Margalef diversity index.

SIMPROF (performed in association with a hierarchical cluster analysis in PRIMER v7) indicated that there were four statistically distinct macrofaunal communities across the 20 sampling stations at Harwich Haven (Figure A1.12; Figure A1.14). Three of the four stations within the disposal site were part of the same cluster (cluster A), while one (station D12) was in a different cluster (cluster B) (Figure A1.12; Figure A1.14). Cluster A also consisted of ten stations that were distributed across all survey areas except for the area at intermediate distance to the south of the disposal site. Both stations from this area to the south were part of cluster C, which also contained single stations from the near field area, the intermediate north area, and the far field areas both to the north and south. In addition to the station inside the disposal site, cluster B consisted of a nearfield station and a station at intermediate distance to the north of the site. The macrofaunal community at one near field station (D27) was distinct from all other stations and was the only station in cluster D.

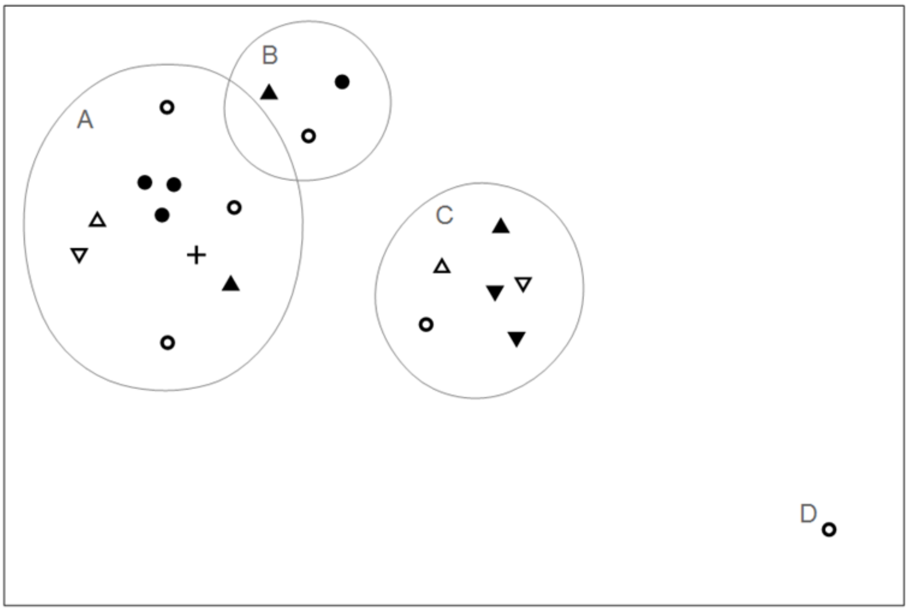


Figure A1.14: Non-metric multidimensional scaling (nMDS) ordination of macroinfaunal community composition (based on ln(x+1) transformed taxa abundances) inside the Harwich Haven dredge disposal site and in nearby areas: ● = inside, ○ = near field, ▲ = intermediate north, ▼ = intermediate south, △ = far field north, ▽ = far field south, + = intermediate southeast. Communities within the same grey ring fall into the same cluster (a, b, c, or d) whereas those in different rings fall into different clusters. Clusters are based on significant differences in species composition ($p < 0.05$). Two-dimensional stress = 0.10.

SIMPER (in PRIMER v7) was used to reveal the taxa which contributed most to community similarity and dissimilarity within and between clusters, respectively. Macrofaunal communities at stations in cluster A had an average similarity of 41 % and were characterised mainly by polychaete species (Table A1.6). Cluster B (average similarity of 36 %) was characterised by species from a range of taxonomic groups (bivalves, polychaetes, bryozoans, and nemerteans; Table A1.6). Taxa characterising cluster C (community similarity of 46 %) were mainly polychaetes, but also contained two bryozoans and a chromistan (Table A1.6). The only four taxa that were recorded at the single station making up cluster D consisted of two polychaetes, an echinoderm, and a chromistan (Table A1.6).

Regarding community variation between clusters, the most distinct cluster was D (95 % dissimilar to cluster A, 94 % dissimilar to cluster B, 86% dissimilar to cluster C), which was distinguished from the others mainly by the paucity of macrofaunal organisms at the single station within this cluster (Figure A1.14). Cluster A, which contains most stations in the disposal site, was more dissimilar to cluster C (80 % dissimilarity) than cluster B (68 % dissimilarity); the latter containing the only other station in the disposal site. The main feature distinguishing cluster A from the other clusters was higher densities of the reef-forming polychaete *Sabellaria spinulosa*, which was rare in cluster B and was not observed at all in clusters C and D. Clusters B and C were 73 % dissimilar, distinguished by their different principal characterising species (i.e., *Abra alba* and *Ophelia borealis*, respectively). After *S. spinulosa*, these taxa were also the main contributors to dissimilarity between cluster A and clusters B and C, with *A. alba* and *O. borealis* occurring at higher densities in clusters B and C, respectively. The polychaete *Glycera* was the only taxon among the major contributors to community similarity in every cluster (Figure A1.14). The abundances of *S. spinulosa*, *A. alba*, *O. borealis*, and *Glycera* in the different survey areas and clusters are shown in Figure A1.15.

Cefas

Table A1.6: Taxa that characterised macrofaunal communities at Harwich Haven in cluster A (stations D08, D10, D11, D26, D28, D29, D38, D42, D45, and D58), cluster B (D12, D24, D36), cluster C (D25, D37, D39, D41, D43, and D46), and cluster D (D27). Average abundance is in terms of individuals m^{-2}. The four taxa reported for cluster D were the only taxa at the single station that forms this cluster.

Cluster	Taxonomic group	Taxon	Av. abund.	% Contrib.	Cum. %
A	Polychaeta	*Marphysa bellii*	17.7	8.3	8.3
A	Polychaeta	*Glycera*	13.2	7.2	15.5
A	Polychaeta	*Goniada maculata*	11.5	6.5	22.0
A	Bivalvia	*Abra alba*	12.8	5.7	27.6
A	Polychaeta	*Lagis koreni*	15.5	5.4	33.0
A	Polychaeta	*Spiophanes bombyx*	15.7	5.3	38.3
A	Polychaeta	*Sabellaria spinulosa*	27.4	5.3	43.6
B	Bivalvia	*Abra alba*	57.2	19.4	19.4
B	Polychaeta	*Glycera*	11.6	16.1	35.5
B	Bryozoa	*Conopeum reticulum*	6.3	10.5	46.0
B	Bryozoa	*Cribrilaria innominata*	6.3	10.3	56.3
B	Nemertea	*Nemertea*	5.4	10.3	66.6
B	Polychaeta	*Notomastus*	11.9	8.9	75.5
B	Bivalvia	*Nucula nucleus*	4.3	4.5	79.9
C	Polychaeta	*Ophelia borealis*	22.6	17.3	17.3
C	Bryozoa	*Cribrilaria innominata*	8.8	15.2	32.5
C	Polychaeta	*Glycera*	9.5	12.5	45.0
C	Chromista	*Lagotia viridis*	4.9	9.8	54.8
C	Bryozoa	*Conopeum reticulum*	5.2	8.4	63.2
C	Polychaeta	*Nephtys cirrosa*	5.2	7.7	70.9
C	Polychaeta	*Polycirrus*	8.1	6.5	77.4
D	Polychaeta	*Glycera*	3.3	-	-
D	Polychaeta	*Pisione remota*	3.3	-	-
D	Chromista	*Lagotia viridis*	3.3	-	-
D	Echinodermata	*Amphipholis squamata*	3.3	-	-

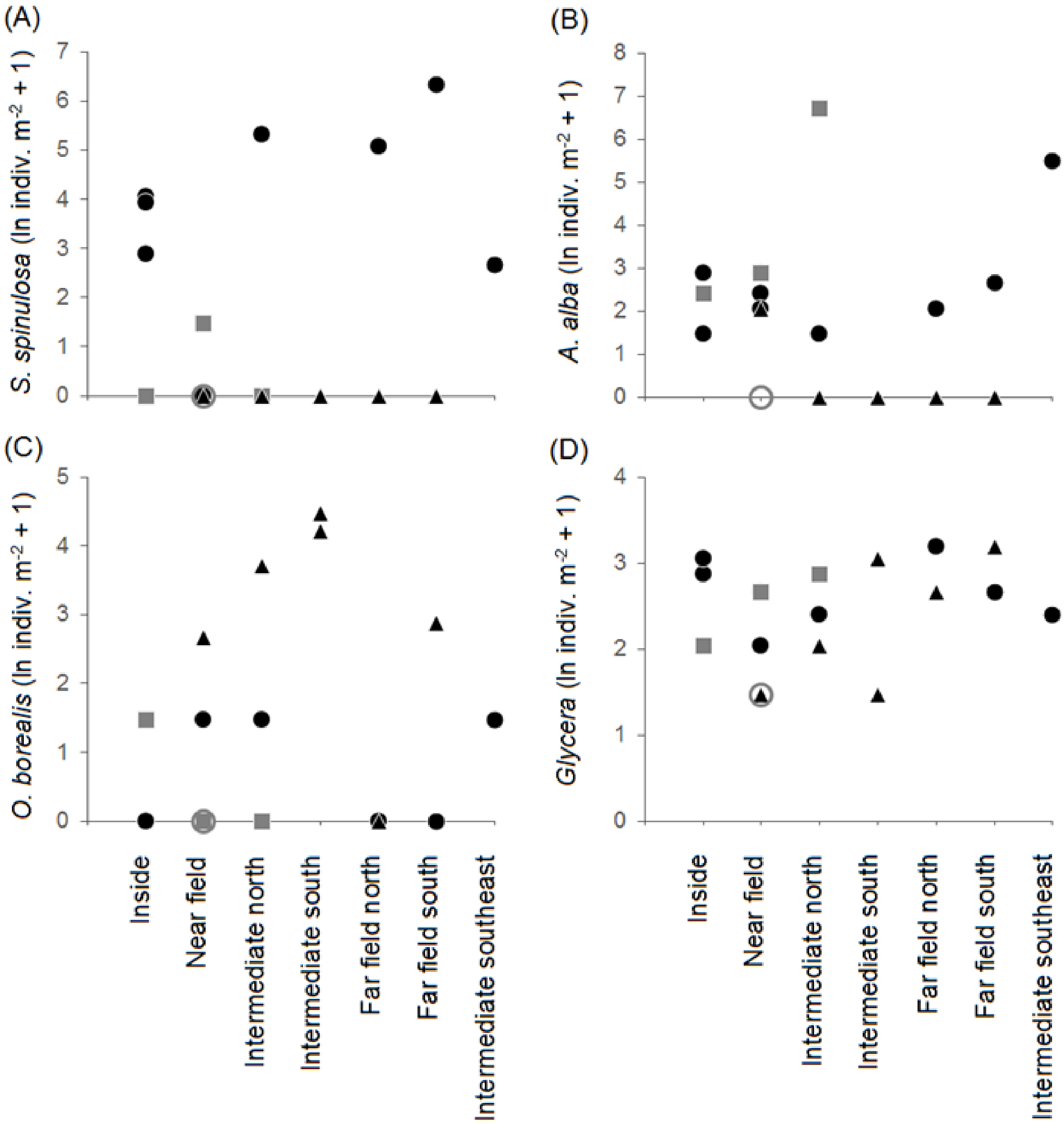


Figure A1.15: Variation in the abundances of taxa that characterise benthic macrofaunal communities at sampling stations located inside the Harwich Haven dredge disposal site and in nearby areas: (a) *Sabellaria spinulosa*, (b) *Abra alba*, (c) *Ophelia borealis*, and (d) *Glycera*. Symbols indicate stations that fall within the same cluster: ● = cluster A, ■ = cluster B, ▲ = cluster C, and ○ = cluster D. Communities from different clusters are significantly different ($p < 0.05$).

In summary, the macrofaunal communities both inside the disposal site and in the wider area were dominated by polychaetes followed by crustaceans and bivalves. Total abundance and biodiversity (species richness, Margalef diversity, and species evenness) of macrofauna at the disposal site were within the ranges observed for the wider area. Macrofaunal communities at three of the four stations within the dredge disposal site clustered together with communities recorded at stations distributed across most of the surveyed areas. The fourth station within the disposal site clustered with a different group of stations, which differed from the former cluster mainly in that the latter had lower abundances of the reef-forming polychaete *Sabellaria spinulosa*. These observations do not indicate any clear effects of dredge disposal on benthic communities and are consistent with the findings of previous surveys of the site.

2 North Edinburgh Channel

2.1 Background

The North Edinburgh Channel disposal site is located along a relatively narrow, shallow channel in the Thames Estuary, north of Ramsgate. The site was opened in 2004 with the first dredged material being disposed in 2006 (125,663 wet tonnes), followed by a relatively large amount in 2007 (1,340,454 wet tonnes) and finally the most recent disposal being carried out in 2008 (277,684 wet tonnes). There have been issues raised regarding the shallowing of this site; a particular concern as the channel offers a viable passage from the Essex estuaries to the north Kent coast for leisure yacht and motor-cruisers.

Presently, the MMO are processing a marine licence application from the Port of London Authority (PLA) for the disposal of approximately 6.23 Mt (wet) of dredged material from Knock John, West Oaze and Black Deep for possible disposal to TH080. This would represent a 10-year licence for the dredging and disposal of maintenance material for the site which has not received material since 2008. In view of this, the MMO required Cefas to undertake a baseline survey of the bathymetric and sediment (granulometric) characteristics of the site and its immediate environs from which any subsequent physical changes associated with this potential licence may be assessed.

2.2 Results

The North Edinburgh Chanel was acoustically surveyed during September 2017 using the vessel SV *Thames Guardian* by the Environment Agency's Geomatics Team *via* a sub-contract under C6794. Multibeam echosounder (MBES) data were acquired using a RESON Seabat T50-P Multibeam sonar system. MBES bathymetry data were processed using CARIS HIPS and SIPS v9.08 to produce a cleaned bathymetric surface corrected to Chart Datum (Figure A2.1). Backscatter data were processed using QPS Fledermaus Geocoder ToolBox v7.4.3 to produce a cleaned backscatter mosaic. Maps were then produced using ArcGIS v10.5. No ground-truthing data were acquired.

2.2.1 Description of Current Bathymetry

The North Edinburgh Channel (the 'channel' hereafter) is a section of naturally occurring deeper water within the Outer Thames Estuary (Figure A2.1). The channel runs west to east, cutting between the shoals of Long Sand to the north, and Shingle Patch to the south. The channel is an extension of Knob Channel and forms a part of the wider network of channels present in the Outer Thames Estuary. The central part of the channel has a charted depth of between 10.2 and 18.0 m below Admiralty Chart Datum (ACD). However, due to the shoaling of the channel, a depth of 5.1 m (ACD) occurs at its seaward end. Indeed, the channel is bordered by shallow regions on both side, with intertidal areas not far to the west of the channel (Figure A2.1).

The area surveyed during September 2017 is 3.8 km in length and 600 m wide. This survey area does not cover the entire extent of the channel, with respect to either length or breadth (Figure A2.1) but encompasses the complete disposal site licenced boundary. The surveyed section shows depths ranging between 7.75 m and 19.17 m (ACD) with the channel being shallower in the western section. Of note is the area of raised seabed in the south of the central portion of the surveyed site (identified as Area 1) and an identified anthropogenic structure (Target 1) on the seabed with approximate dimensions of 85 m in length, 24 m width and 8-9 m in height. Four cross -sectional bathymetric profiles of the channel have been produced (Profiles 1 to 4 in Figure A2.2).

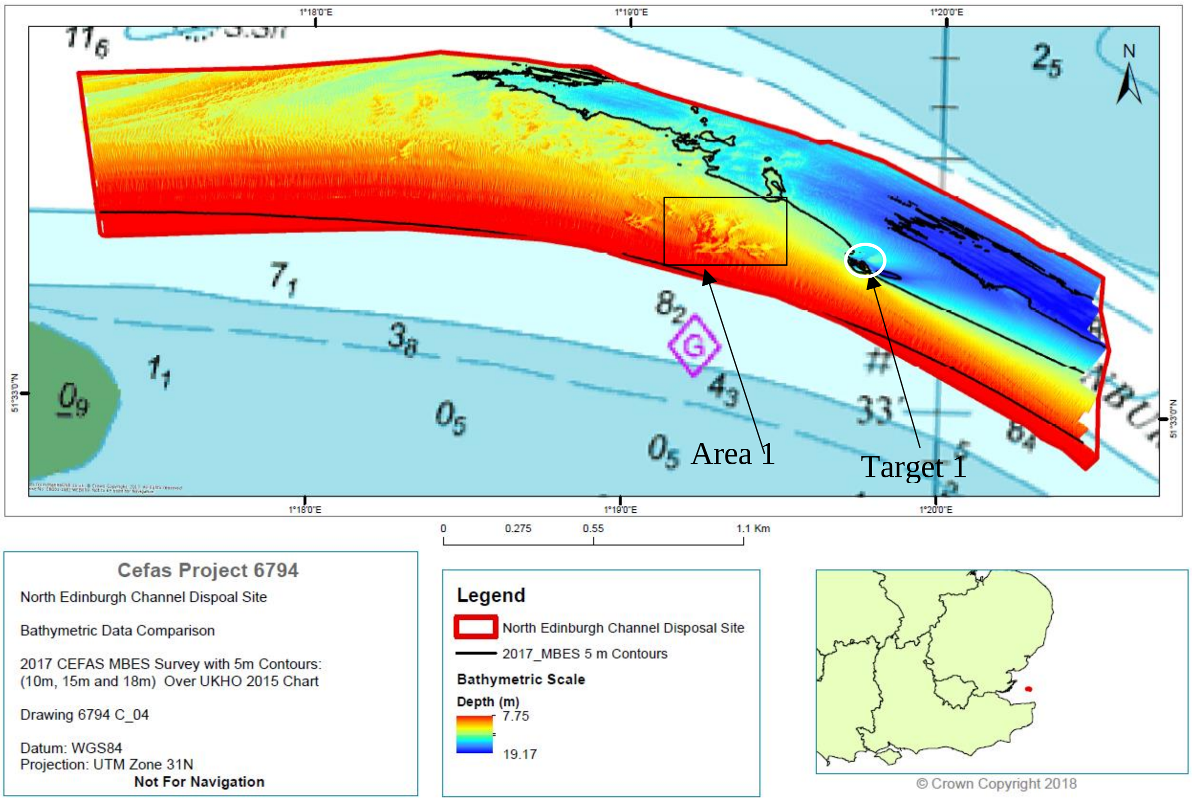


Figure A2.1: MBES bathymetry data acquired (2017) at the North Edinburgh Channel licensed area.

The channel as surveyed is shown to have a shallow southern slope leading to the deeper, central channel (northern slope not surveyed). The southern bank has an average slope of between 1.3° and 1.8° at the eastern section of the channel (Slope Profile 1, Figure A2.3), and a slope of between 0.9° and 1.15° in the western extreme of the surveyed area (Slope Profile 4, Figure A2.3). The slope of the southern bank increases to between 5.9° and 9.5° upon approach to the deepest section of the channel, at the southeast section (possibly attributable to large bedforms at Slope Profile 1, Figure A2.3). Overall the southern bank has a slightly shallower slope in the western section of the surveyed area, with a steeper slope associated with the eastern section (and the deeper central channel). The greatest slope angles observed are associated with bedforms or with Target 1.

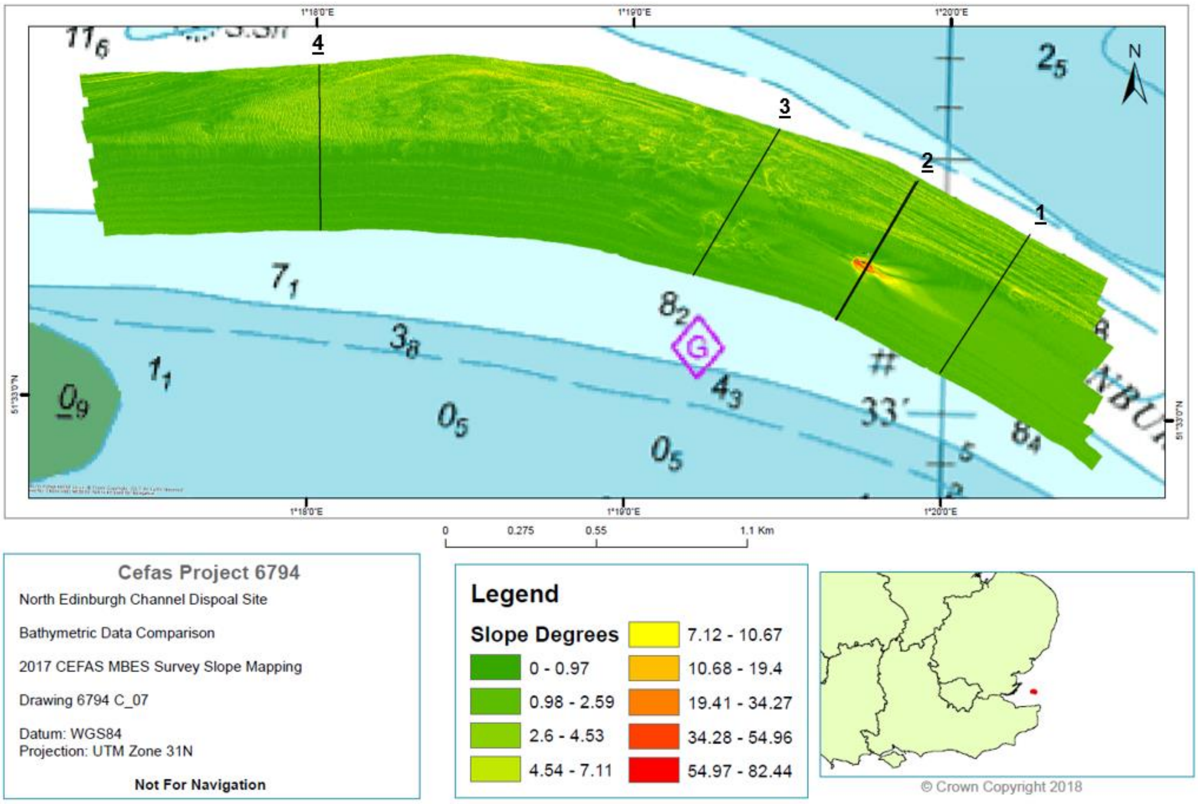


Figure A2.2: Slope profile map, showing slope in degrees across the North Edinburgh Channel licenced area.

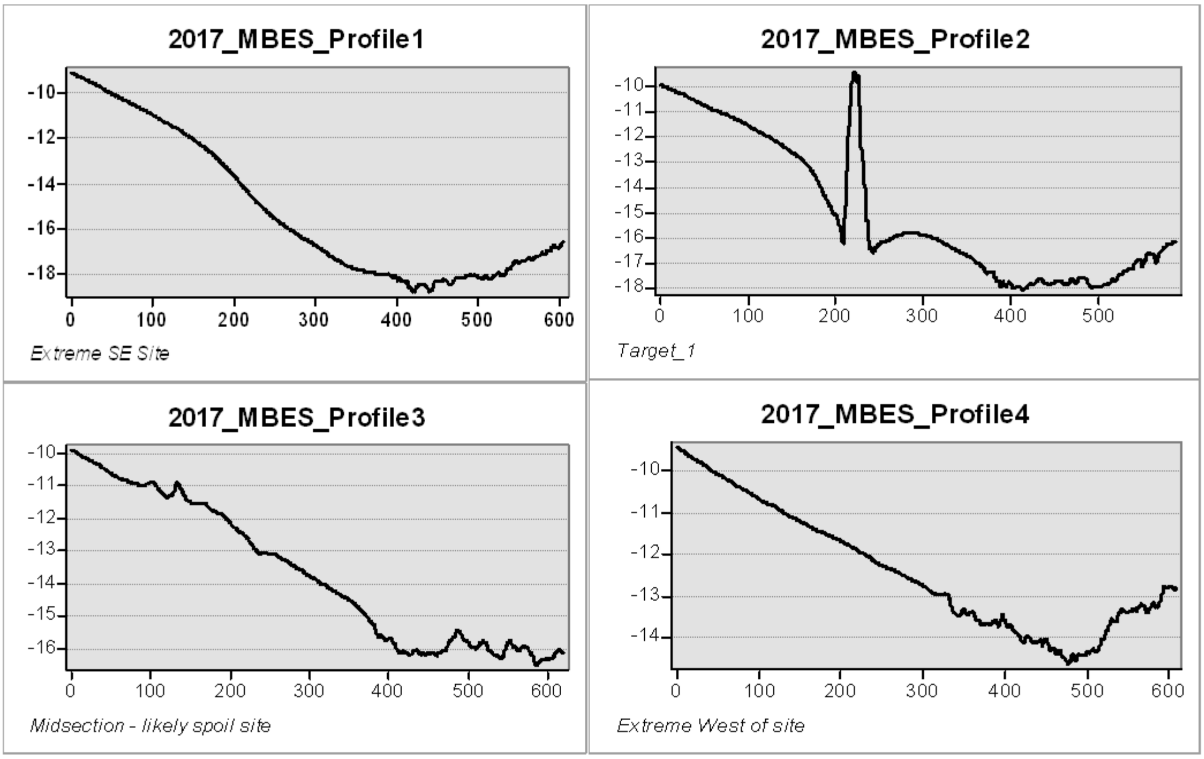


Figure A2.3: Cross sectional bathymetric profiles of the North Edinburgh Channel surveyed area. Depth relative to Admiralty Chart Datum (ACD), profiles run south to north.

2.2.2 Temporal change in bathymetry

A baseline bathymetric data set was downloaded from the Inspire portal[1]. Single beam bathymetry (SBES) data were acquired in 1997[2], and as such are considered not to be representative of current conditions within the outer Thames Estuary. As additional recent bathymetric data were unavailable, a Triangulated Irregular Network model (TIN model) was derived from these data and compared against the 2008 UKHO chart (Chart 1606-0 Thames Estuary Fisherman's Gat to Princes Channel). The resulting map indicates that North Edinburgh Channel migrated north eastwards between 1997 and 2008, by distances of between ~100 m (in the west and centre of the area) to ~550 m in the eastern section. These estimates are based on the location of the (1997-derived) 10 m contour of the northern bank of the channel. Spot depths in the deepest part of the channel were also shown to have changed, with the chart indicating a maximum depth of 16.6 m (ACD) in 2008, compared with soundings of ~19.17 m (ACD) in the 1997 dataset (Figure A2.4).

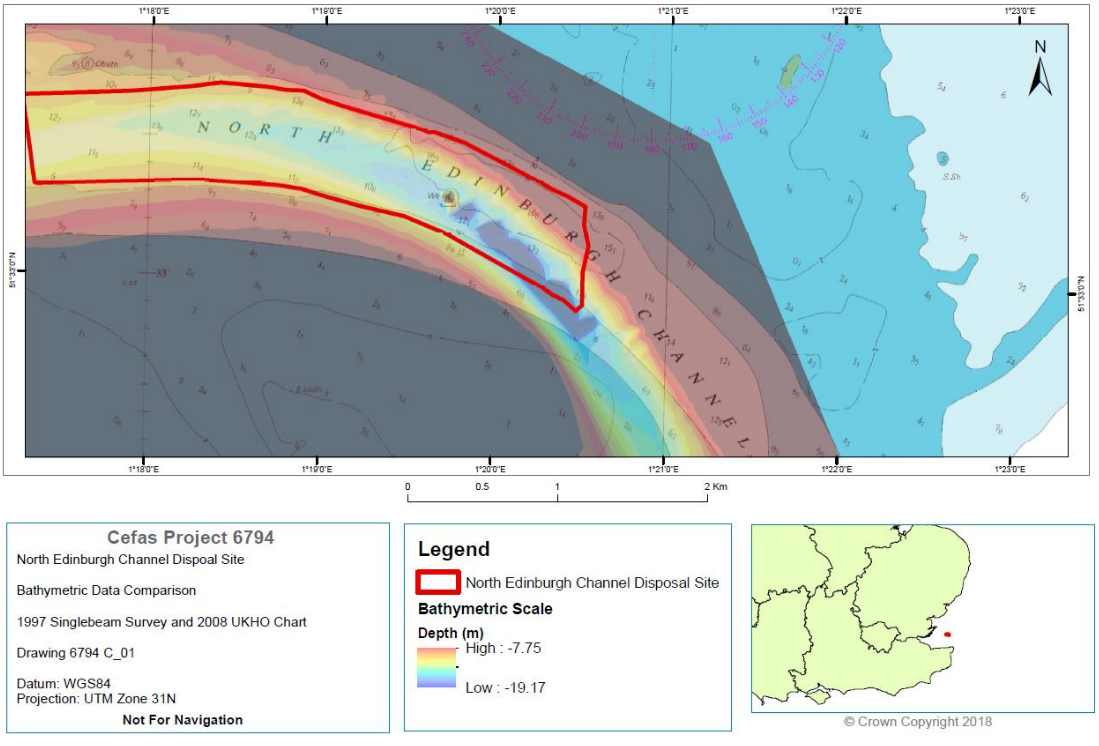


Figure A2.4: Map showing 1997 Single beam bathymetry (SBES) data (TIN Model) in comparison with UKHO chart 1606-0 (dated 2008).

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[1] http://aws2.caris.com/ukho/mapViewer/map.action. Accessed on 26/02/2018.

[2] Contains public sector information, licensed under the Open Government Licence v3.0, from The Port of London Authority (PLA).

A further comparison was then undertaken between the 1997 data (derived TIN model) and the 2015 charting undertaken by the UKHO (Chart 1607-0, in raster format at 1:50,000 scale). The same points on the 10 m contour of the derived TIN model were compared to the charted location of the 10 m contour as charted in 2015. Using this approach, a further migration north eastward of the channel was observed, with distances increasing to ~200 m in the western and central sections, and to > 1000 m in the eastern section (Figure A2.5).

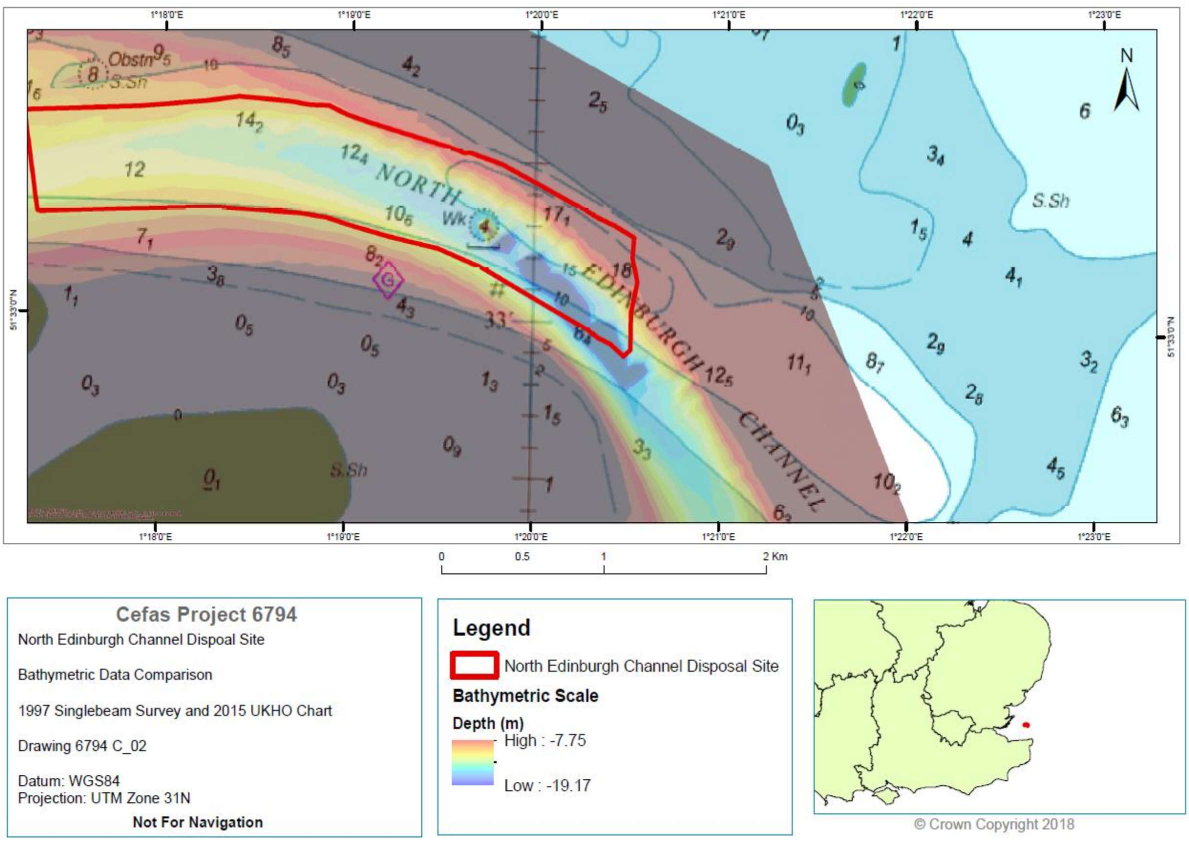

Figure A2.5: Map showing 1997 Single beam bathymetry (SBES) data (TIN Model) in comparison with UKHO chart 1607-0 (dated 2015).

Finally, a similar comparison was then undertaken based on the MBES data acquired in September 2017 under this project. The locations of the 15 m and 10 m contours on the southern bank (as survey coverage did not extend to this contour on the northern bank) were compared between the Cefas 2017 MBES data and the 2015 UKHO chart (in raster format, at 1:50,000 scale). The location of the 10 m contour showed broad agreement between both datasets, with distances ranging from a migration of <10 m to the north (in the western section) to a migration of ~30 m southwards (in the eastern section of the survey area). The 15 m contour shows less agreement, with a migration maximum of ~50 m southward in the central deep (now encompassing Target 1) and a possible enlargement of the deep section, inferred from migration of the 15 m contour ~1.2 km west (Figure A2.6).

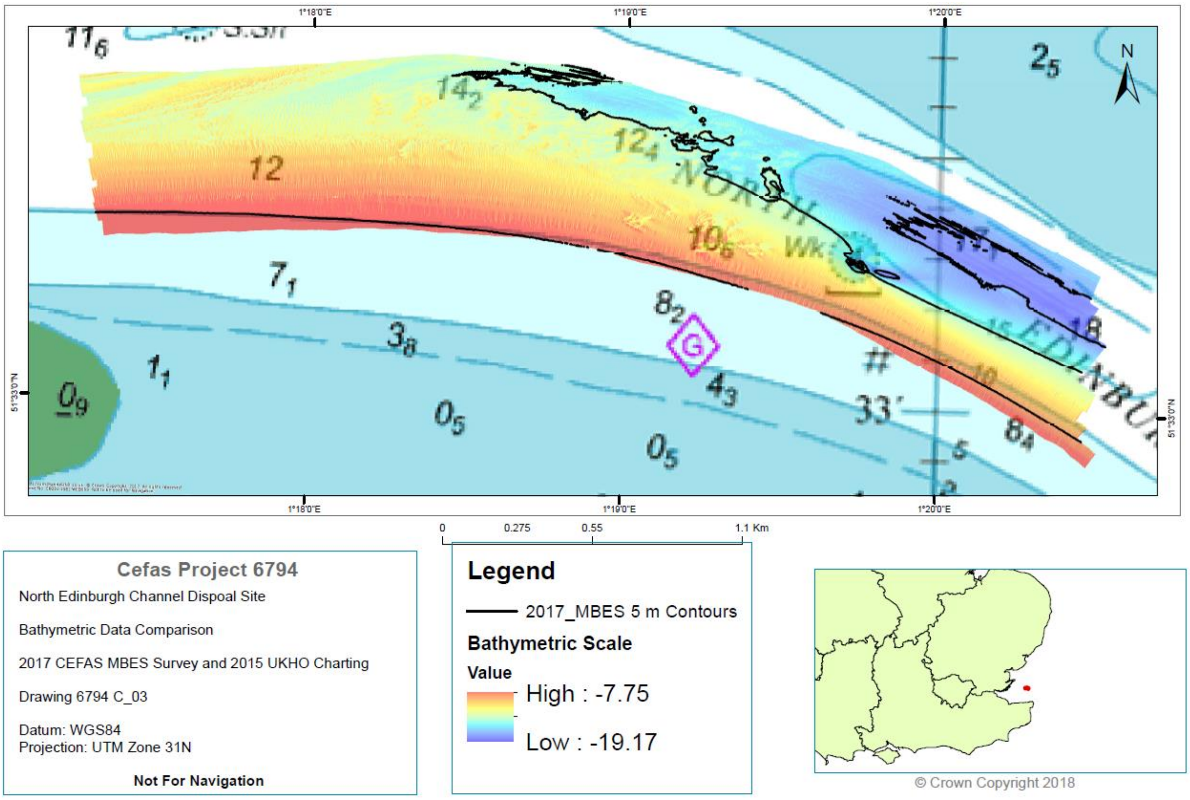

Figure A2.6: Map showing 2017 MBES data (Cefas) in comparison with UKHO chart 1607-0 (dated 2015).

To conclude, analysis of the 2017 MBES dataset, in comparison with previous data and published charts, indicates that the North Edinburgh Channel has been subject to significant bathymetric change over the last 20 years. This change is manifested by marked shifts north eastwards in the main channel, which are distinct over periods of ten years. In the shorter term (i.e. 2015 to 2017), small shifts southwards of the main contours are detectable, however these changes could perhaps be within accuracy tolerances of the comparison process. A notable expansion in area within the 15 m contour (i.e. the central deep section of the channel) has been identified as a result of a significant shift westwards of the 15 m contour. These findings may be used to aid inform decisions regarding the need to revise the exact location of the boundary of the dredged material disposal licenced area. Furthermore, these data form a valuable baseline from which any bathymetric changes associated with potential increased depositions of (capital) material may be assessed.

3 Nab Tower

3.1 Background

Nab Tower is a well-used disposal site in 30 to 40 m water depth and approximately 13 km southeast of Bembridge, Isle of Wight (Figure A3.1). The site is the main disposal location for both maintenance and capital material from ports, harbours, berths and navigational channels in Southampton, Portsmouth and the Isle of Wight. Between 1990 and 2016, over 38 million tonnes of dredged material were disposed to the site; although the site normally receives 500,000 to 750,000 tonnes per annum. Peaks over 1 million tonnes occurred in 2001, 2004, 2012 and 2014 (Figure A3.2). The largest recent capital campaign was in 2014 when 4.4 million tonnes of capital material were disposed.

In recent years, there has been a number of applications for large amounts of material to be disposed to Nab Tower from the Cowes Outer Harbour Development Project, the Southampton Approach Channel Deepening project and a deepening project for Portsmouth naval base. In view of the potential increased usage of the site, monitoring under the auspices of SLAB5 at Nab Tower during 2011 (Bolam et al., 2012) focused on the acquisition of multibeam acoustic bathymetry and backscatter data, and a follow-up survey during 2014 (Figure A3.1) provided more contemporary data to allow an evaluation of the physical and biological changes to the seabed to be conducted (Bolam et al., 2015).

More recently, the MMO granted a marine licence (L/2014/00101), which ran from May 2015 to July 2017, for the disposal of a large amount of material to the site from a large capital dredge to deepen the Portsmouth approach channel to accommodate the new Queen Elizabeth aircraft carriers. Approximately 6 million tonnes (wet weight) of clay, gravel, sand and silt material were licensed to be disposed to the site during the dredging. Monthly disposal returns from 2016 (the most recent available at the time of writing) show that only a small proportion of the licenced capital material was disposed in 2016 (Figure A3.2), therefore, it is likely that significant quantities of capital material were disposed in 2017 (although disposal returns are not yet available to confirm this). In April 2017, Cefas undertook sediment sampling at a number of stations within and in the vicinity of the disposal site from aboard the *RV Cefas Endeavour*. The sediments were processed for particle size distribution, organic carbon and macrofaunal assemblages. These data provide an assessment of the ecological situation at the end of the large disposal campaign of capital material. The macrofaunal data are compared, as far as possible, with earlier data acquired by Cefas in 2014.

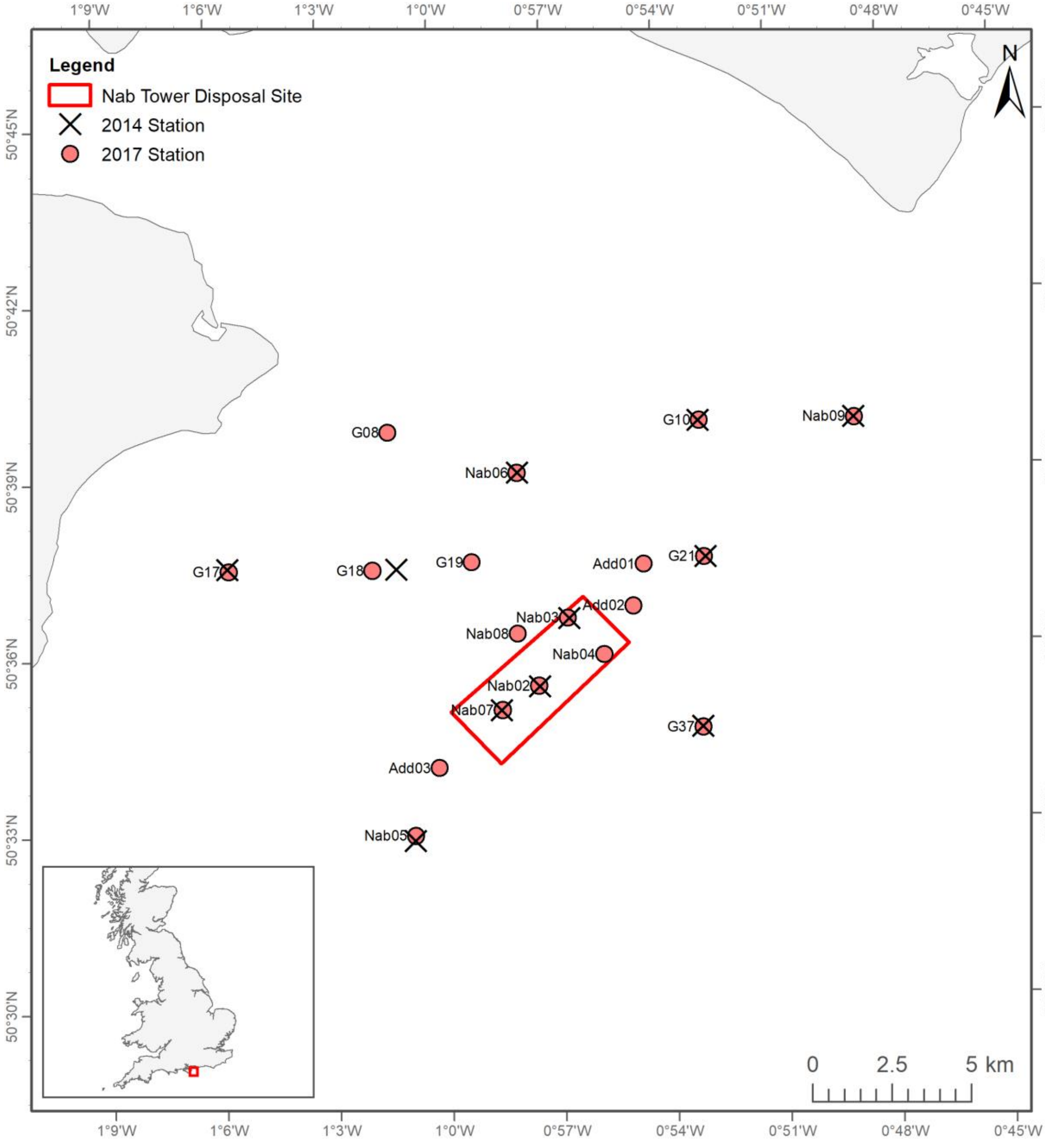

Figure A3.1: Locations of stations sampled for sediment particle size assessment and macrofaunal assemblages at Nab Tower in 2014 and 2017.

Figure A3.2. Annual (2010-2016) and monthly (2016) disposal returns for Nab Tower (WI060) in wet tonnes.

3.2 Results

3.2.1 Sediment Particle Size

The April 2017 Cefas survey revealed that sediments within the Nab Tower environ were predominantly mixed or coarse in composition, being muddy sandy gravels and sandy gravels, with some gravelly sands, gravelly muddy sands, gravelly muds, gravel, slightly gravelly sand and slightly gravelly sandy mud in 2014 and 2017 at Nab Tower (Table A3.1). Three replicates per station were analysed in 2017, while only one was analysed in 2014. Sediment compositions for all samples were assigned to one of five sediment groups, using EntropyMax (Orpin and Kostylev, 2006) (Table A3.1). The resulting sediment groups have been ordered in relation to silt/clay composition with group Nab1a having the highest silt/clay content. Due to the limited different types of sediment present, there is some degree of overlap between sediment groups. This is reflected, for example, by three muddy sandy gravel groups; Nab3a, Nab3b and Nab3c.

Table A3.1: Average sediment descriptions and statistics for each sediment group at Nab Tower (2014 and 2017).

Sediment group	Number of samples	Sample Type	Sediment description	MODE 1 (µm):	MODE 2 (µm):	MODE 3 (µm):
Nab1a	10	Polymodal, Extremely Poorly Sorted	Gravelly Mud	53.3	213.4	9.4
Nab2a	13	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand	301.8	9600.0	4800.0
Nab3a	21	Bimodal, Very Poorly Sorted	Muddy Sandy Gravel	301.8	13600.0	
Nab3b	11	Bimodal, Very Poorly Sorted	Muddy Sandy Gravel	38250.0	301.8	
Nab3c	7	Trimodal, Very Poorly Sorted	Muddy Sandy Gravel	26950.0	13600.0	301.8
Nab4a	4	Unimodal, Poorly Sorted	Gravelly Sand	603.6		
Nab5a	9	Bimodal, Very Poorly Sorted	Sandy Gravel	13600.0	603.6	

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
Nab1a	15.60	33.22	51.18	1.76	2.22	7.80	11.11	10.32
Nab2a	19.85	71.03	9.12	4.52	13.14	32.14	18.96	2.27
Nab3a	43.64	48.12	8.24	3.98	9.28	19.88	12.72	2.26
Nab3b	56.98	37.59	5.43	2.88	7.19	14.11	11.47	1.93
Nab3c	71.85	23.53	4.62	2.10	5.39	9.00	5.56	1.48
Nab4a	16.51	81.56	1.93	7.64	43.04	26.84	3.58	0.45
Nab5a	59.45	38.81	1.73	5.29	16.06	12.69	4.18	0.59

The spatial variation in the proportional representation of gravel, sand and silt/clay for each station sampled in 2017 is shown in Figure A3.3, while the percentages of silt/clay content are presented in Figure A3.4. As already indicated, sediments are classified as mixed or coarse, all having gravel, sand and mud components. Highest silt/clay content was present at Nab03 (within the disposal site).

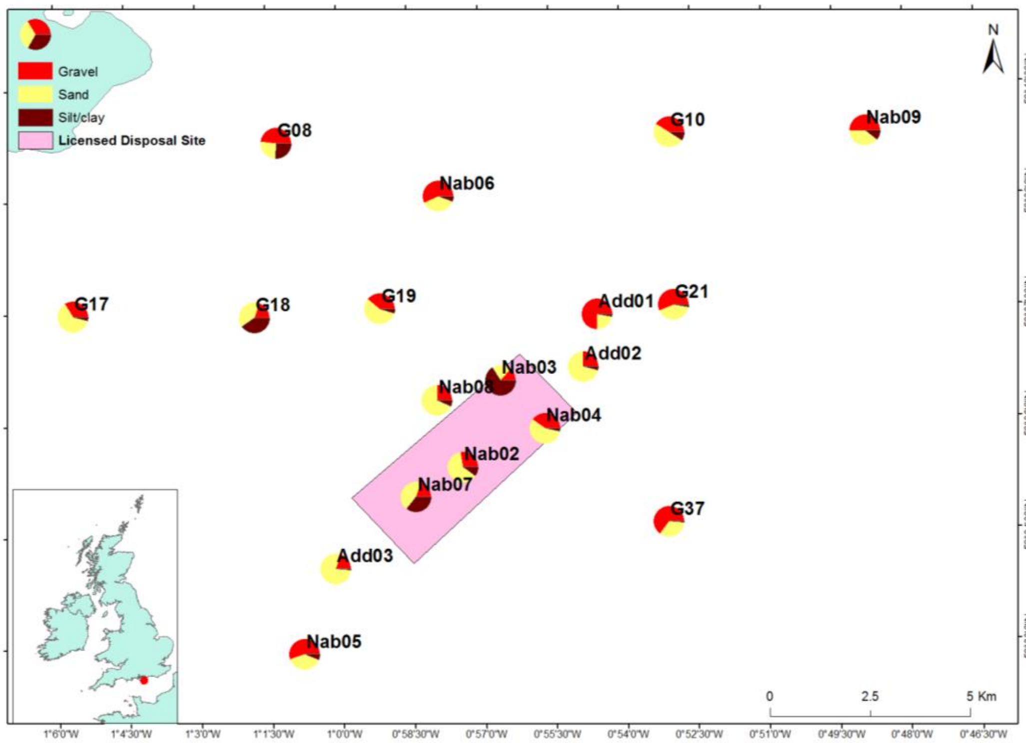

Figure A3.3. Pie charts of gravel, sand and silt/clay (average of replicates measured) at Nab Tower in 2017

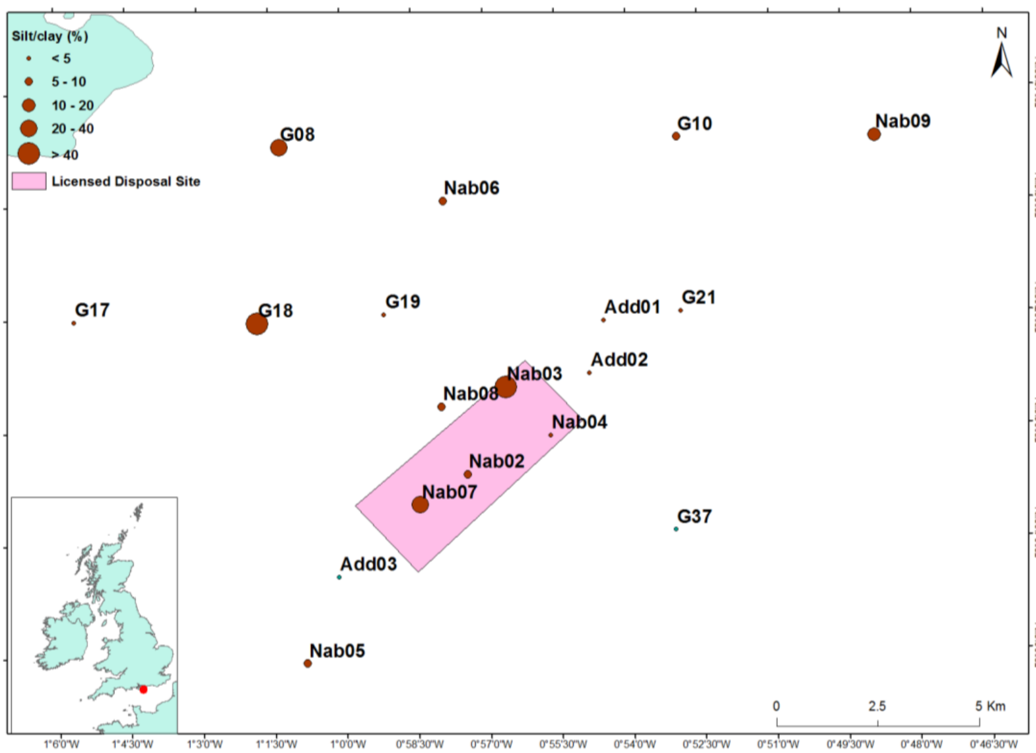

Figure A3.4. Average silt/clay content (%) of sediments sampled at Nab Tower in 2017

The temporal changes in sediment groups for stations sampled in both 2014 and 2017 (all replicates) are presented in Table A3.2, ordered in relation to the position of proximity to disposal site (as used in section 3.2.3 macrofaunal assemblages). As expected with areas with broad sediment distributions, there is some variability between replicates in terms of sediment groups. However, it is clear there are elevations of silt/clay at Nab03 (within the disposal site) in all 3 replicates measured in 2017, and these are higher than silt/clay content measured in 2014. The sediments are similar 'near' and 'far' from the disposal site, with similar sediment groups being measured at sites measured in both years. The sediments are similar at 'reference' sites between years, except at G18, where an increase in silt/clay from 0.6 % in 2014 to an average of 40 % in 2017. This latter grouping based on the 2017 data was consistent for all three replicates sampled.

Table A3.2: Sediment groups for each sampling sites collected in 2014 and 2017 at Nab Tower, ordered in relation to position of proximity to disposal site.

Position relative to disposal site	Sample code	2014	2017_A	2017_B	2017_C
Disposal	Nab02	Nab2a	Nab3a	Nab2a	Nab3a
Disposal	Nab03	Nab3a	Nab1a	Nab1a	Nab1a
Disposal	Nab04	Nab2a	Nab4a	Nab3b	Nab3c
Disposal	Nab07	Nab2a	Nab3a	Nab1a	Nab1a
Near	G21	Nab5a	Nab5a	Nab5a	Nab3a
Near	Nab05	Nab5a	Nab3a	Nab5a	Nab5a
Near	Nab08	Nab2a	Nab3a	Nab2a	Nab2a
Near	Add01	n	Nab5a	Nab3c	Nab3c
Near	Add02	n	Nab2a	Nab2a	Nab3a
Near	Add03	n	Nab4a	Nab4a	Nab4a
Far	Nab09	Nab3a	Nab3a	Nab3a	Nab3b
Reference	G08	Nab3b	Nab1a	Nab3b	Nab3c
Reference	G10	Nab3a	Nab2a	Nab3b	Nab3a
Reference	G17	Nab3b	Nab2a	Nab3a	Nab3b
Reference	G18	Nab3c	Nab1a	Nab1a	Nab1a
Reference	G19	Nab3a	n	Nab3a	Nab2a
Reference	G37	Nab5a	Nab3c	Nab3b	Nab5a
Reference	Nab06	Nab3a	Nab3b	Nab3b	Nab3b

Figure A3.5 shows silt/clay content (%) of sediments sampled at Nab Tower in 2014 and 2017, with error bars to indicate standard deviation of replicates for 2017. The samples are placed in order of position relative to proximity of disposal site as in Table A3.2. Within the disposal site, Nab02 had higher silt/clay content in 2014 than 2017, whereas at Nab03, and for 2 replicates at Nab07, there was a higher silt/clay content in 2017. Silt/clay content is similar in the 'near' and 'far' sites for 2014 and 2017. As already indicated, G18 has higher silt/clay in 2017 than 2014, as well as at G08 (based on one replicate).

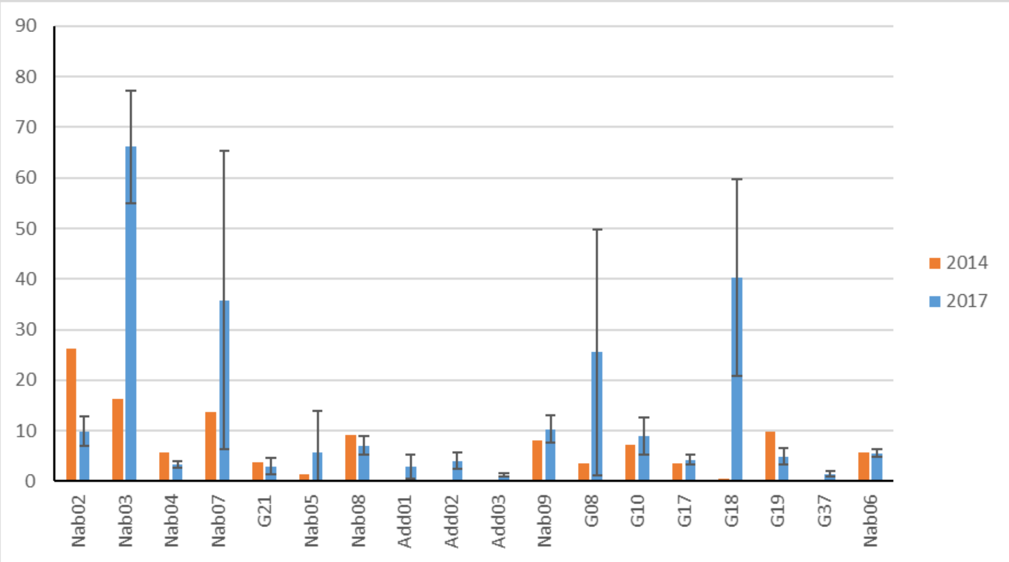

Figure A3.5. Silt/clay content (%) of sediments sampled at Nab Tower in 2014 and 2017. Error bars indicate standard deviation of replicates for 2017.

3.2.2 Sediment organic carbon

Sediment organic carbon values (in the <63 µm sediment fraction) range from 0.36 to 2.74 % (Figure A3.6) with an overall average of 1.2 +/-0.5 %. There is low variability in organic carbon concentrations across this area, and these are similar to those measured in the English Channel in 2005 as part of the regional project ME3112 (Bolam et al., 2008) average of 1.8 +/- 0.5 n = 15.

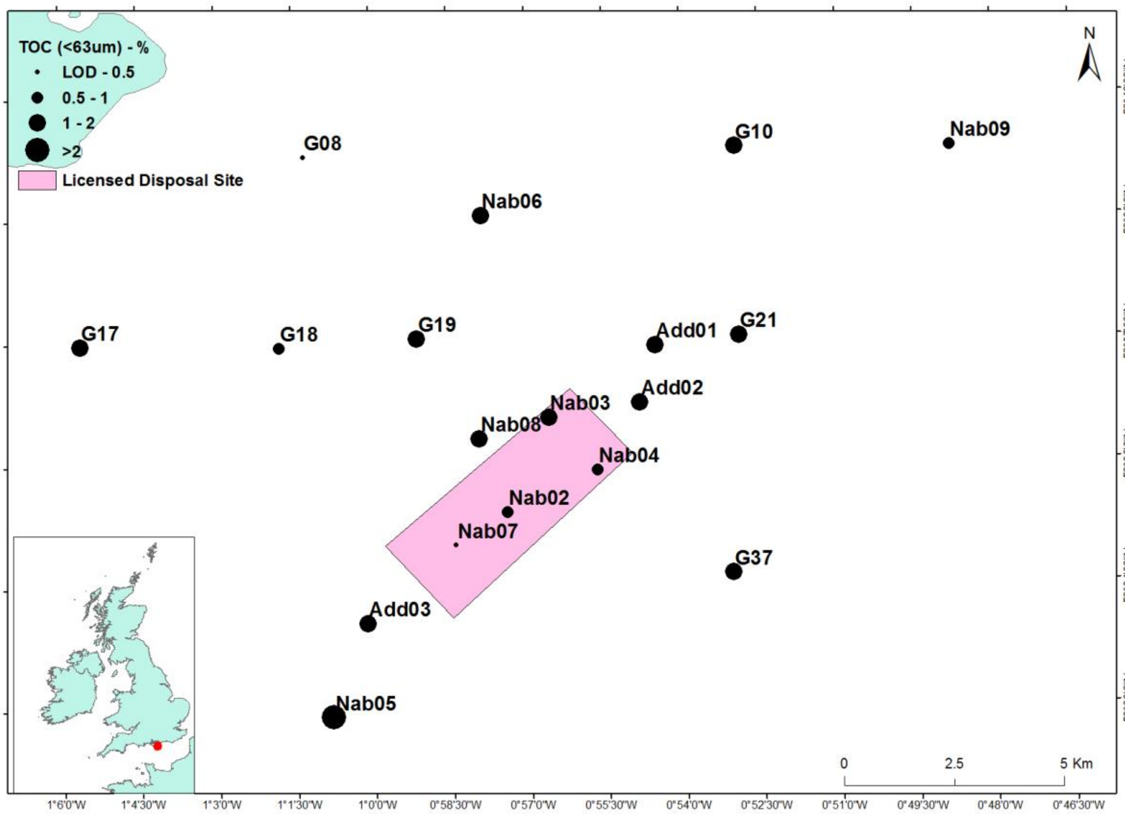

Figure A3.6. Organic carbon (%) in the <63 µm sediment fraction at Nab Tower, 2017.

3.2.3 Macrofaunal assemblages

3.2.3.1 Univariate metrics of community structure

In the 2017 survey at Nab Tower, 18 stations were sampled in replicate (3 samples at 17 stations and 2 samples at 1 station) resulting in a total of 53 samples analysed for macrofauna. Samples were collected with a 0.1m^2 mini Hamon Grab and all macrofaunal individuals from the samples retained on a 1 mm mesh sieve were subsequently identified, and enumerated and the biomass per taxon recorded. The data from the analysis were rationalised (or 'truncated') to remove or combine duplicate records, high level identifications and fragments. Juvenile taxa were also removed for the interpretation to mitigate the effects of seasonal variability on the community structure. Colonial taxa were included in species counts, but not abundance totals. For multivariate analysis colonial taxa were given an abundance value of 1.

Simple univariate metrics of the number of taxa, abundance and biomass are shown in Figure A3.7. The number of species ranged from three taxa per 0.1 m^2 (sample Nab_07_B1) to a maximum of 75 taxa per 0.1 m^2 (sample Nab_09_B1). Total abundance ranged from three individuals 0.1 m^{-2} (sample Nab_07_B1) to 1145 individuals 0.1 m^{-2} (sample Add01_C1). Macrofaunal biomass ranged from 0.008 g (wet weight) 0.1 m^{-2} (sample Nab_07_B1) to 36.327 g 0.1 m^{-2} (sample Add01_C1). When replicates were averaged per station, there was a clear trend of lower species number, abundance and biomass at the stations within and close to the disposal site (Figure A3.7).

The most abundant taxon sampled across the whole survey area was the crustacean *Ampelisca diadema* (1438 individuals from all samples), however this species was unevenly distributed, only occurring in 9 samples with the vast majority being from the 3 samples at station G10. The second most abundant taxon (1107 individuals), the bivalve *Abra alba,* was more ubiquitous occurring in 30 samples, however almost half of this abundance was accounted for from the three samples at station G10. The most commonly encountered taxon was the polychaete species *Lumbrineris cingulata*, found in 43 samples at an average abundance of six individuals per sample.

One notable taxon observed in the survey is the biogenic reef forming polychaete *Sabellaria spinulosa.* Biogenic reefs are potentially qualifying features of the EC Habitats Directive (92/43/EEC), although the taxon itself is not afforded conservation protection. Assessment of the 'reefiness' (see for example Gubbay, 2007) of *Sabellaria* at Nab Tower is not easily achievable with the current data (seabed video and acoustic data are preferable for such assessments). From analysis of the samples, fragments of *Sabellaria* tubes were noted from all except two stations (Nab02 and Nab03). It should be noted that this does not imply the presence of reef. Live individuals of *Sabellaria* were observed in several samples, although they were notably absent from many of the stations with tubes present indicating the breakdown and/or movement (by tides/currents) of the tube structures. Stations with relatively higher abundances of *Sabellaria* were outside of the disposal area, although some stations close to the boundary (e.g. Add02 and Add01) showed high abundances. The data do not support firm conclusions on the presence of S*abellaria* and any possible reef, however it appears possible that the taxon (as with some other taxa) is restricted from the disposal area due to the ongoing disturbances from disposal activities.

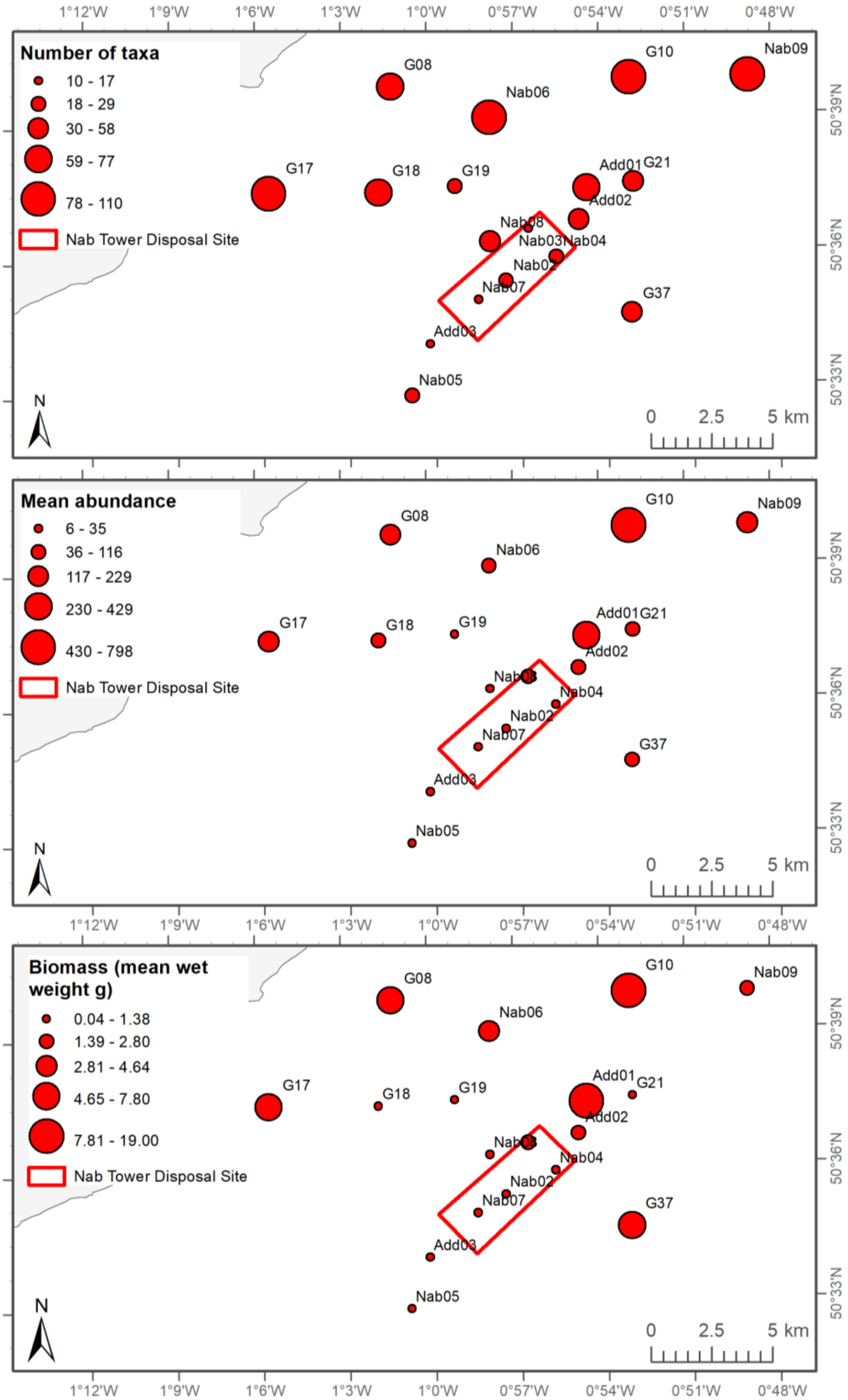

Figure A3.7. Mean number of taxa (top), mean abundance (centre) and mean biomass (wet weight g) bottoms per grab ($0.1m^2$) for 2017 samples from Nab Tower.

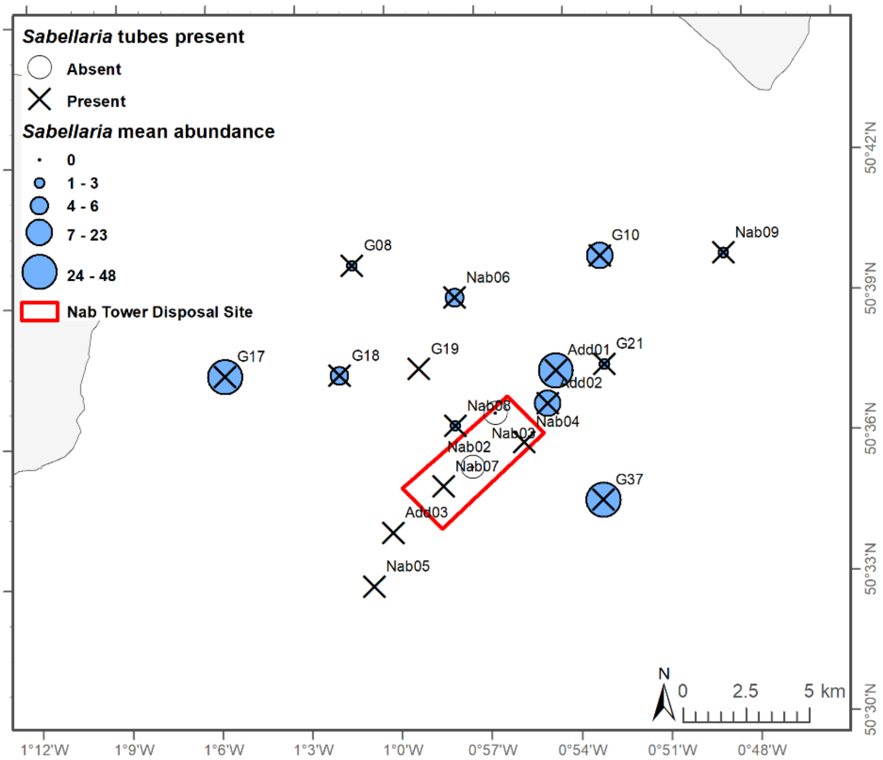

Figure A3.8. Presence of *Sabellaria* 'tubes' and mean abundance of *Sabellaria* per grab (0.1m^2) for 2017 samples from Nab Tower. Note there is no evidence of reef formation at any station from the current data.

3.2.3.2 Multivariate Analysis

Multivariate numerical analyses were conducted on the taxonomic structure of the macrofaunal abundance data. To aid interpretation of these data, the stations were factored according to their location with respect to the disposal and subsequent transport of the disposed material. The results of sediment transport modelling (Cefas, unpubl. data) were used to predict the fate of material disposed at Nab Tower (generally along a southwest-northeast trajectory) and this was the basis for allocating stations into 'disposal', 'near field', 'far field' and 'reference' groups. Following a square root-transformation and Bray-Curtis similarity resemblance, Figure A3.9 shows a nMDS ordination of the samples, illustrating the similarity (closeness of the points) of the overall community assemblages. This figure indicates there are community differences between the samples in the different test groups. For example, the 'Disposal' samples are projected on the ordination towards the top left, while, in general, the 'Reference' group samples are located towards the bottom right.

The apparent differences between the samples within and outside of the disposal site was tested for statistical significance with a one-way ANOSIM test, which tests the pairwise relationships between *a priori* groups. The test shows there is an overall significant difference between the groups (global R = 0.379; p = 0.01). Furthermore, the pairwise tests indicate (based on the value of R, the test statistic) a larger difference between the 'Reference' and 'Disposal' groups (R = 0.737; p = 0.01) and the 'Disposal' and 'Far' groups (R = 0.718; p = 0.02).

Groups of samples with similar assemblage structures can also be identified without *a priori* groups using clustering and the SIMPROF routine. To aid spatial interpretation, samples were averaged per station. This routine resulted in six clusters of stations with statistically similar (within-cluster) assemblages (5 % significance) (Figure A3.10). The clusters separated out the disposal site stations (clusters A and F), however, they also grouped one reference station (G19) into the same cluster (Cluster F). Other stations (Near, Reference and Far) were generally less distinct from one another being placed into different clusters. Plotting the clusters spatially provides further insight and the resulting map (Figure A3.11) shows the spatial trend of the clusters with the stations inside the disposal site generally distinct from those outside, and with clusters close by, but not within the disposal area (e.g. cluster E) also spatially separated. Table A3.3 gives the main (top 5) characterising taxa (from the SIMPER routine) of each cluster, the untransformed abundance of each taxa, and averaged univariate metrics for each cluster. The clusters which primarily contain the 'Disposal' and some of the 'Near' stations (particularly those to the southwest) show lower number of species, abundance and biomass suggesting that disposal may be negatively impacting the benthic communities. Notably, the 'Far', 'Reference' and some 'Near' stations display high levels of abundance, number of taxa and biomass indicating that the depressed abundance and diversity seen at the disposal site does not extend far outside the disposal area.

The previous study at Nab Tower (Bolam et al., 2016) made similar conclusions stating that: "*The results revealed that assemblages within the disposal site, together with those of the two stations sampled further offshore (to the south) of the disposal site are relatively taxon-poor and possess lower densities and biomass compared to those in more inshore, shallower areas to the north of the disposal site*." The present data show that the benthic community assemblages exhibit comparable broad spatial patterns following both the 2014 and 2017 surveys. The quantity of capital material disposed was especially high in 2014 and it was expected to be high in 2017. Therefore, the benthic communities within and nearby to the disposal site may be intermittently disturbed by the significant capital disposals or chronically disturbed by the ongoing maintenance disposals with limited additional impacts from the capital campaigns. With only two sets of survey data, both from periods of intense capital disposals, data are lacking to determine which (either chronic impacts from maintenance disposals or acute impacts from capital disposal) is most significant.

Abundance data from the 2014 and 2017 surveys were further analysed by merging the two datasets together. To avoid duplicating taxa identified to different taxonomic levels a degree of standardisation (or truncation) was required which removed or merged data entries to become common between the two datasets. Therefore, the data from the combined dataset are marginally different from the two separate datasets. Figure A3.12 shows an nMDS ordination of the station-averaged data and SIMPPROF clusters (at 5 % significance) from the combined data. This nMDS illustrates that the benthic assemblages observed in the 2014 are generally similar to those in 2017 (i.e. the 2014 data points are observed close to the 2017 data points). Additionally, the stations from the disposal area are grouped close to each other between years demonstrating that the benthic community present at the disposal site were taxonomically-similar in 2014 and 2017.

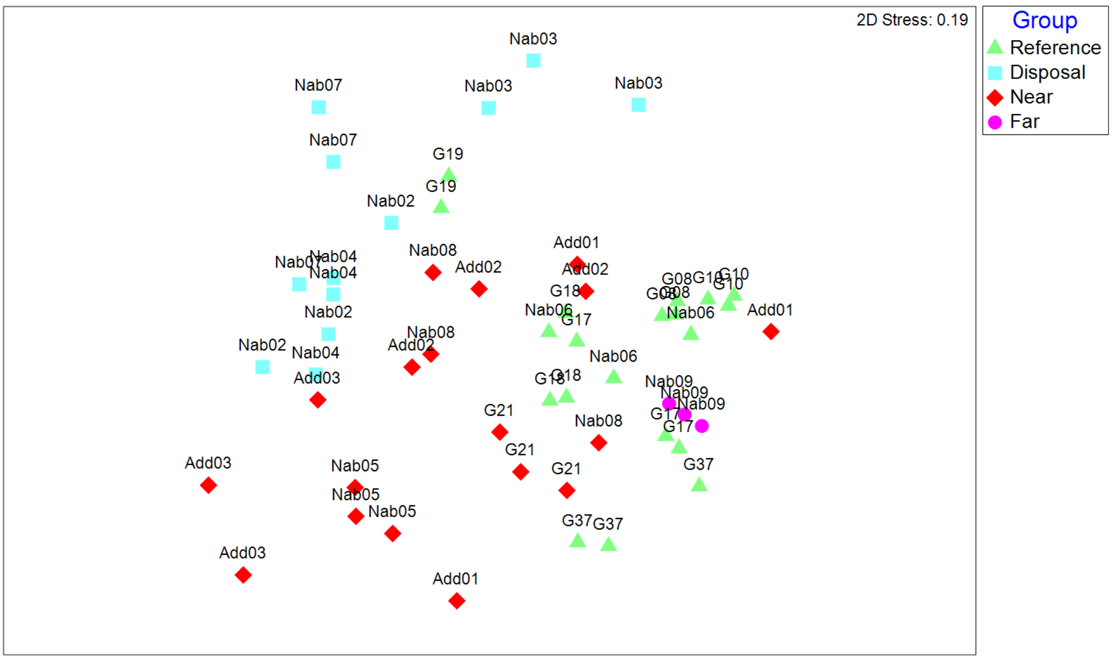

Figure A3.9. 2-D non-metric multidimensional scaling (nMDS) ordination of macrofaunal assemblages in samples from Nab Tower 2017 following square root-transformation and Bray-Curtis similarity.

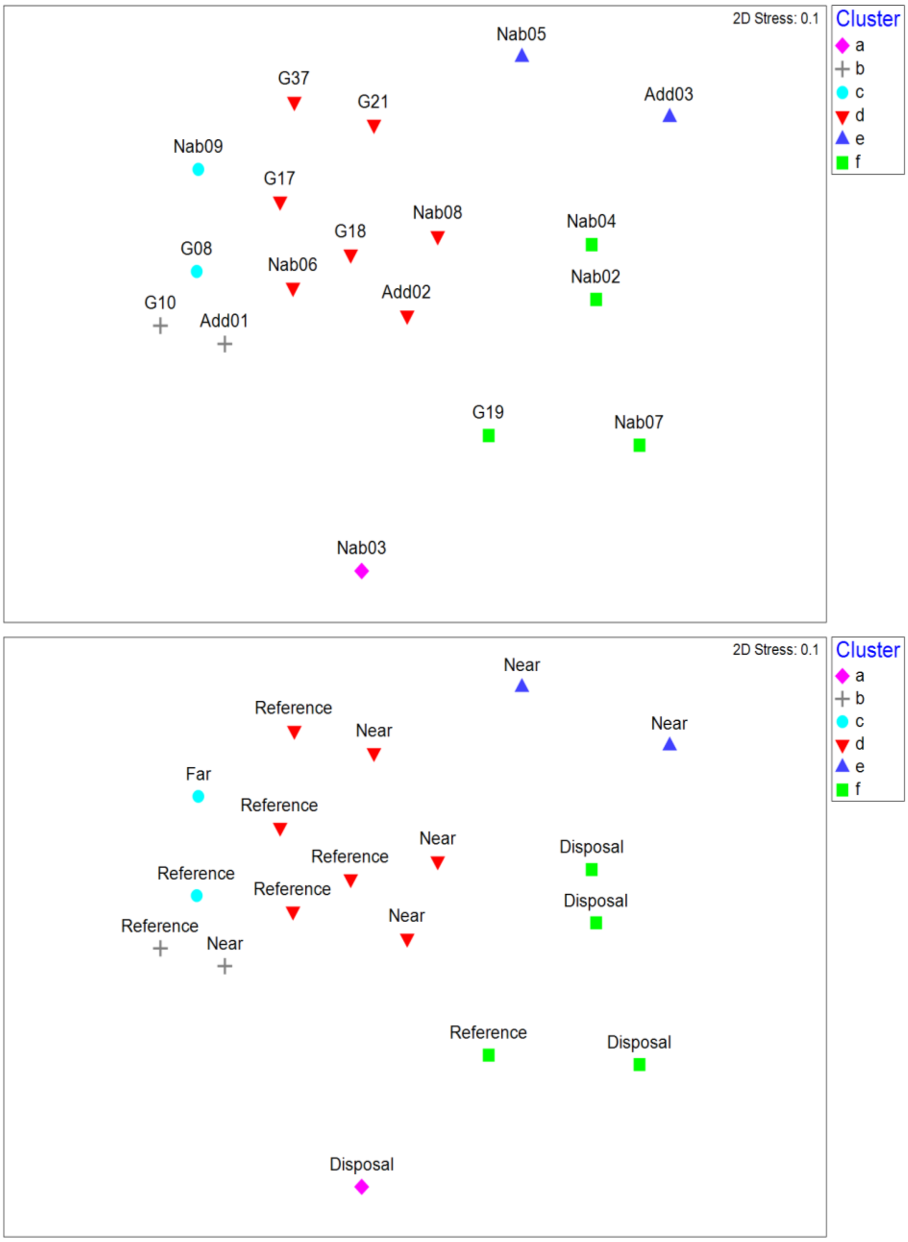

Figure A3.10. 2-D nMDS ordination of macrofaunal assemblages at stations (samples averaged) from Nab Tower 2017 following square root-transformation and Bray-Curtis similarity. Top pane shows station names bottom pane shows disposal zone groups with symbols showing SIMPROF clusters on both.

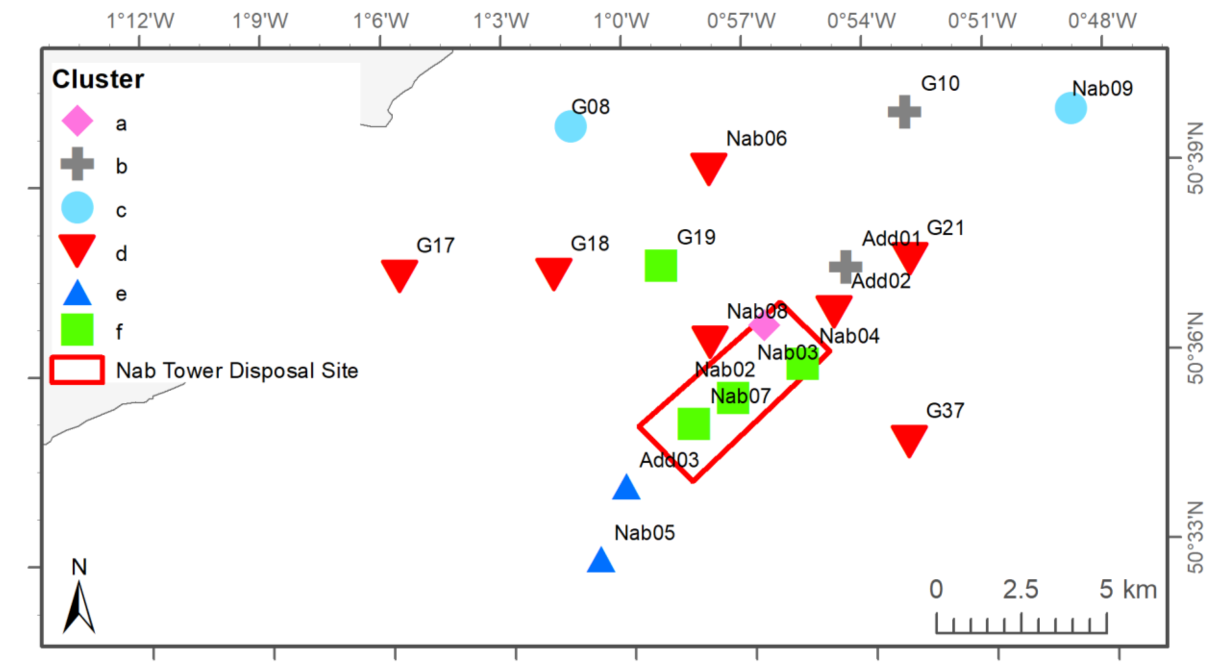

Figure A3.11. Map of macrofaunal assemblage clusters from the 2017 Nab Tower samples.

Cefas

Table A3.3: Characterising taxa (SIMPER) of SIMPFOR derived assemblage clusters from the 2017 Nab Tower macrofauna survey with averaged univariate metrics per cluster.

Cluster	Station (group)	Taxa	Average Abundance (ind m^2)	Average number of species (m^2)	Average abundance (m^2)	Average Biomass (g wet weight) (m^2)
A	NAB03 (Disposal)	*Abra alba*	57	14	69	2.4265
		Mediomastus fragilis	6			
		Nephtys hombergii	4			
		Lumbrineris cingulata	3			
		Notomastus	2			
B	Add01 (Near) G10 (Reference)	*Abra alba*	143	85	614	17.9518
		Ampelisca diadema	238			
		Sabellaria spinulosa	19			
		Nucula nucleus	17			
		Lumbrineris cingulata	11			
C	G08 (Reference) Nab09 (Far field)	*Spirobranchus lamarcki*	13	92	184	4.7017
		Amphipholis squamata	30			
		Lumbrineris cingulata	13			
		Pisidia longicornis	15			
		Notomastus	4			
D	Add02, G21, Nab08, (Near Field) G17, G18, G37, Nab06 (Reference)	*Sabellaria spinulosa*	18	67	89	3.6039
		Lumbrineris cingulata	4			
		Amphipholis squamata	2			
		Unciola crenatipalma	2			
		Abra alba	3			
E	Add03, Nab05, (Near)	*Disporella hispida*	P	23	12	0.5417
		Glycera lapidum	1			
		Glycera oxycephala	1			
		Flustra foliacea	P			
F	Nab02, Nab04, Nab07 (Disposal) G19 (Reference)	*Lumbrineris cingulata*	2	19	14	0.5152
		Nephtys cirrosa	1			
		Urothoe elegans	1			
		Notomastus	<1			
		Chaetozone zetlandica	<1			

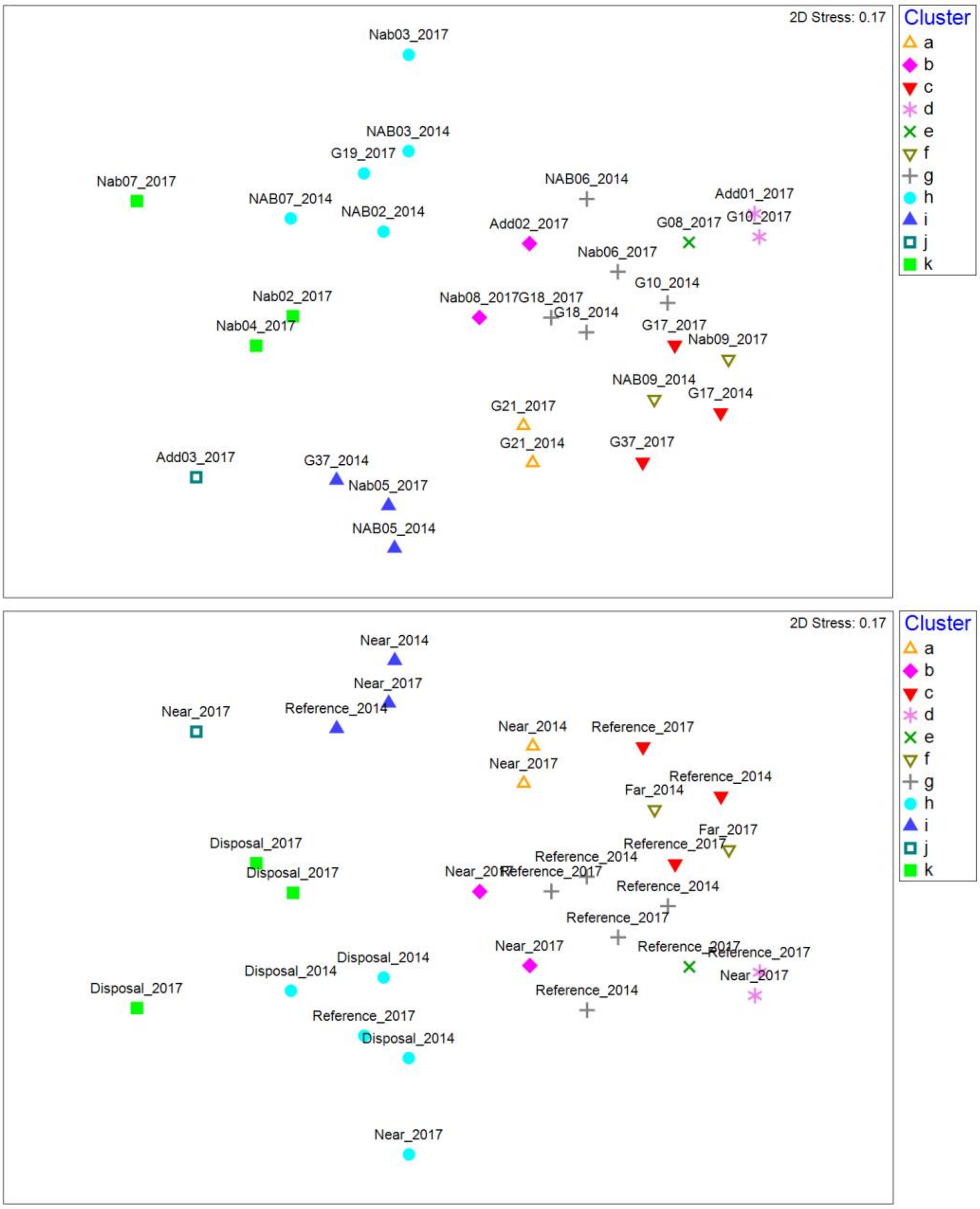

Figure A3.12. 2-D nMDS ordination of macrofaunal assemblages at stations (samples averaged) from Nab Tower in 2017 and 2014 (combined datasets) following square root-transformation and Bray-Curtis similarity. Top pane shows station names bottom pane shows disposal zone groups with symbols showing SIMPROF clusters on both.

4 Plymouth Deep

4.1 Background

Plymouth Deep is a recently-designated dredged material disposal site that was characterised to provide a sustainable site for receiving material resulting from dredging operations within the River Tamar and Plymouth Sound area. Plymouth Deep is located south of Plymouth and the entrance to the Tamar Estuary, around 9 km southwest of the Plymouth breakwater. The site is 1.5 km by 1 km in size and located in approximately 49 to 50 m water depth below Ordnance Datum Newlyn (ODN).

As part of the characterisation process, an assessment of potential impacts associated with disposal of dredged material was undertaken, including short-term changes to turbidity and suspended solids concentrations and long-term impacts to benthic invertebrate assemblages.

The first disposal campaign to Plymouth Deep (May 2017), presented an ideal opportunity to acquire data from which a number of these predictions could be tested. Under the auspices of C6794, monitoring the impacts associated with this disposal campaign focussed on two elements. These are:

1. acquisition of maximum suspended solids (SS) concentrations and turbidity concentrations during disposal and the ambient concentrations at the Western Channel Observatory (WCO) pelagic monitoring station (L4). The acquired data are used to test the accuracy of 3D modelling work upon which turbidity predictions were based. The model will be re-run using the actual disposal values, allowing an accurate assessment of the validity of the model (Section 4.2.1); and
2. acquisition of greater replication of the benthic invertebrate samples taken at the benthic L4 monitoring station. PML currently process one of the four replicates that are sampled more-or-less monthly at this site. Under C6794, the remaining three faunal replicates are to be processed for sampling periods before and after disposal to give an improved ability to make assessments of benthic impacts at the L4 station (Section 4.2.2).

The L4 sampling station (50 15.000N, 4 13.020W), located approximately ten nautical miles southwest of Plymouth, represents one of the main sites of the Western Channel Observatory (WCO). The station constitutes an oceanographic time-series and marine biodiversity reference site and is arguably one of the best-studied marine regions in Europe (http://www.westernchannelobservatory.org.uk) (Zhang et al., 2015). Water depth at the station is approximately 50 m and the seabed is comprised of fine sand. The sediment is also fairly impoverished in terms of organic material with a total carbon content of around 2.5 % of which over 84% is inorganic carbon. This means that only 0.4 % of the total sediment mass is made up of organic carbon. Intermittent observations have been made at L4 for more than 100 years, while for the past 25 years the station has been visited between 40 and 45 times per year, resulting in a rich dataset of both environmental and biological variables sampled at fine temporal resolution (Harris, 2010). These observations have shown that typically, L4 is seasonally stratified from late-April until September with environmental or biological responses and patterns being largely regulated by subtle variations in temperature, light, nutrients and meteorology (Smyth et al., 2010). More recent remote sensing and modelling approaches have allowed the L4 station to be placed in the wider regional context (Harris, 2010; Smyth et al., 2010).

Studies and data acquisition at L4 have, until relatively recently, been largely focused on pelagic sampling. However, regular observations of the benthic system commenced in 2007. At more-or-less monthly intervals, the seabed sediments are sampled using a 0.1 m^2 box corer and the macrofaunal individuals assessed following sieving on a 0.5 mm mesh sieve. The number of replicates sampled and/or processed each month since 2007 varies. The data have been used to provide new insights regarding benthic-pelagic coupling and functional responses of various macrofaunal groups to short-term seasonal changes in food supply from the water column (Zhang et al., 2015, Navarro-Barranco et al., 2017).

The L4 station represents a scientifically-important station, providing one of the few examples where robust time-series data of both the pelagic and, increasingly benthic, systems and the interactions between them have been, and continue to be, assessed. The key importance of the site is to represent a ‘natural’ example where both short-term, seasonal, and long-term temporal trends may be studied. In view of this, it is important to acquire empirical data to confirm whether any changes to ecological characteristics at the new Plymouth Deep site are within the predicted changes of the site characterisation and 3D modelling work.

4.2 Results

4.2.1 Result of observation and modelling of dredged material disposal Plymouth Deep

4.2.1.1 Introduction

Previous reports (e.g. Beraud and Fernand 2017) have detailed the setup, calibration, validation and run scenarios of the Delft 3D model used to simulate the dispersal of material at the Plymouth Deep disposal site. The aim of the present work conducted here under C6794 focusses on the observations undertaken on the sediment plume resulting during, and shortly after, the May 2017 disposal event, and a comparison of these data with those predicted by the model. In accordance with previous modelling for water depths comparable to that of the disposal site (approx. 50 m), the dispersal of material, deposition and erosion is primarily driven by tidal currents and, to a lesser extent, by waves. The purpose of the modelling is to replicate these processes. The 3D model used replicate tidal hydrodynamic forces as these will drive the dispersion of the sediment particularly in relation to peak flows, both during spring (when resuspension may occur) and neap tides (when settling of fines may occur) and also the direction of the residual transport. Wind effects may be important for the residual transport of lighter, finer sediment fractions. The turbulence closure scheme used was a 2nd order k- ε model (Delft, 2014) and the background vertical viscosity was set to 1×10^{-4} m s^{-2}.

The sediment characteristics, i.e. grain size distribution and density, of the disposed material when released was replicated by the model. However, these may change during transit of the dredger and are dependent on the material in the dredger hopper and how the material was extracted. For example, initial extractions from a site may contain a greater fine fraction than those of subsequent extractions.

No thermal or freshwater effects were included in the model. Thus, the model does not simulate the background density structure, or density driven flows, which may result from such processes (Hill et al., 2008). In the winter months, when the bulk of sediment discharge is scheduled to occur, this is not a significant issue as there is no thermal stratification and freshwater flows will only act intermittently and over a small area. However, in May, at the time of the field campaign, the water was stratified meaning differences between the model and observational data may be expected. For instance, fine sediment is likely to remain isolated above the thermocline resulting in high concentrations remaining in the surface as opposed to being spread throughout the water column. Furthermore, the water component of the disposed material (slurry) would have been sourced from the River Tamar. This water would be expected to be warmer, less-saline and thus less dense than the sea water. The greater 'buoyancy' of this material results in it acting as a self-contained 'disc' or 'lens' and persist in the water column for longer than would otherwise be expected. In this situation the larger, heavier sediment particles are expected to fall out of suspension (i.e., be deposited on the bed) while fine fractions may remain as suspended solids.

The *in situ* observations conducted by PML, conducted under the auspices of C6794, are presented in a separate PML report (Annex 1).

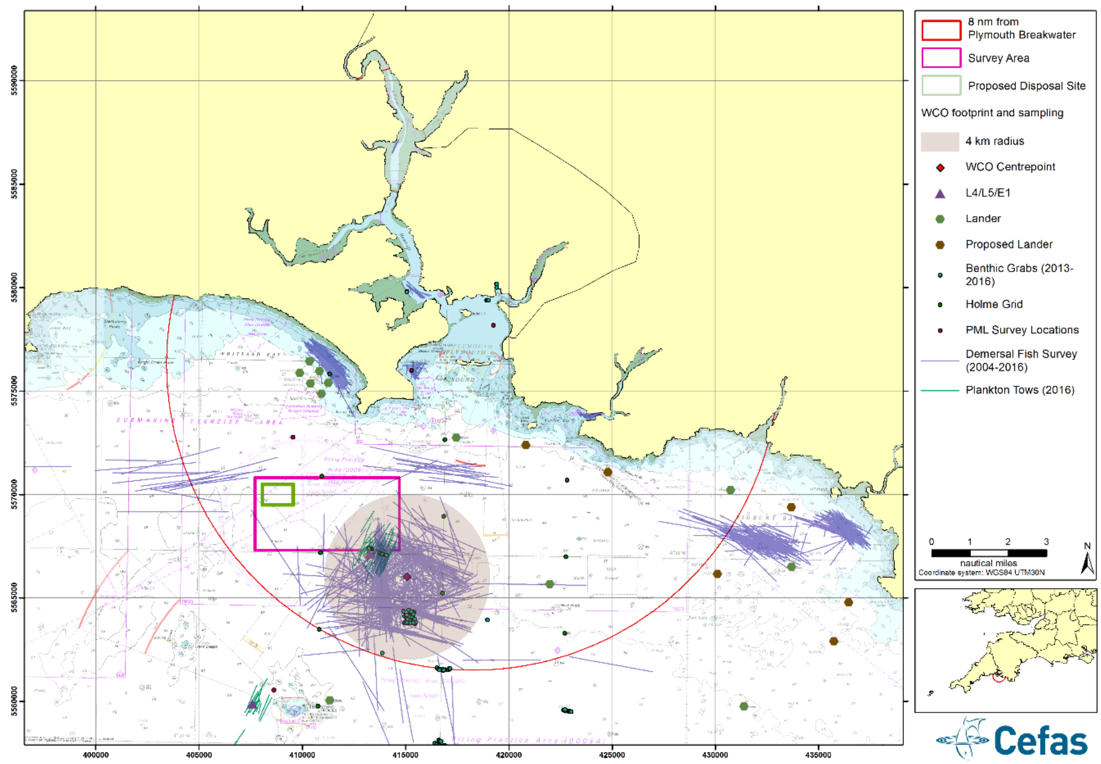

Figure A4.1. Map of the Plymouth Deep disposal site and WCO survey locations. The green box marks the disposal site, the grey shading is the WCO footprint (4 km radius) showing the disposal site location and sensitivity assessment of features within the study area.

4.2.1.2 Comparison of models and observations

Information on the dredger release times and disposal amounts were obtained from the daily disposal logs, and there were then incorporated into the model. The Delft 3D-FLOW barotropic model (with no HLES, or 'Horizontal Large Eddy Simulation') was setup in 3D using 15 sigma layers in the vertical. The model was run with an enhanced near-surface resolution to better represent wind-induced surface shear processes, and an enhanced near-bed resolution to offer an optimal representation of tidal flows, bed deposition and resuspension. The sediment was released in 'layer 3' of the model to provide a reasonable estimate of likely dredger release depth.

The observational data (Figure A4.2) do not show a clear response to the initial disposals, but do show a response to the second disposal phase as indicated with maximum concentrations up to 5 mg/l. However, the observed increase in SSC was for a greater duration and significantly less tidal modulation than in the modelling (Figure A4.3). Curiously, the observed SSC at L4 increased before the second phase of disposals. Understanding the processes resulting in variations in observed SSC is complicated as the background concentrations naturally vary as a result of salinity fluctuations due to changes in freshwater run off from the Tamar. Peaks in freshwater inputs are evident for 1st April and, to a lesser extent, 14th June (Figure A4.3). It is likely that this factor was also responsible for the increase in SSC on 28th May before the main dredge disposal phase. The effect of the disposal phase on SSC was to add to the naturally high SSC resulting from the increased freshwater input. It is possible, albeit unlikely, that the first period of disposal had contributed to the increase, as there was no response to the initial discharge and satellite imagery (Figure A4.4) on the 25th May shows a likely discharge patch significantly to the west of the L4 site.

From Figure A4.2 (upper) it is evident that the model predicted a small increase in SSC associated with the first set of disposals. However, operational problems with the dredger during this phase resulted in a low discharge rate which resulted in a small increase in SSC. After May 28th, following resolution of the dredger issue, sediment release rate was as anticipated with approximately 20,000 t of material in five days. The model indicated a direct response with a substantial increase in SSC and strong tidal variation. The peak concentration of 4 mg/l was associated with the maximum disposal volume. The modelled peak SSC decreased rapidly, but then was predicted to subsequently increase in accordance with fine material resuspension associated with increased wave heights (6th June).

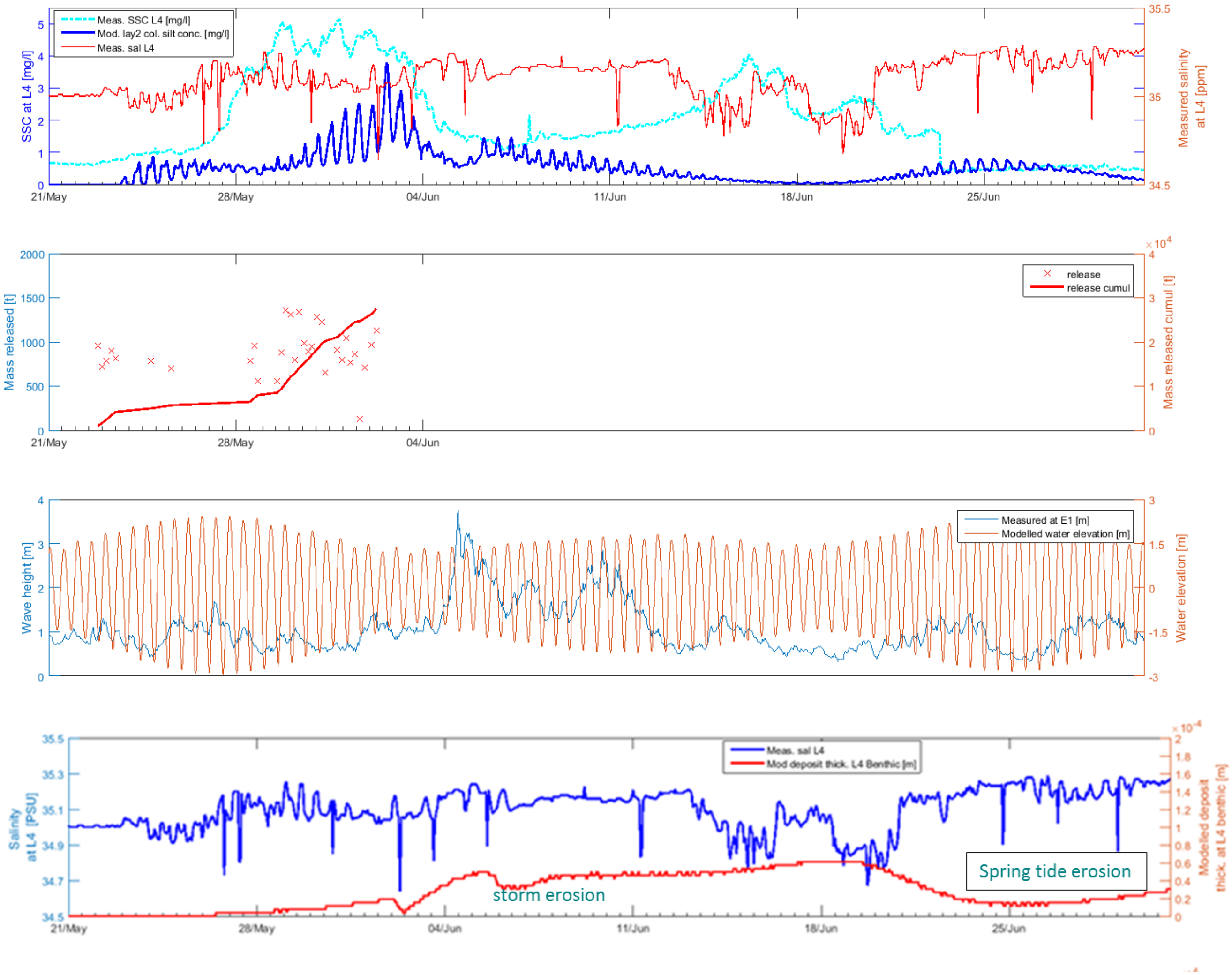

Figure A4.2.Modelled and measured data from L4. Upper figure: suspended sediment concentration (SSC mg/l; left axis), comparison of model (dark blue) and *in situ* observations (cyan). Salinity on the right axis. Date marks are midnight and 12 hrs tick marks. Middle figure: disposal amount (dry tonnes; left axis) and cumulative release (right axis; 10,000 tonnes). Lower middle: wave height (m) and tidal elevation (m). Bottom figure: bed thickness at the L4 benthic site right axis (10^- 4 m) i.e. max approx. 0.1 mm.

During winter conditions, such wave-induced fine-sediment resuspension is likely to result in re-suspended material reaching surficial waters. In contrast, during summer months vertical transfer of sediments is limited due to the barrier posed by the thermocline established *via* thermal stratification. Under these conditions, surficial waters are not anticipated to experience increased SSC following wave-induced sediment resuspension. It should be noted that the model used here does not replicate the thermal structure and thus it predicts an increase in surface suspended sediment when, due to the time of year, none is likely to occur. This is different from the initial disposal release which would have been at around 8 m. The model predicts that sediment deposition (Figure A4.2; bottom panel) at the L4 benthic site will be less than 0.1 mm.

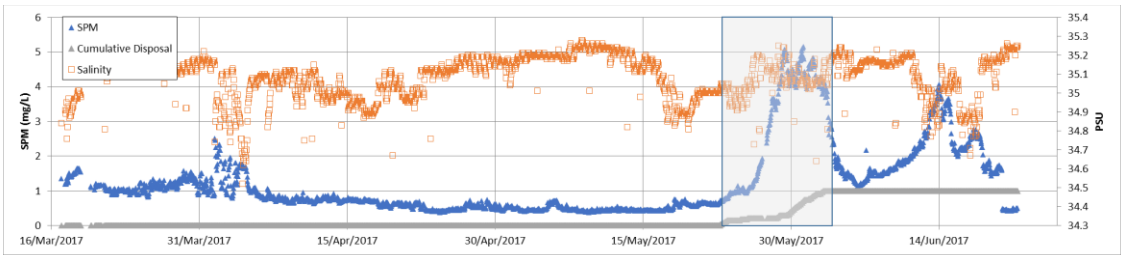

Figure A4.3. Time-series of turbidity (mg/L) and salinity (PSU) observed at the L4 buoy between 16th March and 21st June 2017, extracted from PML report. PML report states "Background salinity values are generally around 35.1 for L4. Period of dredge disposal by the Shoalway are shown as the grey rectangle with the peak in SPM being between 4 – 5 mg/L; cumulative fraction of total disposal by the Shoalway is shown as grey triangles (between 0 and 1). Secondary peak likely to be caused by a combination of riverine and dredged material resuspension / advection. Drop from 1.6 to 0.5 mg/L on 20 June 2017 due to cleaning of a small amount of bio-fouling."

4.2.1.3 *Comment on PML report*

The report produced by PML has been distributed separately (Annex 1). PML adequately performed operations that were in their control. Unfortunately, while useful, the utility of the data from the field campaign was hindered by the limited operation of the dredging vessel, the *MV Shoalway*. The reduced disposal capacity of the vessel at this time meant that the full extent of the changes in SSC could not be measured directly. Nonetheless, CTD (conductivity, temperature and depth) profiles were collected at the disposal site which clearly show a significant near-bed SSC component, indicating direct travel of a substantial fraction of the disposed material to the bed. In addition, acoustic imagery additionally showed sediment above the thermocline. Satellite imagery was available for the 25th May (Figure A4.4) at the start of the disposal campaign but, due to poor weather (cloud cover), was not available thereafter. This lack of spatial coverage that would have otherwise been afforded by the satellite data limits our capacity to put the observations at L4 into a wider geographic context. Indeed, the satellite image from the 25th May (at 11:21 am; before the discharge at 14:26 on that day) does show a high SSC to the west of the disposal site. The PML report states that this elevated SSC is likely to have resulted from the sediment disposal (which was performed at 20:33 the previous day), the fine sediment component remaining in surface waters. These conclusions described within the report are valid, PML have presented their best estimate of the duration of SSC peaks, the discussion of the observations at L4 in section 3.2 of their report is particularly insightful.

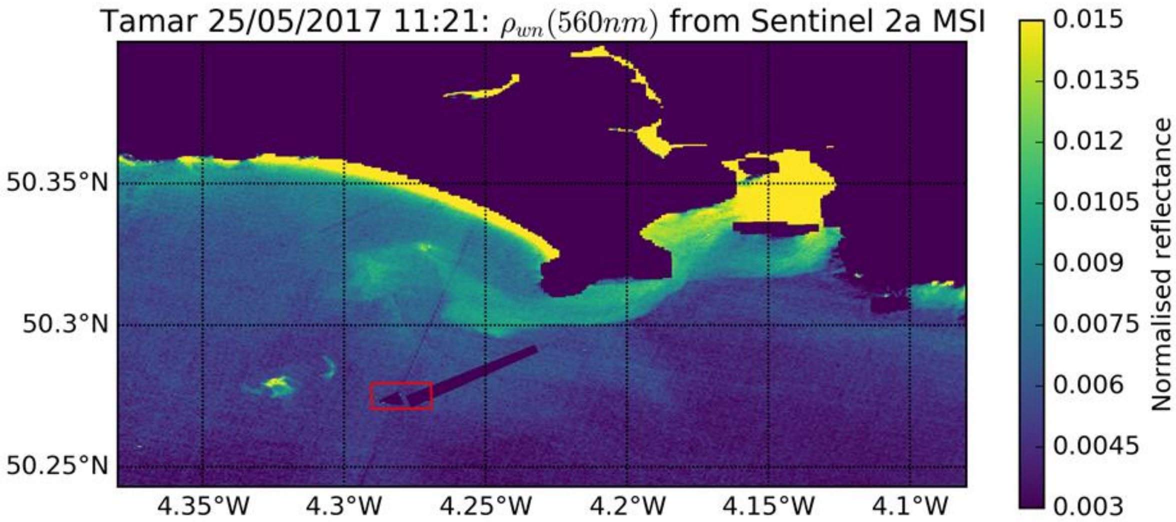

Figure A4.4. Sentinel 2a imagery obtained during the field campaign showing surface reflectance (dimensionless). Position of the PL035 licensed disposal site is shown in red, with the region in black masked out due to artefact caused by aircraft contrail. Regions of high reflectance are apparent within the Tamar Estuary, Whitsand Bay and around Rame Head. The feature to the west of the disposal site is likely caused by disposed dredge material.

4.2.1.4 Conclusions

In situ observations of the SSC resulting from the disposal of dredged material at Plymouth Deep during May 2017 and relevant modelling approaches have been combined to provide a better understanding of the likely impacts of disposal at the site. Through conducting relevant comparisons with the model, the observational data were used to assess the accuracy of the model and, therefore, whether the model represents a reliable basis regarding predictions of future impacts and, as such, as a valid tool for setting disposal limits for the site.

Plume dispersion modelling was undertaken using the Delft 3D-suite of numerical modelling software, primarily using the Flow module for tides and sediment dispersion, and included the effects of waves and wind. The observations showed a response to the discharge and increase in SSC, the modelling predicted the level of peak surface concentration (4 mg/l) to be 80 % of that observed (5 mg/l). However, there is an unquantified natural background to the observations. Thus, the modelling was demonstrated to broadly reflect peak concentrations of suspended sediment.

However, some discrepancies, for example the duration of the increased suspended load, between the model prediction and observational data remain which are currently difficult to resolve. The natural variation in salinity and SSC in this region, which result from variations in freshwater input from the Tamar, represents a particular issue to resolving such issues associated with the capacity of the model to accurately predict these aspects of the sediment movement. Understanding of this issue may have been greatly enhanced if more satellite data had been available; unfortunately, cloud cover did not allow the provision of good imagery during the May 2017 disposal campaign. One recommendation for future work is to investigate satellite imagery during periods of disposal and high SSC events at L4. This would be relatively low cost and, coupled with the ongoing L4 monitoring conducted by the WCO, would enable a better understanding of the SSC recorded at L4 and help afford a better estimate of likely acceptable maximum disposal volumes.

4.2.2 Macrofaunal assemblages at L4

4.2.2.1 Introduction

The analysis below interprets macrofaunal data from 2016 and 2017 and allows an assessment of whether the two disposal campaigns conducted during May 2017 affected the macrofaunal assemblages at L4. This was undertaken by capitalising on the more-or-less monthly sampling conducted at L4 by Plymouth Marine Laboratory. Over recent years, although four replicate box-core samples are routinely sampled, only one replicate has principally been processed. To provide a more robust dataset from which an assessment of change at L4 may be assessed, all four sampled replicates were processed from 14 time points from 2016 and 2017 (Table A4.1). These data were used to determine whether the seasonal variability in macrofaunal community metrics and assemblage structure observed in 2017 was comparable to that observed in 2016 before the disposal campaigns. Thus, we seek to demonstrate if assemblage shifts were evident in 2017 following the disposal, and if these are potentially a response to, or a result from, the disposal activity. There are a number of inherent limitations to this approach, namely:

- the assessment focusses solely on the benthic assemblage at L4, it does not make any reference to benthic changes at any other area that may or may not be affected by disposal activity;
- the assessment is based on data solely from two years and relies on the assumption that seasonal variability in 2016 represents natural seasonal variability for the site, i.e., whether 2016 is a 'normal' year. We do not have sufficient data (additional years) to quantify how representative data from 2016 are for the station;
- the approach is limited to assessing the potential short-term effects of disposal. Further data would be needed to address the possibility of long-term changes associated with the disposal campaign; and
- this assessment focuses solely on the macrofaunal component of the sediments. Potential impacts on other biological groups associated with the seabed (e.g., epifauna, meiofauna) are outside the scope of this assessment.

Table A4.1. Sampling dates in 2016 and 2017 from which replicate (four) macrofaunal data are analysed under C6794. Dates in yellow are prior to any disposal at Plymouth Deep, those in blue are post-disposal.

Month	2016	2017
January	-	-
February	-	-
March	15th	16th
April	-	28th
May	5th	10th
June	16th	15th
July	21st	15th
August	25th	11th
September	-	-
October	14th	4th
November	-	-
December	2nd (NB: only 1 sample)	-

4.2.2.2 Faunal description and univariate measures

Macrofaunal taxa were identified, enumerated and biomasses (wet weight) assessed from 53 samples. The data from the analysis were rationalised (or 'truncated') to remove or combine; duplicate records, high level identifications and fragments. Juvenile taxa were retained in the data so their seasonal changes on the community structure would be represented by the analysis. The juvenile taxa were not combined or truncated with the adult taxa, although they were marked in the data so changes driven by juveniles could be easily identified.

Post truncation, a total of 339 taxa were recorded from all samples. This included 141 annelid (segmented worms) taxa, 108 arthropod taxa, 61 molluscan taxa and 29 other phyla. Thirty-seven rows were marked as representing juvenile taxa.

The most abundant taxa overall were the polychaete *Lumbrineris cingulata* (occurring in all 53 samples at an average abundance of 26 ind. 0.1 m^{-2}), the amphipod crustacean *Ampelisca tenuicornis* (occurring in 52 of the samples at an average abundance of 14 ind. 0.1 m^{-2}) and the echinoderm (Pea urchin) *Echinocyamus pusillus* (occurring in 50 of the samples at an average abundance of 12 ind. 0.1 m^{-2}). Other common taxa occurring in >50 samples, were the eunicid polychaetes *Podarkeopsis capensis* and *Poecilochaetus serpens*.

Biomass, as is typical in marine assemblages, was dominated by few large bodied individuals occurring rarely in the data. The taxon Actiniaria (most typically anemones) accounted for the largest proportion of the biomass (19 % of the total). Of the top ten taxa ranked by biomass, the most commonly occurring and abundant was the capitellid polychaete *Notomastus* (occurring in 45 samples, at an average abundance of three ind. 0.1 m^{-2}, with a total (wet) biomass of 17.14 g).

To describe the temporal changes in faunal assemblages at L4 the top 10 characterising taxa (in terms of abundance) from each sample period are given in Table A4.2. In this table the font size has been varied to indicate the top five taxa in each sample. This table illustrates that, on the whole, the main characterising taxa remain consistent over time at L4 with *Lumbrineris cingulata, Ampelisca tenuicornis,* and *Echinocyamus pusillus* always present in relatively high numbers in the samples. Other taxa show short-term increases in abundance, such as the terebellid polychaete *Loimia medusa* which occurred in high abundance in April and May 2016, but was generally absent at other times. Notably few juveniles were present in the top ten charactering taxa, indicating that juvenile recruitment does not have a strong influence on the overall community structure.

Univariate metrics of replicate-averaged number of taxa, abundance biomass, evenness (Pielou's J') and diversity (Shannon H') are shown in Figure A4.5. These plots show that the trend in these metrics over the 2016 and 2017 data are similar, with error bars (95 % confidence limits) overlapping. Particularly notable is that there is no observable change in any metric after the disposal campaign in May 2017 (calendar day 141). Meanwhile, mean numbers of species, abundance and diversity of the L4 assemblage are consistently higher during June to October 2017 than they were in 2016. This implies that there is no detectable short-term impact on the benthic community univariate metrics at L4 from the disposal activity. Any subtle changes in species composition are explored by means of multivariate analysis in section 4.2.2.3.

Table A4.2: Top characterising macrofauna (by abundance) at each sampling time at L4. Values show average abundance (per 0.1 m^2). Top ten most abundant taxa per sampling period are shown. Font size represents the highest values for each sampling period. The double line column boarder indicates post disposal sampling events. *Only one sample was reported in December 2016.

Month	March	May	June	July	Aug	Oct	Dec*	March	April	May	June	July	Aug	Oct
Day_Year	77_2016	125_2016	167_2016	202_2016	237_2016	287_2016	336_2016	74_2017	117_2017	129_2017	165_2017	185_2017	222_2017	276_2017
Lumbrineris cingulata	27	25	18	25	34	35	56	11	26	26	23	26	2	34
Ampelisca tenuicornis	6	5	1	7	12	19	23	13	15	9	10	14	42	30
Echinocyamus pusillus	39	14	11	2	12	5	7	11	10	12	8	3	3	4
Loimia medusa	0	0	0	0	0	0	0	0	33	88	6	0	0	0
Poecilochaetus serpens	6	2	3	3	8	15	14	5	9	14	15	4	12	14
Peresiella clymenoides	3	7	4	2	7	8	15	2	13	9	14	7	15	16
Mediomastus fragilis	3	7	10	20	9	10	4	2	14	3	2	20	5	4
Cerianthus lloydii Juv	3	4	7	18	3	0	0	0	13	18	15	5	1	1
Photis longicaudata	7	1	7	2	6	11	0	3	7	2	19	7	4	7
Magelona minuta	3	5	1	5	5	7	5	1	15	6	1	4	5	9
Abra alba	4	5	11	2	5	5	0	1	1	8	5	5	12	5
Phaxas pellucidus Juv	3	3	9	9	4	3	1	0	1	3	8	5	16	7
Amphiura Juv	6	3	3	3	8	13	0	2	1	5	5	9	7	5
Nemertea	2	4	3	3	5	5	6	1	4	5	5	6	4	6
Podarkeopsis capensis	5	6	2	4	8	2	3	2	4	3	5	4	2	3
Magelona alleni	1	3	2	2	3	4	2	1	5	4	5	8	4	3
Nephtys Juv	7	5	3	4	4	4	2	2	1	1	3	2	2	5
Isaeidae	8	2	3	4	5	8	0	0	1	2	0	3	3	2
Dipolydora coeca	1	2	1	2	6	5	0	3	5	3	2	4	2	4
Tharyx #1	1	3	1	4	3	3	3	2	3	2	4	2	3	4
Spiophanes kroyeri	3	2	4	6	4	3	3	0	1	1	3	2	1	2
Terebellides stroemii	1	0	0	2	7	3	5	1	0	1	3	4	5	5
Notomastus	3	2	3	2	2	4	1	2	1	1	2	4	2	2
Cerianthus lloydii	0	1	9	0	1	2	0	1	2	11	3	1	0	0
Spiophanes bombyx	1	0	2	2	2	1	2	1	1	3	3	3	5	5
Polycirrus	3	2	2	3	3	2	3	1	2	1	1	1	3	1
Nephtys hombergii	7	1	2	1	3	2	0	2	2	2	1	1	1	2
Diastylis bradyi	1	1	1	3	3	10	0	0	1	1	1	2	3	1
Ampharete lindstroemi	1	0	0	0	1	1	1	1	1	1	2	2	3	10
Diplocirrus glaucus	2	1	1	1	2	2	0	0	3	1	3	3	3	2
Phoronis	1	2	1	1	3	1	0	0	2	1	1	8	1	2
Chaetozone gibber	0	1	1	1	2	1	3	2	2	1	2	1	3	2
Eumida sanguinea	0	0	0	0	1	1	1	1	0	0	9	2	0	0
Lucinoma borealis	3	1	0	1	0	0	0	0	0	0	1	0	1	2

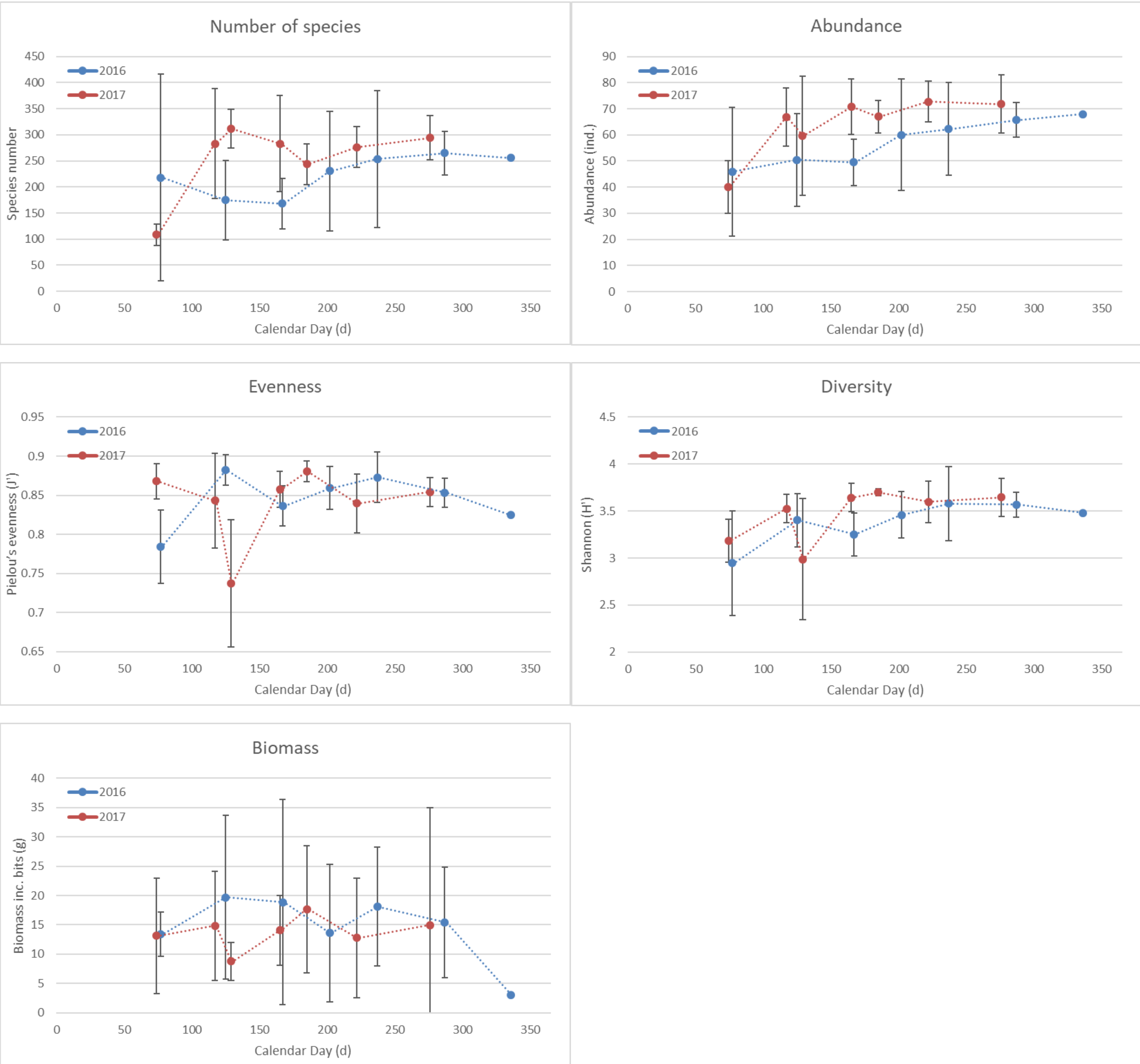

Figure A4.5. Averaged univariate metrics (±95 CI) of the benthic macrofaunal assemblages at L4 from 2016 and 2017.

4.2.2.3 Multivariate analysis

Multivariate numerical analyses were conducted on the taxonomic structure of the faunal abundance and biomass data. To aid interpretation of these data, the stations were 'factored' according to their time (month, year and calendar day) and pre- or post-disposal. Various transformation techniques have been used (including non-transforming) on the data to explore abundance changes in the data.

Figure A4.6 shows a nMDS ordination of the samples points, illustrating the similarity (closeness of the points) of the overall community assemblages. This ordination is based on non-transformed data to allow the changes in abundance expected in seasonal data to be apparent in the results. This figure illustrates that while there is a spread of points (as may be expected in temporal data), there is no clear departure from the centre of post-disposal data points. Formal testing of this with an ANOSIM test shows that there is no statistical difference between the 'pre' and 'post' disposal groups ($\rho = -0.001$, $p = 0.44$) (note that this test does not account for seasonal changes and only tests for a change in the 'post' group outside of the variation in the 'pre' group). This suggests that there are no evident changes in the community structure observable in the data following the disposal activity.

Sample replicates were averaged and a series of nMDS plots created with trajectories of the progression of the assemblages by calendar day, separated for the 2016 and 2017 data (Figure A4.7). This enables the temporal changes in the community to be observed and compared between the two years, the important observation being if there is any change in the progression of the assemblage between 2016 and 2017 which can be attributed to the disposal activity. The first three plots in Figure A4.7 show the abundance data un-transformed, with a square root-transformation and, finally, with a fourth root-transformation. In each plot the blue (2016 data) and red (2017 data) lines are closely aligned, with the progression over time generally bringing the two trajectories closer together. While there is a noticeable difference between the years at the beginning of the year (e.g. comparing sample 77_2016 and 74_2017), as the season progresses the assemblage types align more closely, with the final data points (287_2016 and 276_2017) being projected in very close proximity to one another. This trend in the plots in apparent with and without data transformation demonstrating that the changes to species composition and species abundance follow the same pattern. The final plot in Figure A4.7 is based on the untransformed biomass data. Biomass data can be heavily influenced by the occurrence of few large bodied individuals and therefore seasonal changes can be harder to detect in the data. This is apparent in the resulting nMDS ordination which does not show the same temporal trajectory as the abundance data. However, akin to the situation observed based on the abundance data, the biomass-based plot shows no evidence of a deviation in the post-disposal 2017 data. Changes observed are within the range of changes observed in the pre-disposal data.

In summary, based on a number of univariate metrics of community structure, and abundance- and biomass-based multivariate analyses, there is no indication that the macrofaunal assemblages sampled at L4 during 2017 show any deviation from those in 2016. These findings must be embraced with due regard for the limitations of the approach taken here under C6794 described earlier in Section 4.2.2.1. In particular, this assessment pertains solely to the detection of potential impacts resulting from the disposal campaign conducted during May 2017; it cannot be used to provide an assessment of potential effects of ongoing disposals associated with the longer-term use of the site. On the assumption that Plymouth Deep is to be the recipient of routine material from the Plymouth region, it would seem prudent to sanction further comparable assessments over longer temporal periods (depending on the realised disposal regime).

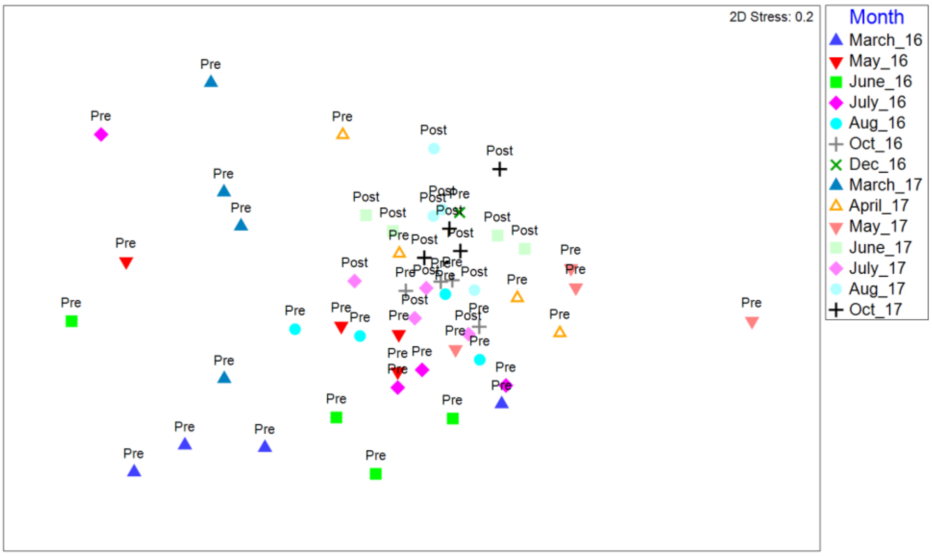

Figure A4.6. Non-metric MDS ordination of all samples from L4. Symbols indicate the month and year of the data point and labels show pre- or post-disposal activity (May 2017) at Plymouth Deep.

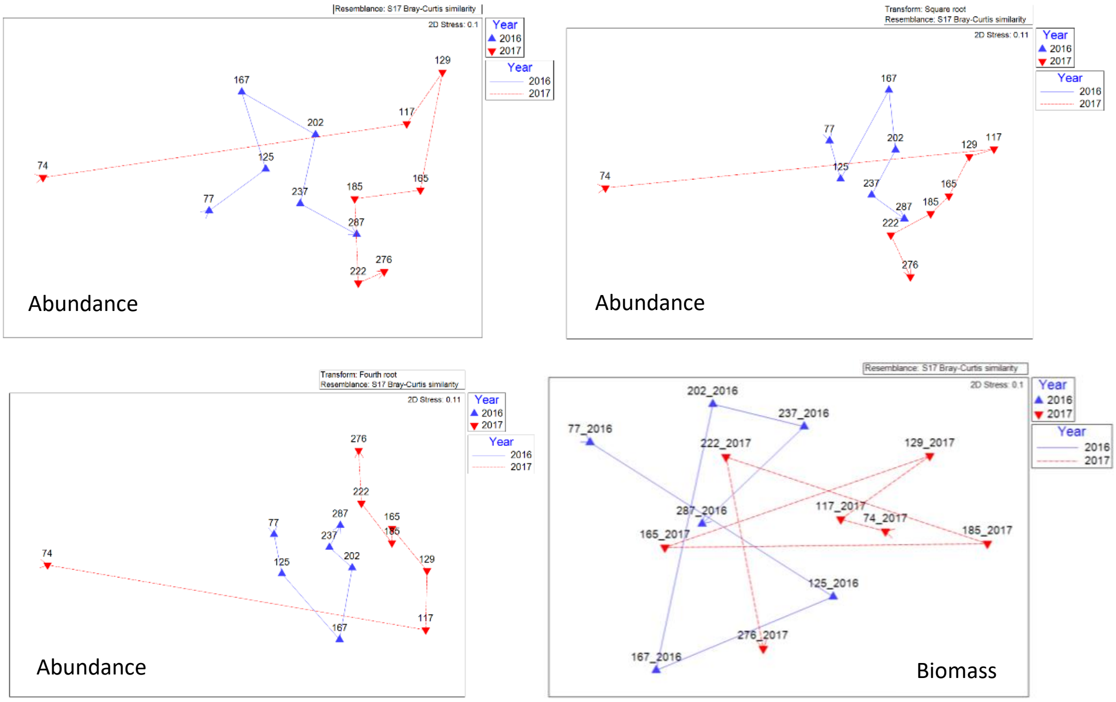

Figure A4.7. Non-metric MDS ordinations with temporal trajectory of replicate averaged macrofaunal samples from L4.

5 Barrow-in-Furness

5.1 Background

The Barrow-in-Furness (IS205) dredged material disposal site is situated off Morecambe Bay on the northwest coast of England at an approximate depth of 20 m. Earlier studies have shown sediment pathways in the area to be complex but an offshore transport (i.e., westerly) is dominant. IS205 was commissioned during 1991 in response to the need to dispose of a large volume (8 MT in total) of mixed capital material resulting from the lengthening and deepening of the access channel to Barrow Docks (Ware et al., 2010). The material was largely comprised of silty material from the docks and dock entrances along with sand, gravel and clay from the approach channel. During subsequent years, this site has continued to receive small amounts of maintenance dredged material and occasionally, small amounts of capital material (Ware et al., 2010).

The MMO have recently received a variation to an existing marine licence to grant the disposal of approximately 400,000 m^3 from Anchorsholme. It has been concluded that IS205 offers the most suitable site for receiving this material but, as this quantity represents a notable increase in capital material compared to recent years, the MMO consider it judicious to monitor possible impacts resulting from the disposal operations. Indeed, while this site receives modest quantities of maintenance material per annum, averaging 680,000 wet tonnes each year since 1992, capital material has not been disposed of to IS205 since 2003.

Monitoring at IS205 by Cefas was first conducted as far back as 1991 as a response to the large capital campaign at that time, and sampling continued in subsequent years until 1997 and, more recently, in 2007 (Ware et al., 2010). During those years, the same stations have been sampled for sediment granulometry and benthic assemblages (Figure A5.1); these represent a suitable set of historic data with which contemporary data may be compared. In 2017, sampling under C6794 targeted these five stations; two stations within the site and three along a transect to the west of the site (all replicated; Figure A5.1), for sediment particle size and macrofauna. The resulting data, reported here, provide an important example where the impacts associated with a relatively large capital disposal campaign may be assessed (see section on Nab Tower in this report for another example).

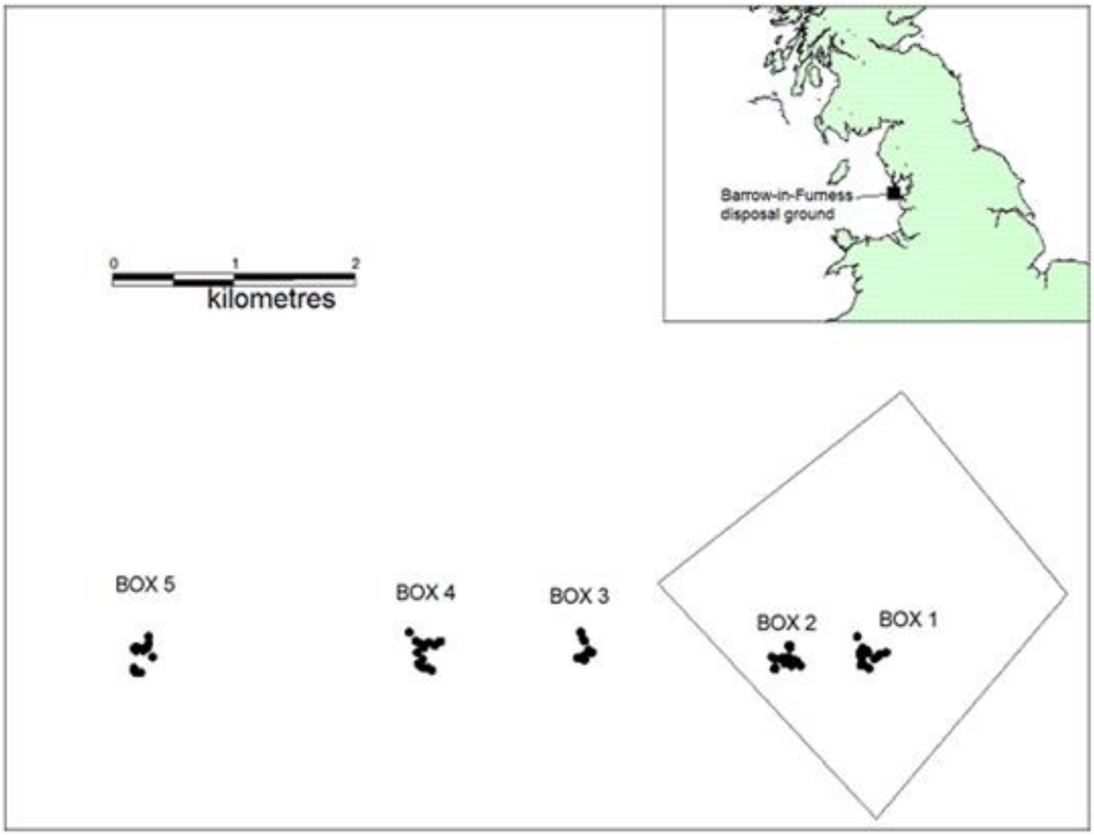

Figure A5.1: Barrow-in-Furness disposal site and the locations of stations previously sampled by Cefas during the 1990s and 2007.

5.2 Results

5.2.1 Sediment particle size

Sediments sampled at Barrow were predominantly slightly gravelly sands and slightly gravelly muddy sands with some gravelly sands, gravelly muddy sands, sands and gravelly mud (Figure A5.2 and Figure A5.3). These show that the highest silt/clay contents were located at Box04. Overall, there was relatively low variability in silt/clay content with 16 out of the 21 samples containing less than 1% silt/clay. This is likely to result from the high sediment transport regime known to be present in this area.

No sediment particle size data are available for 1993, and particle size methodology differs between samples analysed in 1991, 1996, 1999 when compared with those measured in 2007 and 2017. Replicates (three) were measured in all years. The 1991 silt/clay content has been adjusted using method comparison data to minimise the influence of these method differences for temporal assessment. However, sediment groups have not been derived as these are likely to be affected by method differences.

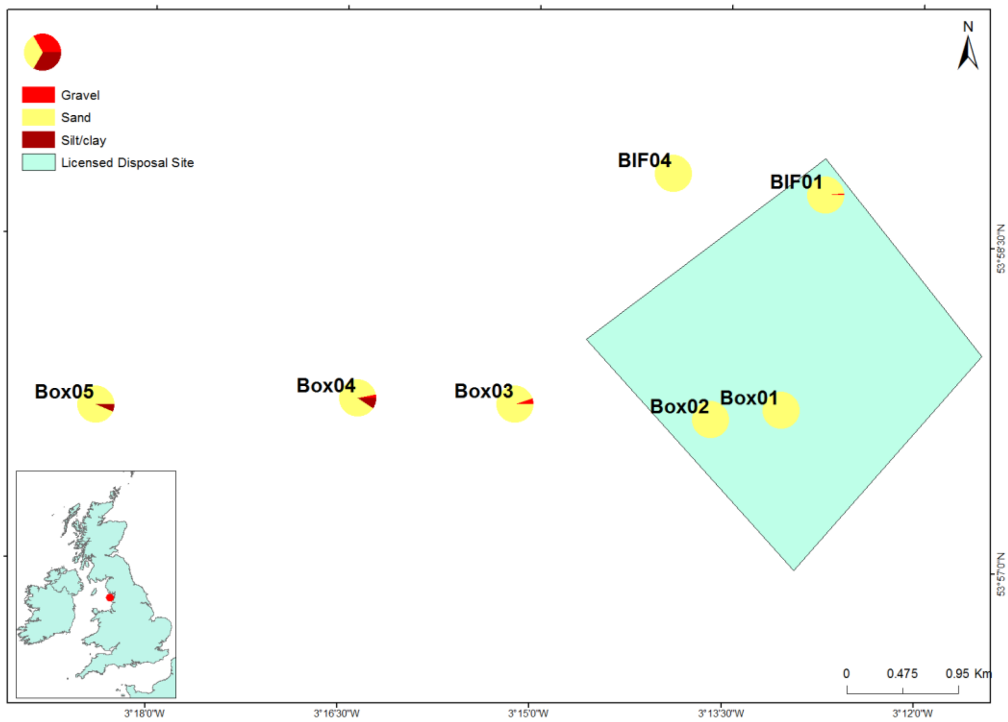

Figure A5.2: Pie charts depicting the proportions of gravel, sand and silt/clay (average of replicates measured) at Barrow in Furness, 2017.

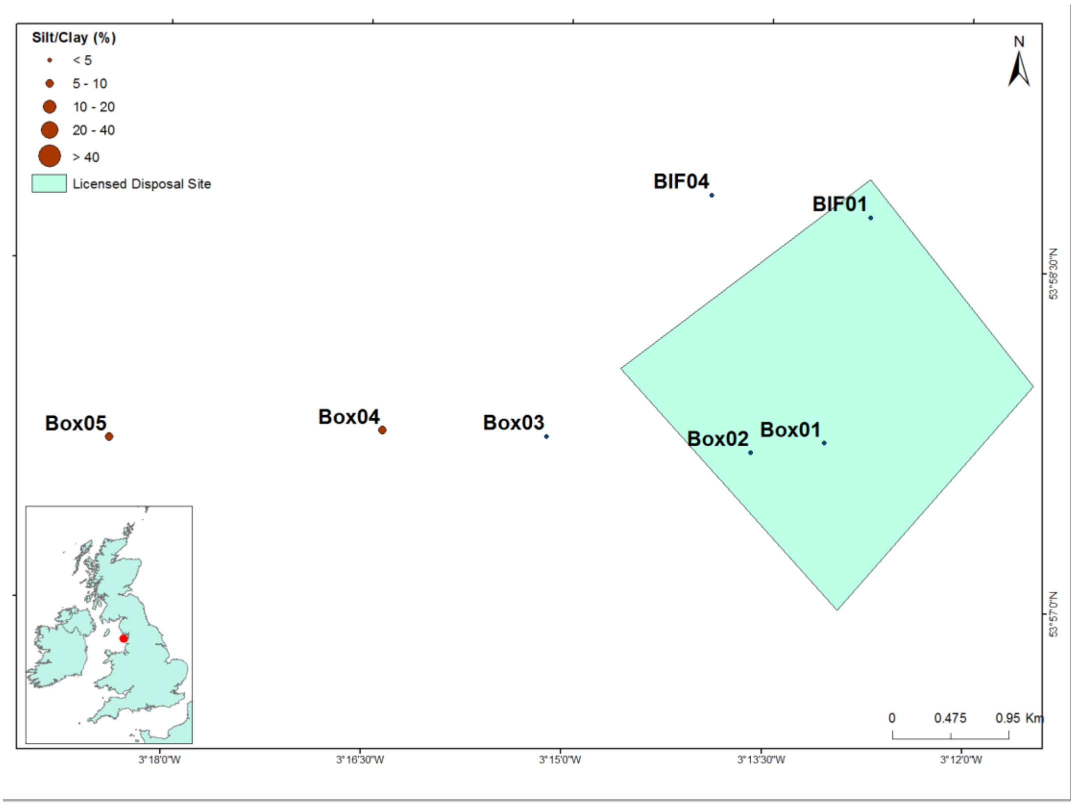

Figure A5.3: Average silt/clay content (%) of sediments sampled at Barrow-in-Furness, 2017.

The temporal changes in sediment type (Folk and EUNIS sediment classifications; Long, 2006) for sampling stations in 1991, 1996, 1999, 2007 and 2017 are presented in Table A5.1, and temporal changes in average silt/clay content are presented in Figure A5.4. These show that the patterns observed in 2017 are broadly consistent with those observed previously. Samples from Box04 and Box05 contain the highest levels of silt/clay which suggests that deposited maintenance material may be dispersed from the disposal site under the westward sediment transport regime known to exist. Generally, sediments from 2007, and even more so for 2017, have lower silt/clay contents than previous years. This could be related to various factors including when monitoring survey occurred relative to disposal operations, volume of material being disposed, and the nature of sediment being disposed.

Table A5.1: Folk symbols and EUNIS sediment description for each sample code for 1991, 1996, 1999, 2007 and 2017 at Barrow-in-Furness disposal site

	1991		1996		1999		2007		2017	
Station code	Folk symbol	EUNIS	Folk symbol	EUNIS	Folk symbol	EUNIS	Folk symbol	EUNIS	Folk symbol	EUNIS
Box01	gS	coarse	(g)S	sand and muddy sand	S	sand and muddy sand	S	sand and muddy sand	S	sand and muddy sand
Box02	gS	coarse	gS	coarse	(g)S	sand and muddy sand	(g)S	sand and muddy sand	S	sand and muddy sand
Box03	gmS	mixed	gS	coarse	(g)mS	sand and muddy sand	gS	coarse	gS	coarse
Box04	(g)mS	sand and muddy sand	(g)mS	mud and sandy mud	gS	coarse	gS	coarse	(g)mS	sand and muddy sand
Box05	gmS	mixed	gmS	mixed	(g)mS	mud and sandy mud	mS	mud and sandy mud	S	sand and muddy sand

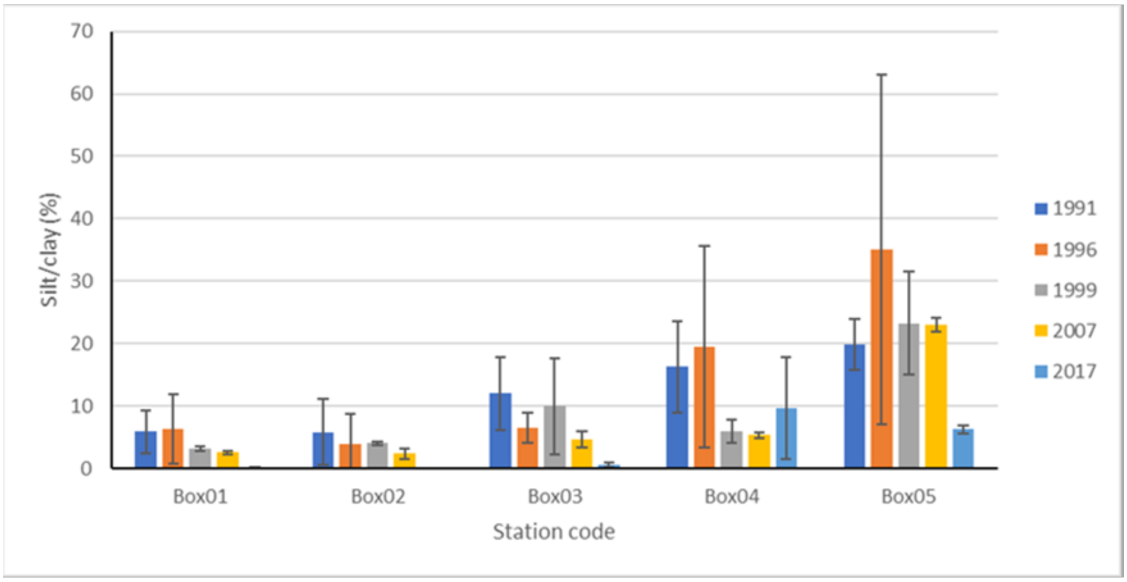

Figure A5.4: Average silt/clay content (%) of sediments sampled at Barrow-in-Furness disposal site from 1991 to 2017 inclusive. Standard deviation indicated with error bars.

5.2.2 Sediment macrofauna

The 2017 Cefas survey at Barrow-in-Furness sampled the five historic stations (see earlier) plus two new stations. The latter two stations; BIF1 and BIF2, were added to augment the spatial representation of the survey. In total, 21 successful samples were obtained using a 0.1 m^2 Day grab with three replicates samples successfully taken at each station. Samples were processed to extract all fauna present in each sample and these were then identified to the lowest taxonomic level possible and enumerated. The benthic faunal dataset was checked to ensure consistent nomenclature using the World Register of Marine Species (WoRMS) taxon match tool. Duplicate records, fragments and juveniles were removed from the dataset.

From the 21 samples, a total of 1151 individuals were sampled from across 76 taxa. The most well-represented phylum was annelids, or segmented worms (33 taxa sampled), followed by molluscs (29 taxa), and crustaceans (17 taxa). The most abundant taxa sampled were the bivalve molluscs *Kurtiella bidentata* (168 individuals in total) and *Nucula nitidosa* (142), and the brittle star *Amphiura filiformis* (111). Colonial taxa were included in species counts and, for statistical analysis, were given and abundance value of one.

The number of taxa (S) and the number of individuals (N) were calculated for each station. These ranged from 4 to 35 taxa 0.1 m^{-2} and 8 to 244 individuals 0.1 m^{-2}; both maxima values were found in replicates from Box05 (the most westerly station) whilst the minima values where from stations within the disposal site, Box02 and Box01 (taxa and individuals respectively). Figure A5.5 shows the mean number of taxa and individuals at each station displayed geographically, clearly supporting the notion that assemblages within the disposal site have both reduced number of taxa and individuals compared to the stations outside.

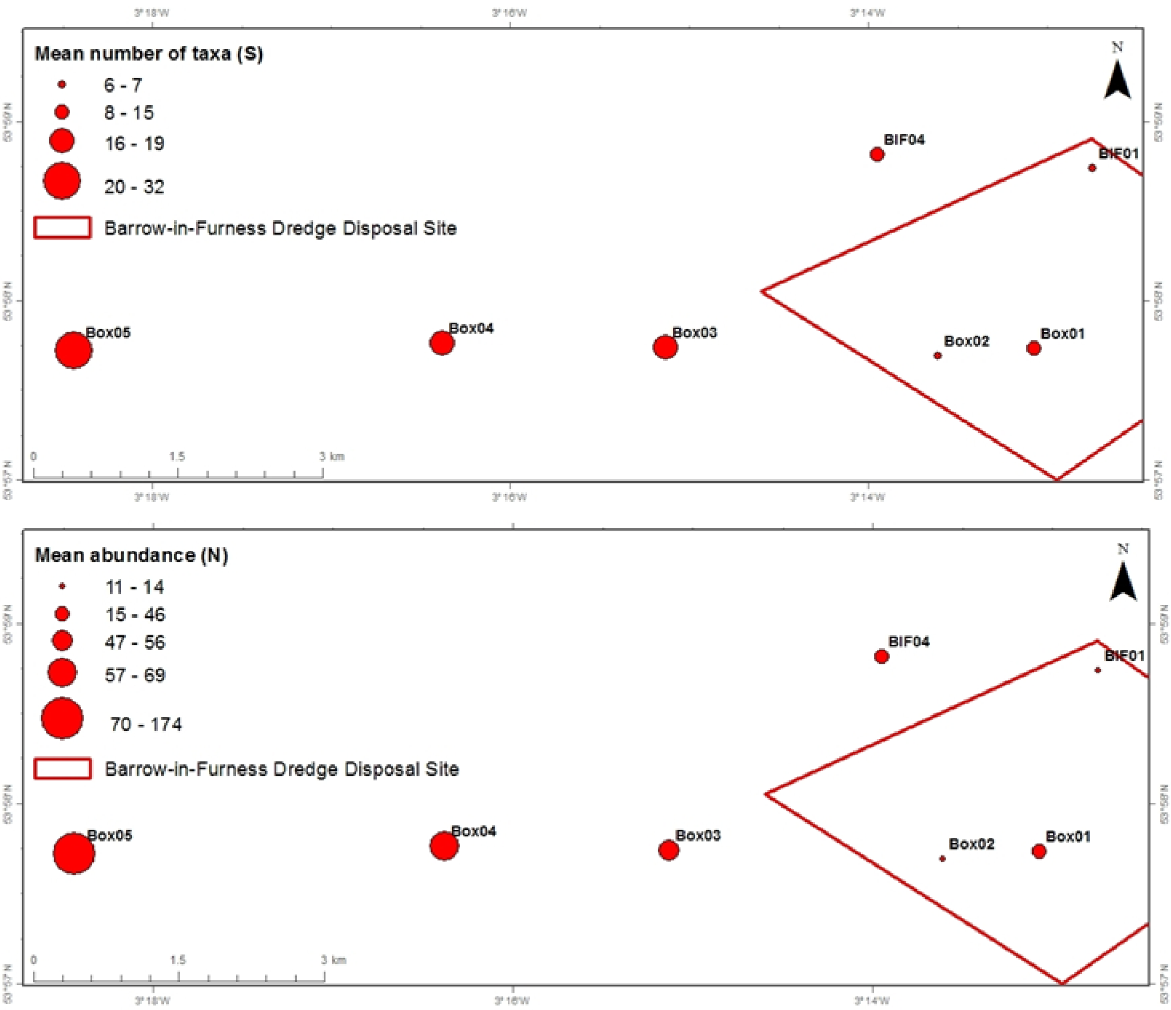

Figure A5.5: Mean number of taxa (top) and mean abundance (bottom) for each of the stations sampled for macrofaunal assemblages at Barrow-in-Furness in 2017. Means based on three replicates at each station.

Multivariate numerical analyses were conducted on the taxonomic structure of the faunal data in Primer V7. Data were square root-transformed followed by the calculation of Bray-Curtis similarity resemblance. Figure A5.6 displays the relative similarities in assemblage structure of each station (replicates shown separately) in 2-dimensions in an ordination plot following non-metric multidimensional scaling (nMDS). There are assemblage differences between samples, with stations inside the disposal site being plotted on the left of the ordination plot with those outside the disposal site to the right. A two-way ANOSIM test conducted on the abundance resemblance matrix indicated that this difference observed in location on the nMDS is significant (global R = 0.696, p = 0.01). Cluster analysis (SIMPROF) was used to further explore this pattern to identify significantly different communities ($p < 0.05$) within the data. This analysis distinguished four distinct assemblages (Figure A5.7). All stations within the disposal site (Box01, Box02 and BIF01) were contained within cluster 'd' with the four stations outside the disposal site in three separate clusters.

Table A5.2 presents the main characterising taxa (based on the SIMPER routine in PRIMER), the average abundance of each taxa, the SIMPER within-group similarity percentage and mean number of species and abundance univariate metrics for each cluster. The faunal assemblage found within the disposal site show low similarity between samples as well as a low mean number of species and abundance. This latter observation supports the results from the earlier analyses which implied this assemblage was relatively impoverished compared to those outside the site. The faunal assemblages outside the disposal site have greater similarity between samples and higher mean number of species and abundance with increasing distance from the disposal site. Although no baseline data are available to support this, one may postulate this implies that disposal activities negatively impact the benthic community in and around the disposal site, with impacts reducing with distance from the site.

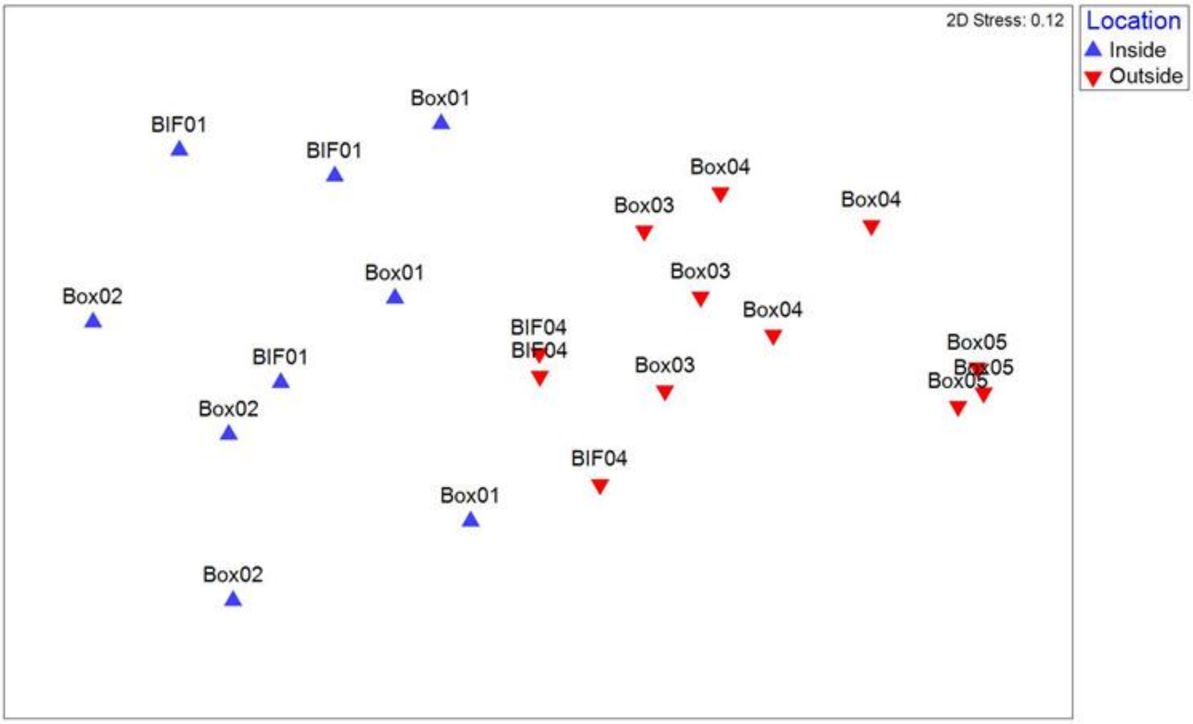

Figure A5.6: nMDS ordination of macrofaunal assemblages in samples from Barrow-in-Furness 2017 following square root transformation and Bray-Curtis similarity.

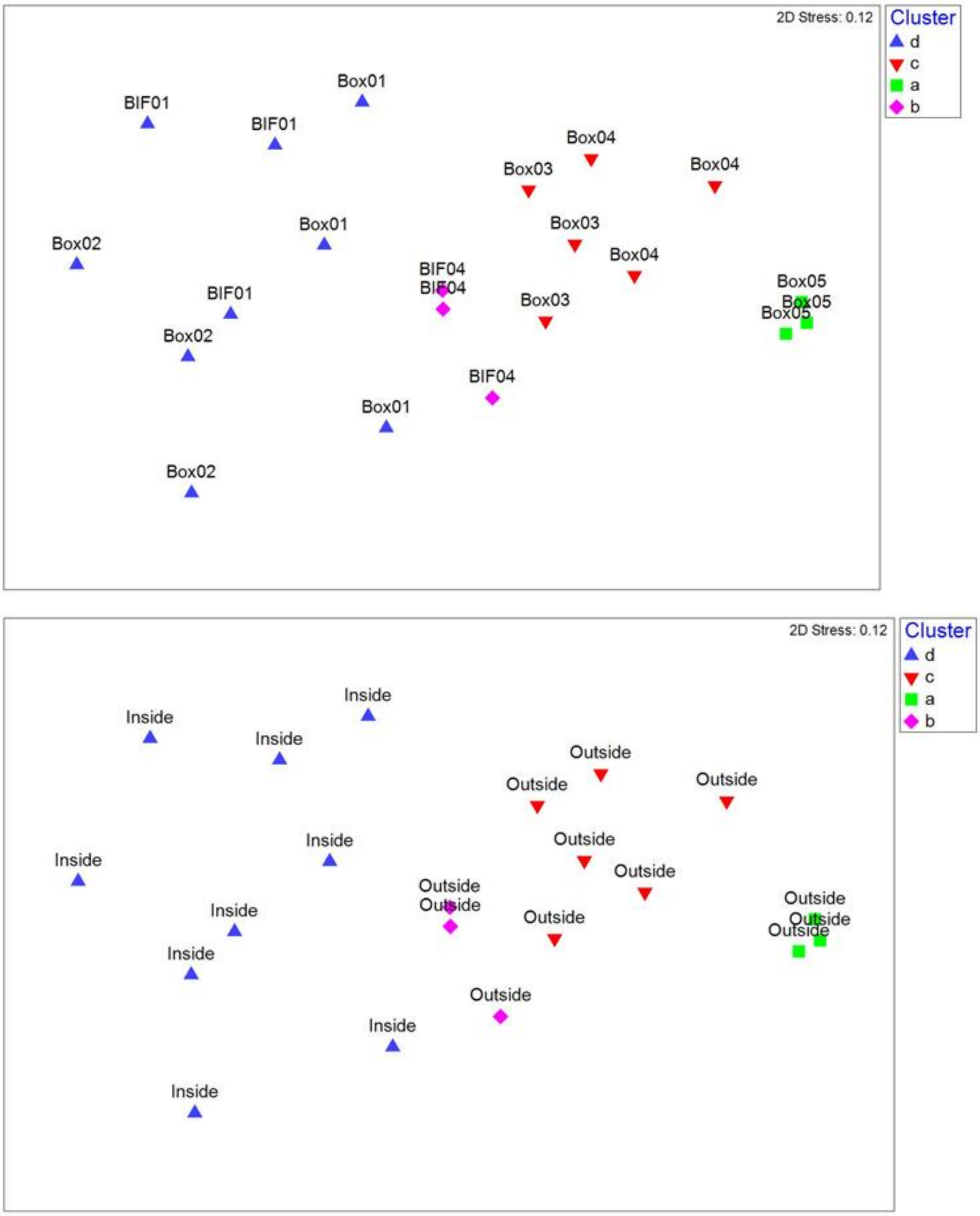

Figure A5.7: nMDS ordination of macrofauna assemblages at stations from Barrow-in-Furness 2017 following square root transformation and Bray-Curtis similarity. Top pane shows station names and bottom pane shows location with symbols showing SIMPROF clusters on both.

Table A5.2: Characterising taxa (SIMPER) of SIMPROF-derived assemblage clusters from the 2017 Barrow-in-Furness macrofauna survey with averaged univariate metrics per cluster.

Cluster	Station (Location)	Taxa	Average Abundance	SIMPER Average within group similarity (%)	Mean number of species (S)	Mean abundance (N)
A	Box05 (Outside)	*Kurtiella bidentata*	6.06	70.66	31	173
		Lumbrineris cingulata agg.	4.37			
		Amphiura filiformis	5.11			
		Diplocirrus glaucus	3.25			
		Pholoe baltica	3.17			
B	BIF04 (Outside)	*Fabulina fabula*	4.09	66.59	14	46
		Nucula nitidosa	2.71			
		Spisula subtruncata	1.72			
		Bathyporeia tenuipes	1.66			
		Abra alba	1.55			
C	Box03 Box04 (Outside)	*Nucula nitidosa*	4.1	52.62	19	62
		Nemertea	2.2			
		Kurtiella bidentata	2.48			
		Fabulina fabula	1.45			
		Spiophanes bombyx	1.31			
D	Box01 Box02 BIF01 (Inside)	*Nephtys cirrosa*	1.71	31.41	8	13
		Fabulina fabula	1.36			
		Magelona johnstoni	0.73			

The macrofaunal data from previous Cefas surveys at these stations (except BIF1, BIF2) were merged with those of 2017 and, to minimise artefacts resulting from historic identification issues or name changes in the data, truncated to the ‘Family’ level. Prior to fourth root-transformation and Bray-Curtis similarity matrix calculation, the data were also averaged to station and survey year to aid spatial interpretation. Figure A5.8 shows the nMDS plot for all six surveys, revealing that the spatial pattern evident in the 2017 data existed previously. All the stations within the disposal site are located on the left of the nMDS plot and stations outside the disposal site to the right. A two-way ANOSIM test again indicated that this difference observed in location on the nMDS is significant, albeit with a lower test statistic than that based on the 2017 data alone (global R = 0.308, p = 0.01). The same pattern could also be seen in the univariate data with the stations within the disposal site having both reduced number of taxa and individuals compared to the stations outside the site (Figure A5.9).

To conclude, the 2017 data have revealed that the ongoing disposal of dredged material to Barrow-in-Furness appears to negatively impact the benthic assemblages within the disposal site. Assemblages are dominated by different taxa from those outside and exhibit lower abundance and numbers of species. The data imply that such impacts are not extended much further west from the site (no data are acquired for other regions outside due to depth differences making such assessments problematic). This situation in 2017 concurs with the conclusions based on earlier data from the 1990s and also from 2007. These data represent a suitable contemporary baseline from which potential impacts resulting from any changes to the disposal regime at the site may be assessed.

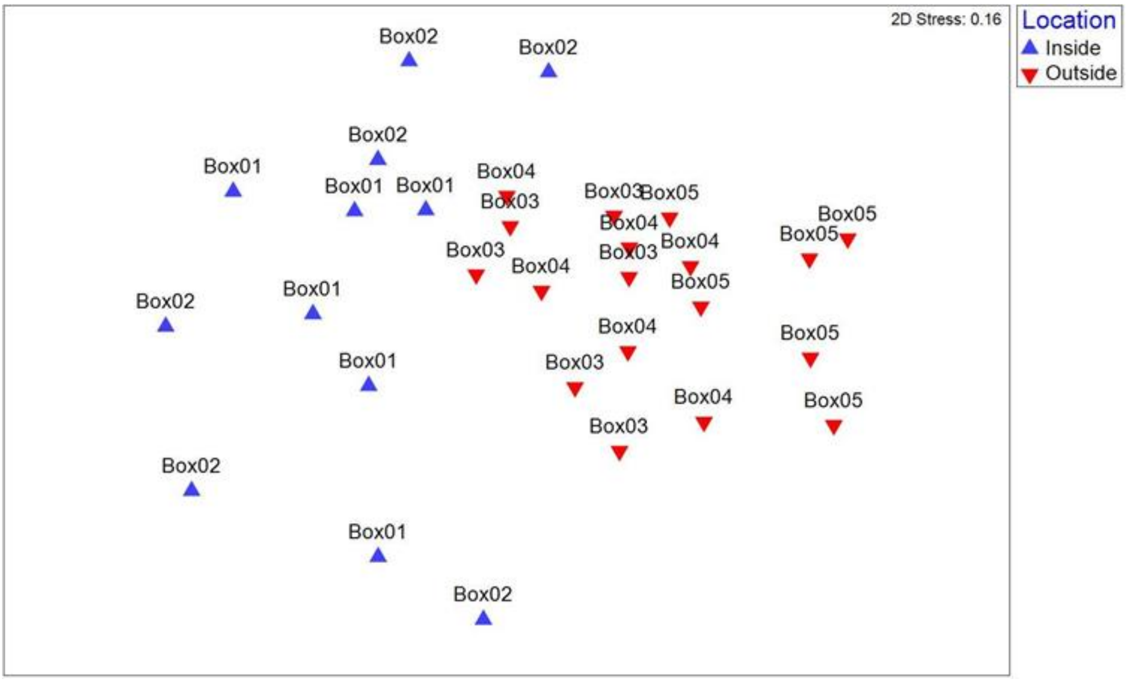

Figure A5.8: nMDS ordination of macrofauna assemblages from all six surveys at Barrow-in-Furness following forth root transformation and Bray-Curtis similarity

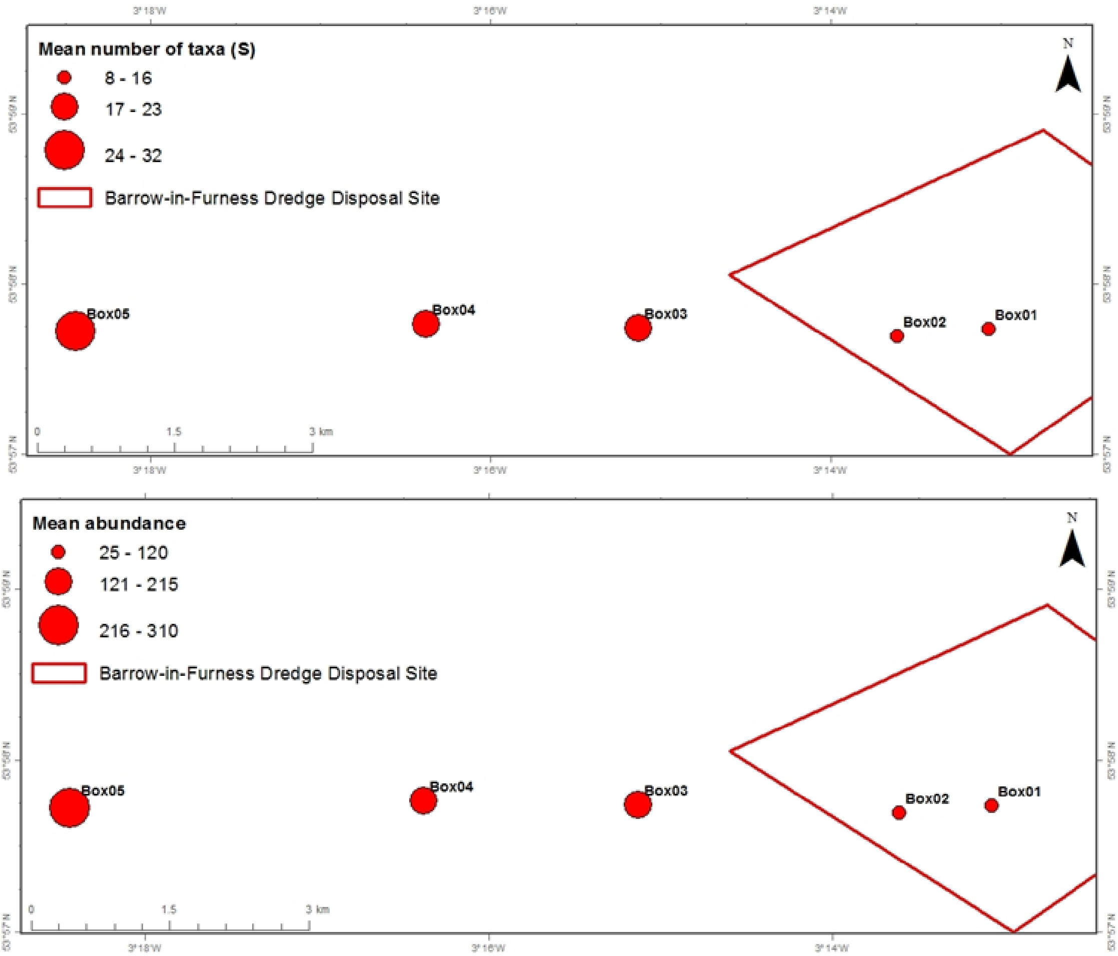

Figure A5.9: Mean number of taxa (top) and mean abundance (bottom) for each of the stations sampled for macrofaunal assemblages over the six survey years at Barrow-in-Furness.

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