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Dredged Material Disposal Site Monitoring Round the Coast of England: Results of Sampling (2019-2020)

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World Class Science for the Marine and Freshwater Environment

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 2019-2020.
- 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);
  - to facilitate our improved understanding of the impacts of dredged material disposal at both a site-specific and a national (i.e. non site-specific) level.
- One disposal site was targeted for assessment during this period: Site Y in Liverpool Bay. The results of sampling seabed sediments within and surrounding the disposal site for sediment particle size, organic carbon content, contaminants and macrofaunal assemblages are presented, together with their implications for future licensing of material to the site.

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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 environment 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 approximately 109 open sites (numerous sites are opened and closed every year) 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).

Although total quantities vary year to year, 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 are 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 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 the licensing team 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 findings is presented (Section 2), forms an important element of such scientific communication. The current report, which presents the findings of work undertaken during 2019-20, constitutes the 12th 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 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 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 provides a scientifically valid rationale for the assessment of risks associated with relinquished, current and proposed disposal sites to the surrounding environment and amenities.

One disposal site was targeted for Cefas monitoring during 2019-20: Site Y in Liverpool Bay. This site was 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.

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 2019-20 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 2019-20 results with those of previous years to provide a temporal assessment (see Bolam et al., 2009; 2011a; 2012a; 2012b; 2014b; 2015a; 2015b; 2016b; 2017 and 2018; 2019 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; 2018; 2019), the main findings and conclusions regarding Site Y are presented within Section 2 (below). More detailed scientific data (e.g. sediment particle size, organic carbon, macrofauna, contaminants) for the site, together with their interpretation, are described in Appendix 1. For background information regarding the Site Y disposal site, the reader is directed towards this appendix.

2 Conclusions and implications for further monitoring

The main findings of the monitoring undertaken during 2019-20 are presented within this section, 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 stakeholder concerns are all embraced within, and have a direct bearing on, the selection process for disposal site monitoring under this project. Thus, the recommendations for monitoring presented here, although representing an important component of the decision-making process, may or may not be altered by other factors.

2.1 Site Y

Site Y (IS150), situated within Liverpool Bay on the west coast of the UK, is licensed to receive dredged material resulting from dredging of the maintenance docks and navigation channels, and that of capital projects, in the Mersey Channel. The site is currently scheduled to receive increased amounts of material, partly due to the limited use of the nearby Site Z site which has traditionally received most of the maintenance material dredged from the Mersey. This increased tonnage, and the shift towards receiving maintenance material (Site Y has traditionally received capital material), implied an increased need for monitoring under C6794.

During November 2019, six sediment samples were acquired from within the disposal site and six from each of a north and a south reference area, in accordance with a previous monitoring survey conducted at the site in 2015. The sediment samples were processed to assess particle size, organic carbon, macroinfauna and sediment contaminants. As the survey was conducted following a period of no disposal activity to the site since 2015, the acquired data serve as both a baseline from which impacts associated with future maintenance disposals may be assessed and also as a basis from which to evaluate recovery following a large 2015 disposal campaign.

The sediments within Site Y are predominantly unimodal, gravelly sands and gravelly muddy sands, and have shown a decrease in the fine fraction (silt/clay) and a concomitant increase in coarser material (gravel) since 2015. Summed polycyclic aromatic hydrocarbon (PAH) concentrations observed were generally found to be low. However, the effects range low (ERL) (but not the effects range median, or ERM) for both the low and high molecular weight (LMW and HMW respectively) PAHs were exceeded at one station (of the six sampled) within the disposal site. In general, PAH concentrations were comparable to those sampled at other disposal sites located along the west coast of England and to those found further offshore within this region.

Sediment organohologen (OH) results revealed that brominated diphenyl ethers (BDEs) and chlorobenzenes (or CBs) were detected at 13 and 15 of the 18 stations respectively, while organochlorine pesticides (OCPs), primarily due to BDE209, was detected at all 18 stations. $\sum_6$DDTs concentrations were above Cefas action level 1 at one station within the disposal site. Seven stations had 'good' environmental status for all ICES 7 CBs and 'good' status overall according to OSPAR guidelines. The remaining 11 stations had one CB with 'bad' environmental status but 'good' status overall - no station was classed 'bad' overall status for CBs. Compared with 2015, the disposal site and the south reference region showed a decrease in OH concentrations, while a slight increase in the northern reference could be discerned.

The sediment concentrations of seven trace metals revealed concentrations were much higher than the OSPAR background assessment concentrations (or BACs), especially for mercury and lead. This is generally due to the legacy from the historical and current industrial activities of the area. When assessed alongside proposed regional baseline values which were derived accounting for regional variability, observed concentrations were elevated but to a lower level than that based on OSPAR BACs. Assessment of the temporal data for trace metals inferred a general southward drift of metal contamination.

The sediment macrofaunal data revealed high numbers of *Phoronis* spp. in the north reference stations which were typically absent from the disposal site and south reference areas. Stations within the disposal site, on average, had slightly lower species richness than those of the north reference but demonstrated higher variability in total abundance and biomass in 2019, with some stations having similar values to those of the north reference stations, when compared to the 2015 data. In 2019, stations from within the south reference site were generally less speciose and comprised lower biomass and abundances of their macrofaunal assemblages. Macrofaunal assemblages within the disposal site, several years after the large capital disposal campaign to the site, are represented by an altered assemblage structure but not notably impacted in terms of basic metrics of assemblage structure.

The data obtained *via* the successful conduct of the 2019 survey at Site Y offer valuable insights regarding the site's current the physical, chemical and biological conditions. The results imply that there is no requirement to alter the current disposal regime to the site. We advocate that future monitoring of the site, in accordance with the design established hitherto to maximise utility of the data, be conducted in *circa* five years' time. This timeframe should be flexible to account for currently unforeseen large-scale depositions, or if the resumption of future disposal events is delayed.

3 Acknowledgements

Many Cefas staff have helped contribute to the work which has been conducted to produce this report. Such staff have been involved in all aspects of the work from an early stage, e.g. during discussions of the specific issues regarding dredged material disposal sites around the coast of England (e.g. Cefas' SSMM team), through to the field sampling and the laboratory processing of the various components. Staff within the Cefas Sedimentology, Benthic Ecology and Chemistry teams are gratefully thanked for processing the samples which form the core of this report. Finally, staff at the Environment Agency (particularly Luke Martina) and the crew of the RV Mersey Guardian are thanked for their contribution to the successful survey conducted to acquire the samples.

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Appendix 1: Results

1 Site Y, Liverpool Bay

1.1 Background

Site Y (IS150), situated within Liverpool Bay on the west coast of the UK, is licensed to receive dredged material resulting from dredging of the maintenance docks and navigation channels, and that of capital projects, in the Mersey Channel. IS150 has a seabed sloping to the southwestern edge of the site, with large sand waves to the western side of the site orientated north to south (Bolam et al., 2015a, 2015b). The average water depth for the disposal site is 20 m below Chart Datum; while the north-eastern section shallows to approximately 16 m, deeper waters (27 m below Chart Datum) can be found in the western sector. The sediments within this site are generally moderately well-sorted, slightly gravelly sand (Bolam et al., 2015a, 2015b). Approximately 1.8 Mt (wet weight) of capital dredged material, derived from the construction of the new deep-water container terminal, Liverpool II, was disposed to Site Y during 2013. To prevent shoaling at Site Y, the stiff, consolidated material was licensed to be disposed of in a grid fashion, with the subsequent finer maintenance dredged material to be disposed as evenly as possible over the disposal site. Monitoring at Site Y conducted under the auspices of SLAB5 at that time focussed on the acquisition of acoustic and sediment granulometric data to determine the location of the disposed material on the bed and conformity to licence conditions (Bolam et al., 2015a). The data obtained showed that each deposit of capital material resulted in an acoustically identifiable mound on the seabed which indicated conformity with licence conditions. This monitoring was followed the subsequent year by a second acoustic survey to ascertain the fate of finer material disposed of to the deeper regions of the site (Bolam et al., 2015b).

Following this capital disposal operation, the project at Liverpool II required a maintenance dredging campaign. While the capital material had posed no contamination risk, extensive sampling of the sediments to be subsequently dredged in Liverpool docks demonstrated that some of the material was unacceptable for marine disposal due to elevated levels of certain contaminants (e.g. mercury (Hg) and polycyclic aromatic hydrocarbons (PAHs)). While management practices were implemented to prevent the more contaminated material going to sea (a proportion of the material was destined for land-based disposal) and to ensure that material disposed to Site Y possessed contaminants below Cefas action level 2, there remained the potential for increased contaminant concentrations being present at this disposal site.

Subsequent monitoring under C6794 during 2015 primarily focussed on the acquisition of data to assess the spatial variability in sediment contaminant concentrations. This was to provide reassurance that measures to ensure that the more contaminated material was not placed to sea were successful and that the concentrations in the region remain acceptable. Sampling of the macrofauna was additionally undertaken during the survey (Figure A1.1.1) to allow a contemporary assessment of the biological assemblages of the area following the placement of the large amounts of both the recently deposited capital, and subsequent maintenance, dredged material (Bolam et al., 2016b).

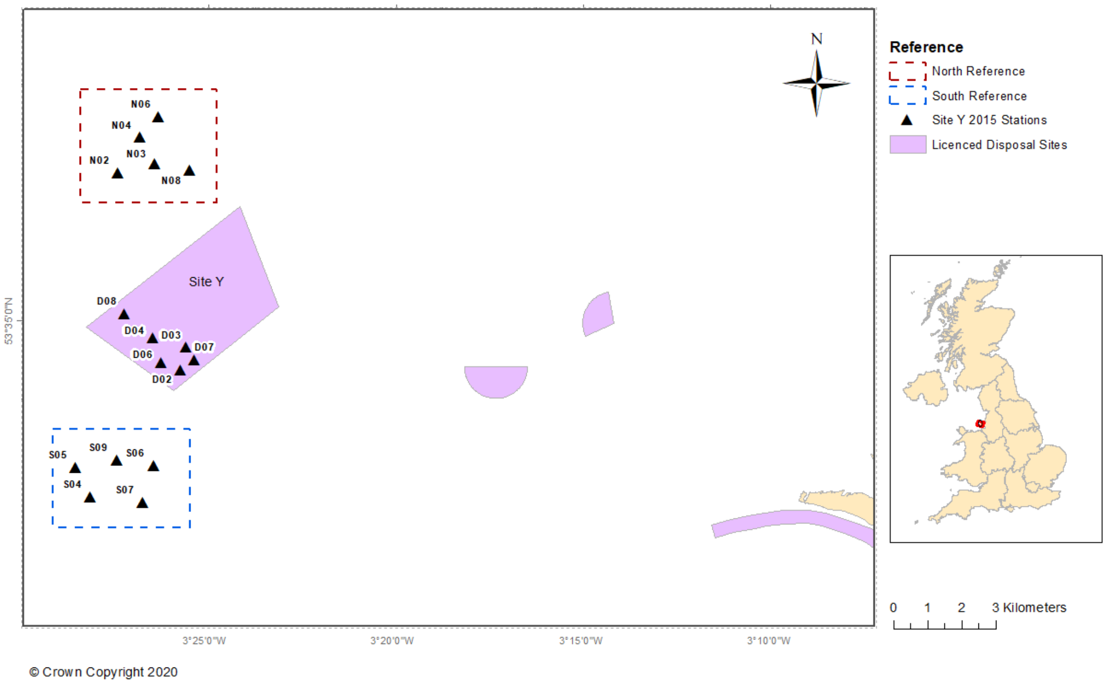

Figure A1.1.1. Stations previously sampled at Site Y, 2015. The design consisted of replicate samples within a southern reference and a northern reference, together with replicates within the deeper region of the disposal site where disposal activity is focussed.

Site Y is scheduled to receive increased amounts of material, partly due to the limited use of the nearby Site Z site, due to site shallowing, which has traditionally received most of the maintenance material dredged from the Mersey. This increased tonnage, and the shift towards receiving maintenance material (Site Y has traditionally received capital material), implies an increased need for monitoring under C6794. During November 2019, sediment samples were acquired from within the disposal site and from the north reference and south reference areas, in accordance with the design implemented during the 2015 survey (Figure A1.1.1), to assess sediment particle size, organic carbon, macroinfauna and sediment contaminants. The survey was conducted at a time following a period of no disposal activity to the site subsequent since 2015 (Figure A1.1.2). Thus, the data acquired serve as both a baseline from which impacts associated with future maintenance disposals may be assessed and to evaluate the recovery following the large 2015 disposal campaign.

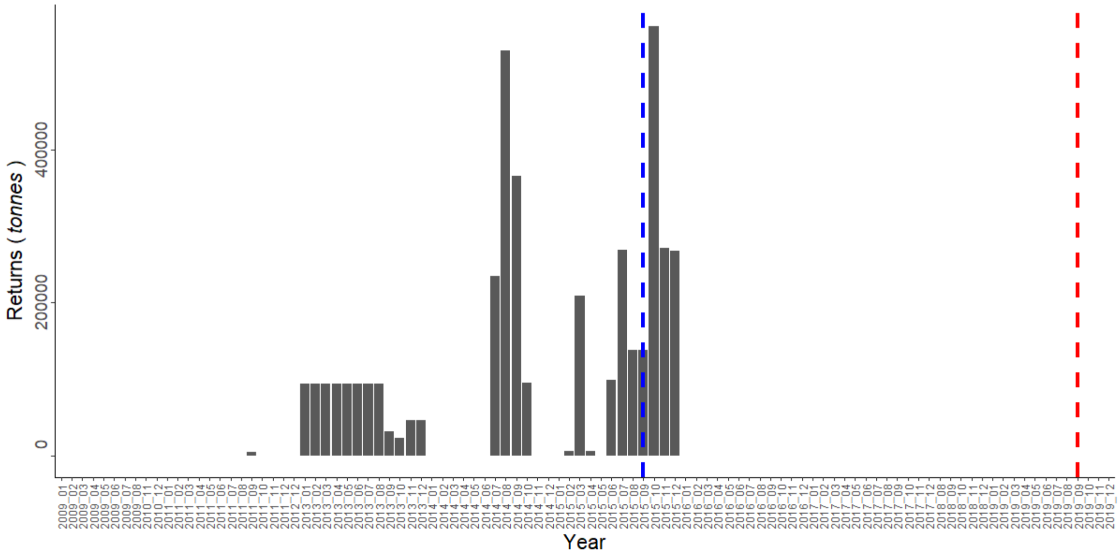

Figure A1.1.2. Monthly tonnages (wet weight) of dredged material disposed to Site Y between 2009 and 2019. The timing of the 2015 sediment sampling survey is highlighted in blue dashed line while the present 2019 survey is identified in red.

1.2 Results

1.2.1 Sediment Particle Size

The sediments sampled at Site Y are predominantly unimodal, gravelly sands and gravelly muddy sands (Table A1.2.1, Table A1.2.2; Figure A1.2.1). Generally, samples within the disposal site and the north reference area contain the highest silt/clay content. Station D01, located near the southeastern perimeter of the disposal site, contained the highest measured component of silt/clay (*circa* 26%).

Table A1.2.1. Sediment descriptions for each sample at Site Y in 2019.

Station	Sample Type	Sediment description
D01	Unimodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand
D02	Bimodal, Moderately Sorted	Slightly Gravelly Sand
D03	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand
D06	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand
D07	Unimodal, Poorly Sorted	Slightly Gravelly Sand
D08	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
N03	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
N04	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
N05	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
N06	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
N07	Unimodal, Poorly Sorted	Sand
N08	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
S02	Unimodal, Poorly Sorted	Slightly Gravelly Sand
S05	Bimodal, Poorly Sorted	Gravelly Sand
S06	Unimodal, Moderately Sorted	Slightly Gravelly Sand
S07	Unimodal, Moderately Sorted	Slightly Gravelly Sand
S08	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand
S09	Unimodal, Moderately Sorted	Slightly Gravelly Sand

Results derived using Gradistat (Blott and Pye, 2001)

Table A1.2.2. Sediment statistics for each sample at Site Y in 2019.

Station	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
D01	0.3	73.4	26.3	0.2	0.7	4.1	55.8	12.6
D02	0.5	95.7	3.8	0.8	14.9	27.0	50.1	2.9
D03	0.1	96.0	3.9	0.1	3.0	22.8	62.2	7.8
D06	0.1	97.5	2.4	0.1	2.9	36.7	55.9	1.9
D07	0.5	92.4	7.1	0.4	5.2	21.6	60.4	5.0
D08	0.2	89.6	10.2	0.2	23.6	50.2	14.2	1.4
N03	0.0	89.4	10.5	0.2	14.1	46.0	27.2	2.0
N04	0.0	89.6	10.3	0.1	14.1	42.5	30.6	2.4
N05	4.9	82.4	12.7	3.4	14.4	30.8	31.4	2.4
N06	0.8	87.2	11.9	0.6	13.5	38.7	32.5	2.0
N07	0.0	94.1	5.9	0.0	9.7	46.1	36.3	1.9
N08	2.8	83.5	13.7	1.6	20.5	38.0	21.3	2.0
S02	4.5	90.1	5.5	3.8	22.9	44.3	17.9	1.2
S05	5.4	91.0	3.6	5.2	20.3	38.1	26.4	1.0
S06	0.4	96.7	3.0	1.4	32.7	51.6	10.3	0.7
S07	1.8	97.0	1.2	6.2	44.8	34.6	10.9	0.5
S08	0.2	97.7	2.1	0.2	31.2	54.0	11.6	0.7
S09	1.3	93.7	5.0	0.5	28.9	48.6	14.7	1.0

Results derived using Gradistat (Blott and Pye, 2001)

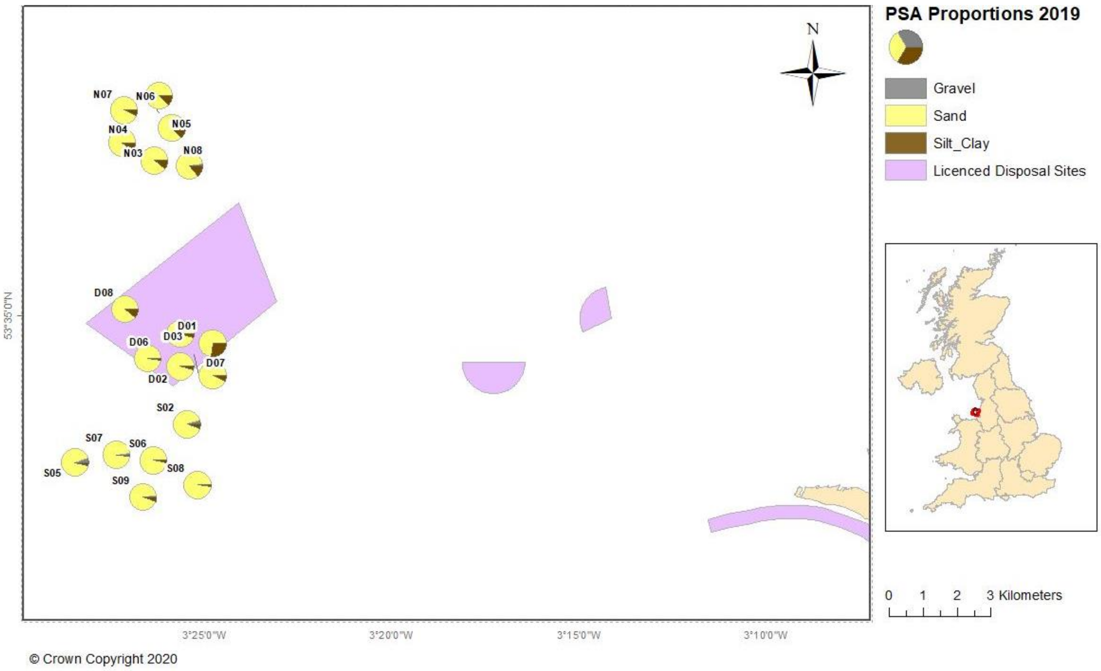

Figure A1.2.1. Pie charts of gravel, sand and silt/clay at Site Y in 2019.

Temporal comparisons with the data acquired during the 2015 Site Y survey indicates that while no marked change is evident for the two reference areas, average silt/clay fractions in the disposal site notably declined in 2019 (Figure A1.2.2). This is concomitant with an increase in the sand component of these sediments.

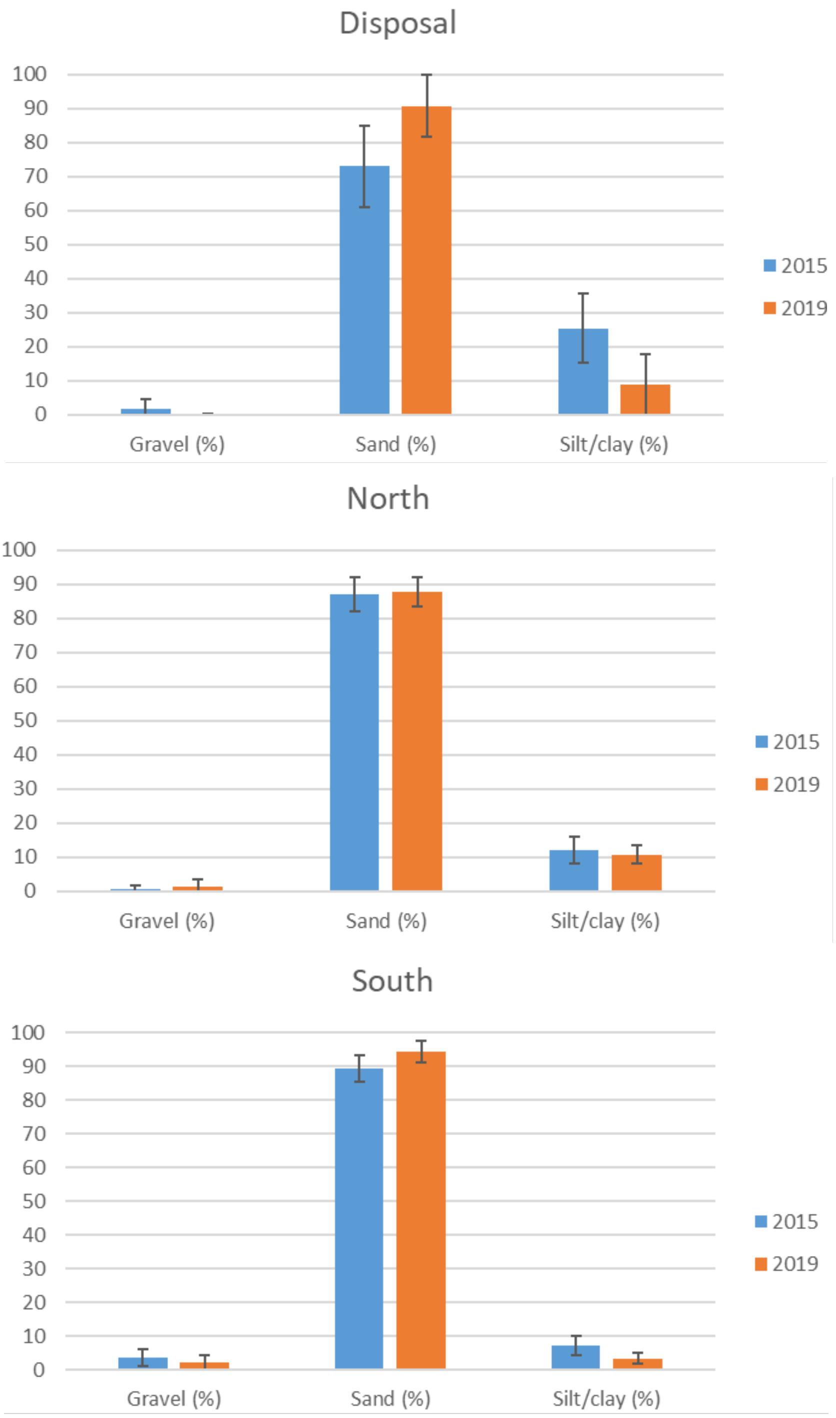

Figure A1.2.2. Average sediment fraction composition (%) for the sediments sampled at the Site Y disposal site (top) and north (middle) and south (bottom) reference areas in 2015 (blue) and 2019 (orange). Error bars represent standard deviation.

1.2.2 Sediment organic carbon (POC)

Sediment organic carbon values across the whole survey area range from 0.04 to 0.26% m/m in the <2 mm sediment fraction (Figure A1.2.3), and from 1.53 to 2.10 % (average 1.74 ± 0.16 m/m) in the <63 µm fraction (Figure A1.2.4). The values in the <2 mm fraction are slightly lower compared to those observed in 2015 (2015 range was 0.16 to 0.65% m/m), while no temporal shift is evident for organic carbon in the <63 µm fraction (2015 range was 0.46 to 2.32% m/m).

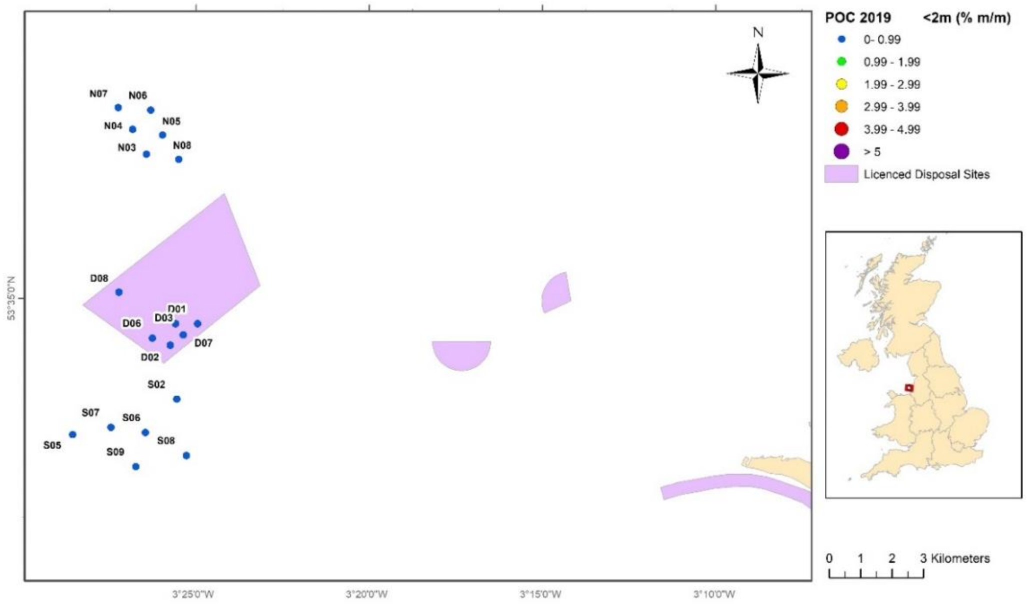

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Figure A1.2.3. Organic carbon (% m/m) in the <2mm fraction at Site Y in 2019.

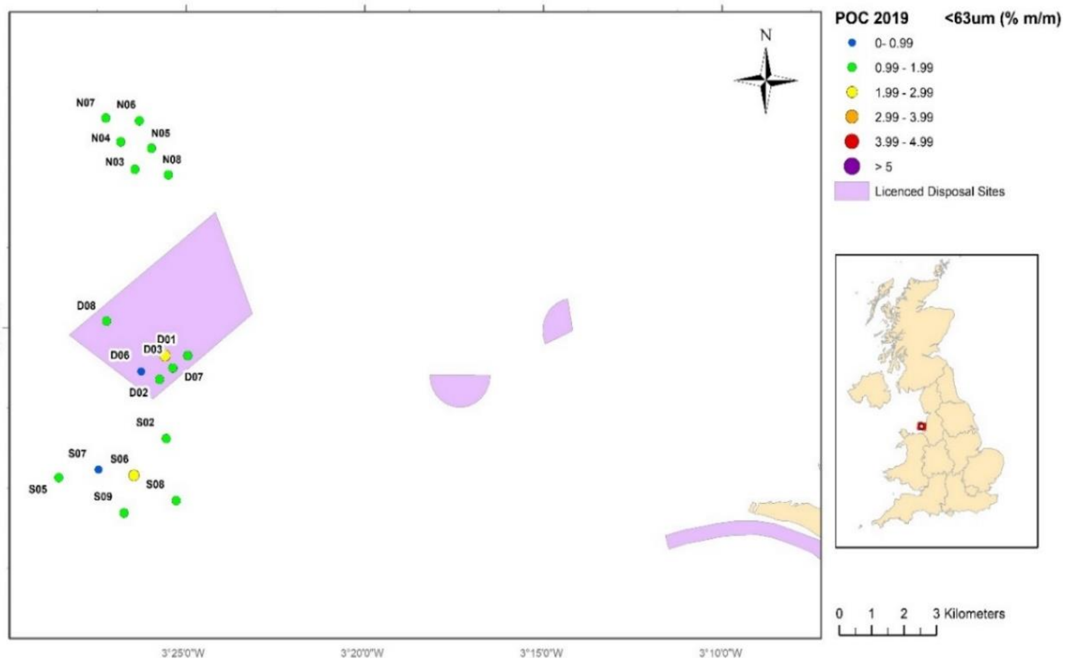

Figure A1.2.4. Organic carbon (% m/m) in the <63µm fraction at Site Y in 2019.

1.2.3 Sediment Chemistry

1.2.3.1 Polycyclic aromatic hydrocarbons (PAHs)

The highest summed PAH concentration (ΣPAH) at Site Y in 2019 was 8,797 µg kg^{-1} dry weight (dw) at station D01 within the disposal site (Figure A1.2.5). Although D01 was not sampled in 2015 (Figure A1.2.6), the concentration observed at this station was significantly higher than the highest level reported across all stations sampled in 2015. In 2015, the highest ΣPAH, 3,000 µg kg^{-1} dw, was observed at D04 (not sampled in 2019) (Figure A1.2.6). The second highest concentration in 2019 at Site Y, 802 µg kg^{-1} dw, was located north of the disposal site at N03. In 2015, N03 was less than one quarter of 2019 levels (Figure A1.2.6). Relatively low ΣPAH concentrations (<1000 µg kg^{-1} dw) were found at all other stations sampled in 2019, including those within the disposal site and at the two reference areas. ΣPAH concentrations in 2019 generally decreased across all disposal site stations compared with 2015 levels, as did those at reference stations N04, S05, S07 and S09 (Figure A1.2.6). The lowest ΣPAH concentration in 2019 was 22 µg kg^{-1} dw at S06 in the southern reference area (Figure A1.2.5): this station recorded the lowest ΣPAH (119 µg kg^{-1} dw) in 2015 (Figure A1.2.6).

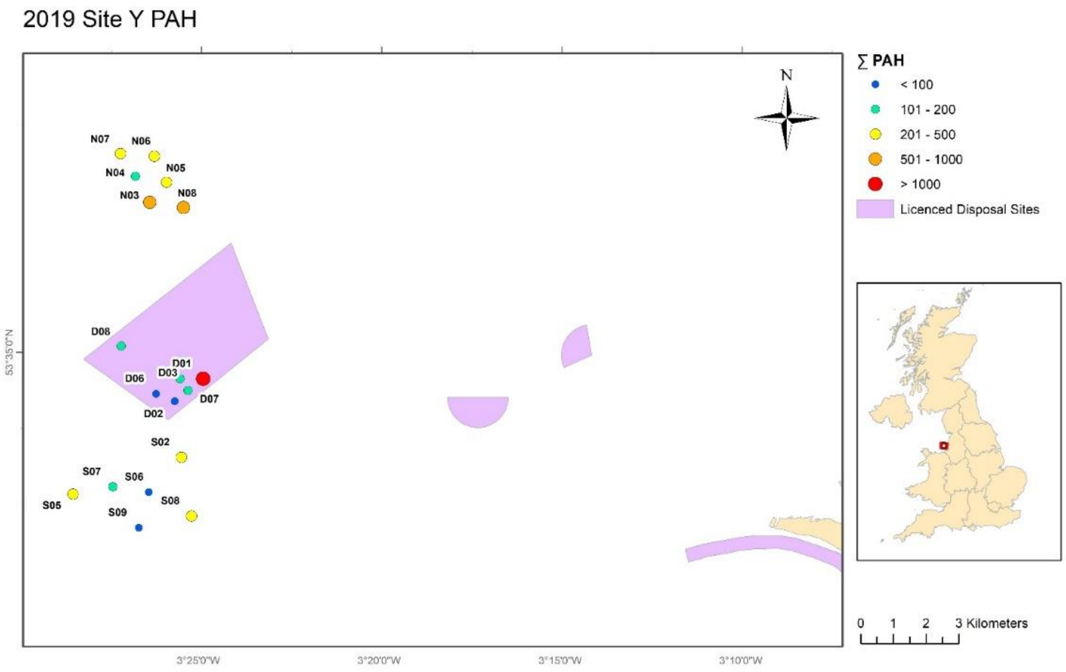

Figure A1.2.5. Map of summed PAH (∑PAH) concentrations (µg kg-1 dry weight) for stations sampled at Site Y under C6794 2019

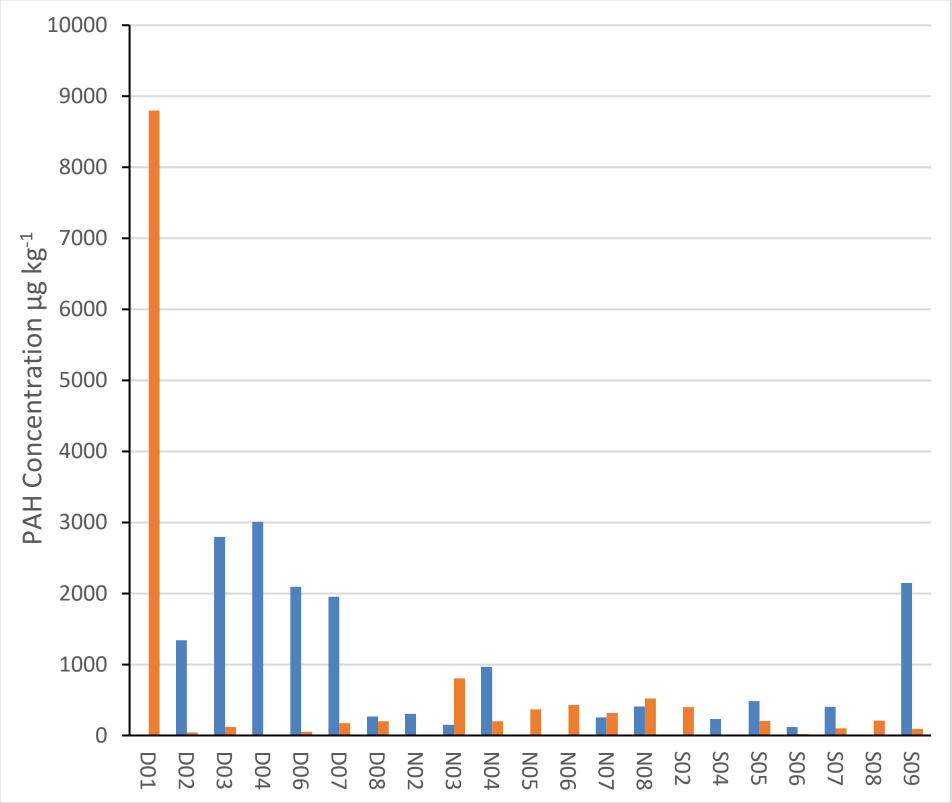

Figure A1.2.6. Summed PAH concentrations (µg kg $^{-1}$ dw) for stations sampled at Site Y during 2015 (blue) and 2019 (orange).

Thus, summed PAH concentrations observed at Site Y during 2019 were generally low. However, the effects range low (ERL) (but not the effects range median, or ERM) for both the low and high molecular weight (LMW and HMW respectively) PAHs were exceeded at D01 station within the disposal site (Figure A1.2.5). This exceedance was by a factor of three for LMW PAHs and by a factor of nearly two for HMW PAHs. Evaluation of the PAH data indicated that the source in several stations had an oily signature, with northern reference stations N03, N05, N07 and N08 displaying >70% of the PAH content arising from oil sources. D08 within the disposal site and S05 within the southern reference also indicated 70% or above PAH content from oil sources. Oil source contribution of the PAHs from all other stations was *circa* 60%, although at D01 and S07 this was as low as 45% (the remaining 55% of the PAH content arising being from combustion sources). The one exception to this was southern reference site S08 where the contribution from combustion sources was around 70%. Except for the exceedance at D01, ΣPAH concentrations at Site Y are generally comparable to those sampled at other disposal sites located along the west coast of England and to those found further offshore within this region (e.g. *circa* <500 µg kg $^{-1}$ dw at Station 715 of the Clean Seas Environment Monitoring Programme (CSEMP), 2012).

Station D01, where significantly elevated sediment ΣPAH concentrations were observed, was not surveyed in 2015 so it is difficult to speculate as to whether this represents a temporal increase, but concentrations at the other stations within the site which were sampled in 2015 indicate a reduced concentration in 2019. It is possible that between 2015 and 2019, sediments with elevated ΣPAH concentrations have migrated in an easterly direction towards D01. This may help explain the generally substantial reduction (by one to two orders of magnitude) in concentrations at all other Site Y disposal sites surveyed in 2019 compared with 2015 levels. Generally, ΣPAH concentrations at both the northern and southern reference areas of Site Y remained low or decreased further in 2019, indicating that the increased within the disposal site is predominantly contained and centred around D01. Since no material has been placed at Site Y since 2015, data from 2015 and 2019 will together help form a useful baseline from which further maintenance deposits may be assessed.

1.2.3.2 *Organohalogens (OHs)*

At Site Y, ICES 7 chlorobenzenes (or CBs) were detected at 15 of the 18 sampled stations (∑ICES 7 CBs range <0.06-1.04 µg kg^{-1} dw) (Figure A1.2.7). The highest concentration of 1.04 µg kg^{-1} dw was at D01 where elevated ΣPAH concentrations were also observed (see previous section). ∑ICES 7 CB concentrations were <1 µg kg^{-1} dw at all other stations. Generally, the concentrations to the north of the disposal site were slightly higher than those to the south or within the disposal site.

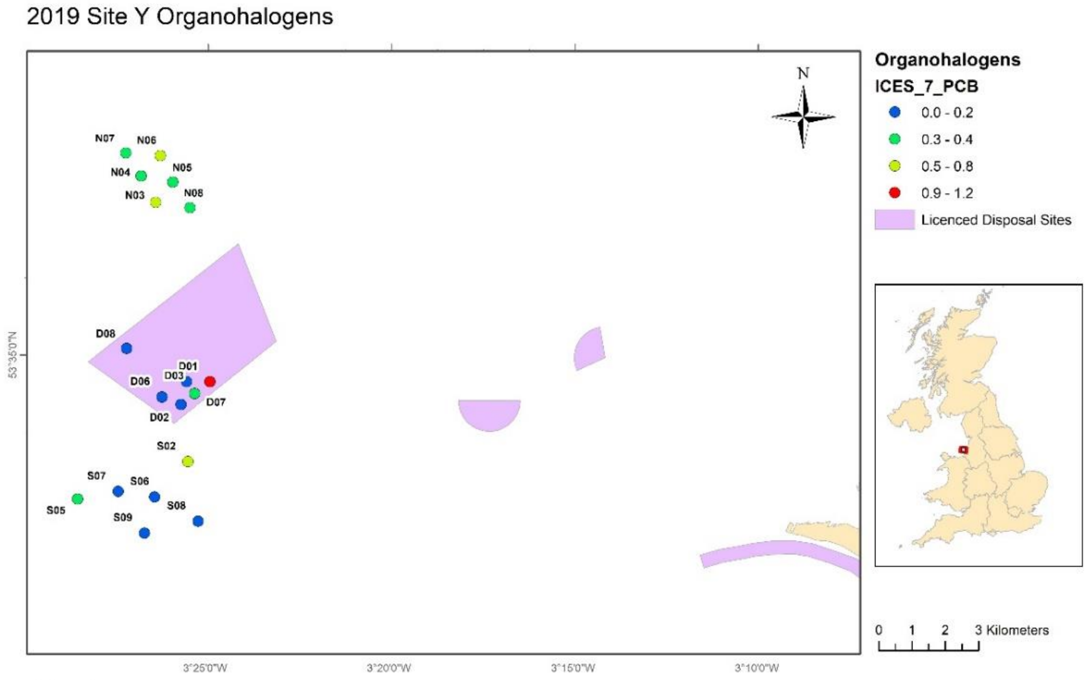

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Figure A1.2.7. ∑ ICES7 CB concentrations for the Site Y Stations, 2019.

Organochlorine pesticides (OCPs) were detected at every station sampled at Site Y in 2019 (Figure A1.2.8). ∑$_6$DDTs concentrations ranged from 0.14-1.54 µg kg^{-1} dw, the highest value derived from D01. All other results were below 0.6 µg kg^{-1} dw (Figure A1.2.8). Generally, the concentrations to the north of the disposal site were slightly higher than those to the south or within the disposal site. Dieldrin was detected at only two (N07 and N06) of the 18 stations (concentrations ranged from <0.05 to 0.17 µg kg^{-1} dw).

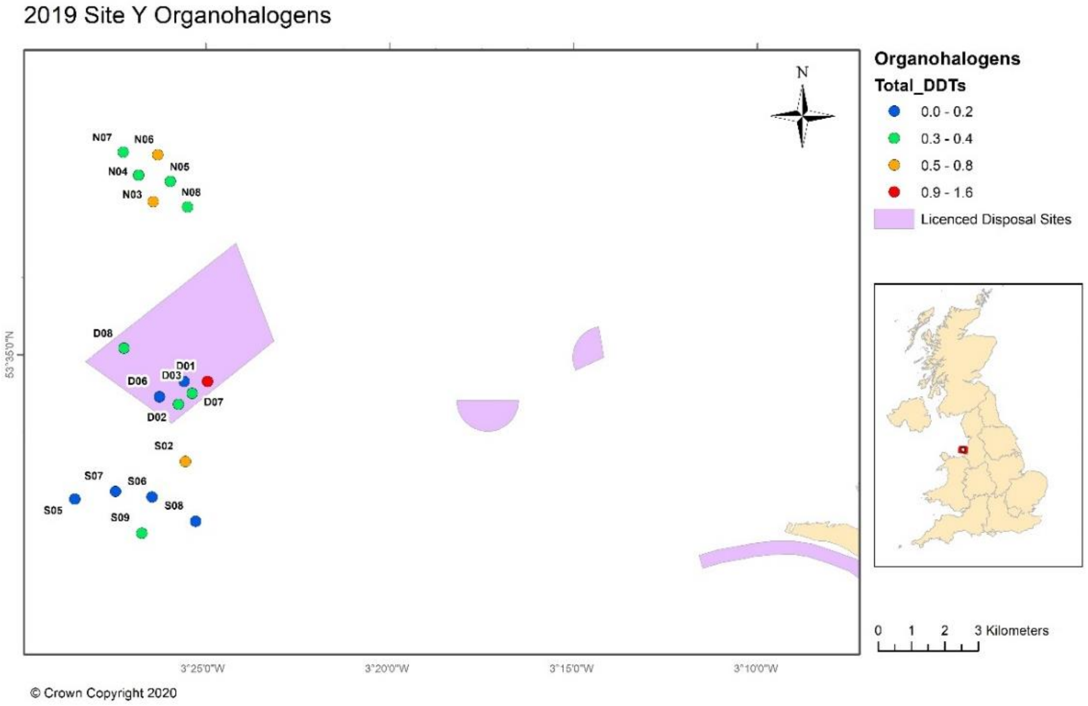


Figure A1.2.8. ∑6 DDTs concentrations for the Site Y Stations, 2019.

Brominated diphenyl ethers (BDEs) were detected in 13 of the 18 stations (∑11 BDEs range <0.075-0.409 µg kg^{-1} dw) (Figure A1.2.9). The highest concentrations, 0.409 and 0.339 µg kg^{-1} dw, were observed at D01 and N03 respectively. None of the next six highest ∑11 BDEs concentrations were within the disposal site. Generally, the concentrations to the north of the disposal site were slightly higher than those to the south or within the disposal site. BDE183 was the dominant congener present, indicative of the octaBDE or decaBDE technical mixture.

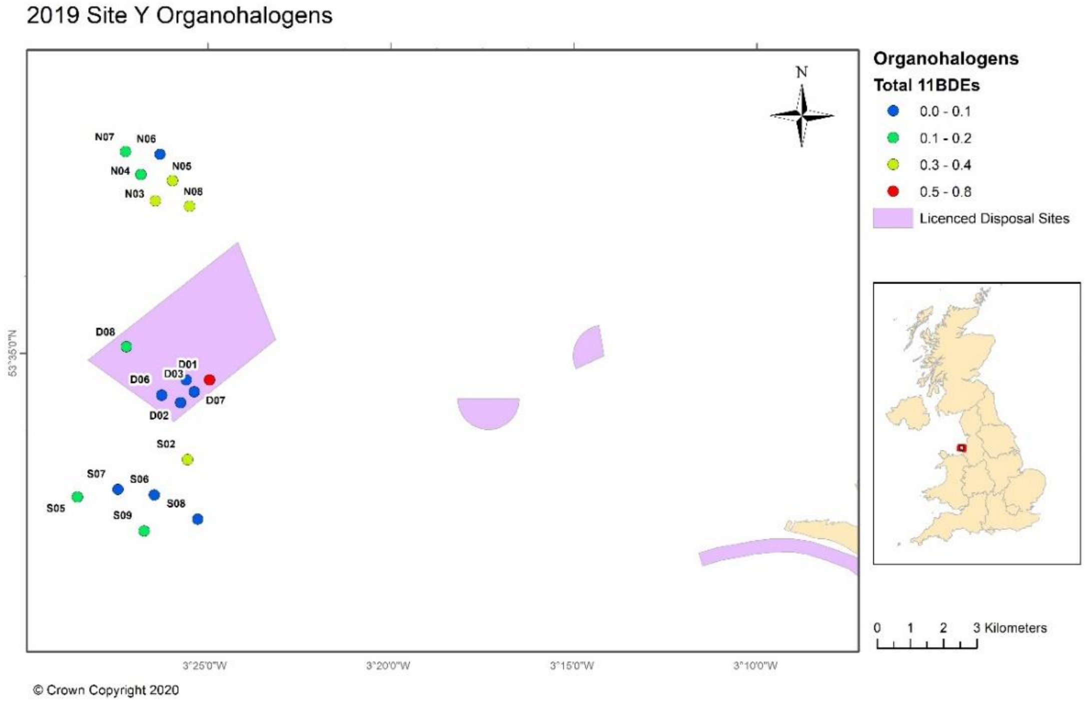


Figure A1.2.9. ∑11 BDEs concentrations for the Site Y Stations, 2019.

BDE209 was detected in all 18 stations at Site Y, making it the most ubiquitous contaminant analysed (concentrations ranged from 2.4 to 110 µg kg^{-1} dw) (Figure A1.2.10). BDE209 made up >97% of total 12 BDEs at all stations (concentrations ranged from 97 to 100%). Highest concentrations were at stations D01, N03, S02 and N06 with values of 110, 68.4, 67.6 and 53.4 µg kg^{-1} dw respectively. Several stations within and to the south of the disposal site exhibited BDE209 concentrations <10 µg kg^{-1} dw, while stations to the north generally had slightly higher concentrations.

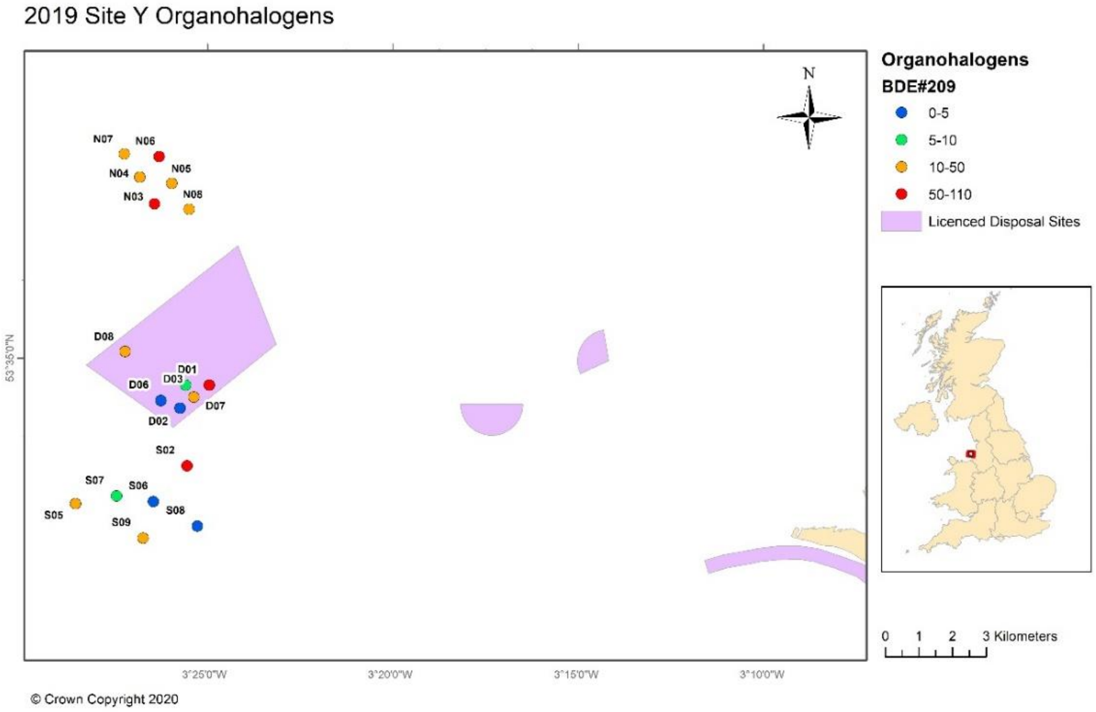


Figure A1.2.10. BDE209 concentrations for the Site Y Stations, 2019.

Concentrations of CBs and dieldrin at all stations were below Cefas action level 1 (AL1). $\sum_{6}$DDTs concentrations were above Cefas AL1 at one of the 18 stations: D07 within the disposal site. No Cefas ALs exist for BDEs, including BDE209. According to the OSPAR guidelines (see Appendix 2), seven stations (D03, D06, D02, S06, S07, S08 and S09) had 'good' environmental status for all ICES 7 CBs and 'good' status overall. The other 11 stations had one CB (CB118) with 'bad' environmental status but 'good' status overall. No stations had 'bad' overall status for CBs. Using the new OSPAR guidelines for BDEs, all stations were below the environmental assessment criteria (EAC) for all congeners, apart from BDE209 which was above the Canadian Federal Environmental Quality Guideline (FEQG) value (Appendix 2) at all stations. Comparing the results with those from OSPAR background stations analysed under the CSEMP programme, most Irish Sea sediment stations are also above this threshold (http://ices.dk/marine-data/assessment-tools/Pages/ospar-cat-app.aspx).

There are data available to compare levels of contaminants between 2015 and 2019 (Table A1.2.3, Table A1.2.4, Table A1.2.5, Table A1.2.6). For CBs and DDTs (Dichlorodiphenyltrichloroethanes), the same temporal pattern was observed. Most stations in the disposal site and to the south showed a decrease in concentration since 2015. A few stations to the north: N03; N06; and N08, increased slightly. PBDEs and BDE209 displayed a similar pattern, but with one additional station to the south, S07, also showing an increase. The results are consistent with the fact that no additional material has been placed at the disposal site since 2015 and sediments have dispersed slowly northwards.

Table A1.2.3. Temporal trends (2015-2019) of ∑ICES 7 CBs concentration (µg kg^{-1} dw) at Site Y in the stations sampled during 2019.

Station	∑ICES 7 CBs concentration (µg kg^{-1} dw)	
	2015	2019
N07		0.323
N06	0.393	0.512
N04	1.370	0.222
N05		0.310
N03	0.249	0.680
N02	0.332	
N08	0.402	0.391
D08	0.436	0.182
D03	2.010	0.134
D01		1.040
D07	3.040	0.298
D04	2.920	
D06	2.730	0.076
D02	1.460	*0.060*
S02		0.593
S04	0.113	
S06	0.176	*0.060*
S08		*0.060*
S09	0.272	0.136
S07	0.201	0.229
S05	0.448	0.080

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

Table A1.2.4. Temporal trends (2015-2019) of $\sum_3$DDTs concentration (µg kg^{-1} dw) at Site Y in the stations sampled during 2019.

Station	$\sum_6$DDTs concentration (µg kg^{-1} dw)	
	2015	2019
N07	0.329	0.342
N06	0.346	0.447
N04	1.250	0.279
N05		0.347
N03	0.267	0.562
N02		
N08	0.394	0.400
D08	1.070	0.241
D03	19.200	0.193
D01		1.540
D07	3.140	0.363
D04	2.620	
D06	2.490	0.167
D02	1.250	0.204
S02		0.515
S04	0.175	
S06	0.225	0.140
S08		0.165
S09	0.318	0.221
S07	0.177	0.172
S05	0.604	0.171

∑6DDTs includes *o,p'*-DDE, *o,p'*-TDE, *o,p'*-DDT, *p,p'*-DDE, *p,p'*-TDE and *p,p'*-DDT

Table A1.2.5. Temporal trends (2015-2019) of ∑11 BDEs concentration (µg kg^{-1} dw) at Site Y in the stations sampled during 2019.

Station	∑ 11 BDEs concentration (µg kg^{-1} dw)	
	2015	2019
N07		0.128
N06	0.224	0.093
N04	0.791	0.145
N05		0.234
N03	0.267	0.339
N02	0.329	
N08	0.337	0.239
D08	0.291	0.116
D03	0.337	0.094
D01		0.409
D07	0.467	0.084
D04	0.454	
D06	0.445	*0.075*
D02	0.328	*0.075*
S02		0.337
S04	0.175	
S06	0.225	*0.075*
S08		*0.075*
S09	0.318	0.104
S07	0.177	0.198
S05	0.604	*0.075*

Concentrations in italic represent estimates of concentrations for samples where all 11 BDEs congener concentrations were below LODs.

Table A1.2.6. Temporal trends (2015-2019) of BDE209 concentration (µg kg^{-1} dw) at Site Y in the stations sampled during 2019.

Station	BDE209 concentration (µg kg^{-1} dw)	
	2015	2019
N07		29.10
N06	19.20	53.40
N04	106.00	18.50
N05		31.50
N03	10.30	68.40
N02	17.70	
N08	25.00	38.00
D08	28.10	16.80
D03	59.90	6.20
D01		110.00
D07	162.00	25.40
D04	101.00	
D06	90.80	3.51
D02	69.90	3.60
S02		67.60
S04	18.50	
S06	12.90	2.52
S08		2.40
S09	24.80	11.20
S07	11.80	25.50
S05	49.70	5.40

1.2.3.3 *Trace metals*

Trace metals enrichment (see Appendix 2) for Site Y stations using OSPAR background assessment concentrations (BACs; see Appendix 2) and regional baseline values are represented in Figure A1.2.11 to Figure A1.2.19. Concentrations of As (arsenic) (Figure A1.2.11) at most stations are lower than the OSPAR BAC and regional baseline values, indicating no enrichment. Slight enrichment is observed for a few stations located within the disposal site. Compared to 2015, there has been very little change in As concentrations (Figure A1.2.12). Enrichments tend towards the southern region of the disposal site, with all northern sampling stations possessing no enrichment based on both assessment methods.

Both enrichment assessments concluded similar findings for Cd (cadmium) with moderate enrichment being observed for one station located within the disposal site (D03), and no enrichment elsewhere (Figure A1.2.13). Cd enrichment in 2019 is lower than was observed in 2015, although direct comparisons must remember that different stations have been sampled within the disposal site. D06 showed a reduction in concentration for Cd compared to 2015 (Figure A1.2.12).

Cr (chromium) displayed similar enrichment patterns to that observed in 2015. Assessing against baseline shows no enrichment in the two reference areas, while four stations within the disposal site exhibit enrichment according to both assessment methods (Figure A1.2.14). However, D08 within the disposal site showed a lowered concentration in 2019 than previously (Figure A1.2.12). Assessing against the OSPAR BAC, all stations showed slight enrichment except D03 which increased into moderate enrichment. Overall, there has been very little change in Cr enrichment compared to 2015 (Bolam et al., 2016).

Generally, Cu (copper) remains slightly to moderately enriched at most stations using the OSPAR BAC approach (Figure A1.2.15). The disposal site stations exhibit less enrichment relative to those of the southern reference area. This spatial pattern is also reflected by the enrichment factors according to the baseline assessment approach.

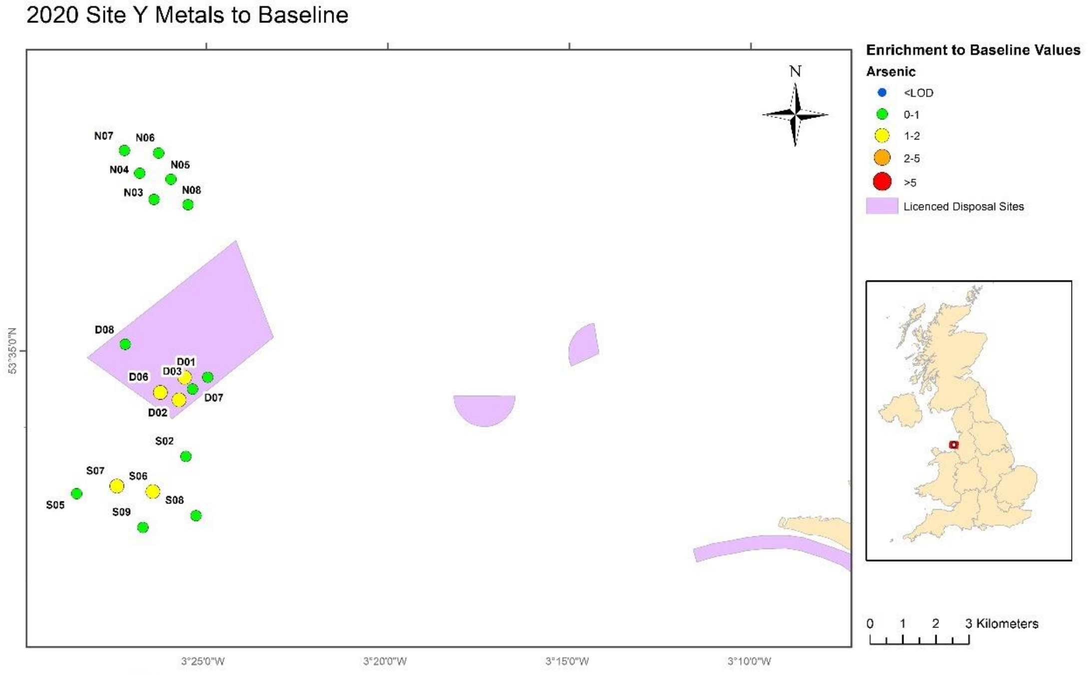
Levels of mercury (Hg) have declined in the stations sampled in the northern reference area compared to that observed there in 2015 according to both assessment approaches (Figure A1.2.16). The disposal site stations, and those of the southern reference area, remain very enriched for Hg. D03 displayed a very high level of enrichment which is comparable to that observed in 2015 and of its neighbouring station D04 (not sampled in 2019) at that time. D06 showed a lower enrichment value compared to 2015, but it’s enrichment in 2019 remains very high (Figure A1.2.16).

Nickel (Ni) baseline assessment shows no enrichment within the disposal site (Figure A1.2.17) which represents a reduction in concentrations compared to 2015 (Figure A1.2.12). The reference areas display similar trends as seen in 2015 with no enrichment apart from two stations (S06, S07) south of the disposal site being slightly enriched. The OSPAR assessment approach depicts a slight enrichment across all stations, like previous monitoring in 2015 (Bolam et al., 2016).

Levels of lead (Pb) are moderately enriched when assessed against the OSPAR BAC values (Figure A1.2.18) which is in harmony with the situation observed in 2015. Enrichment is less pronounced using the baseline assessment approach, where a slight enrichment increase is evident in the southern reference area (i.e. slight to moderate enrichment) (Figure A1.2.18).

Concentrations of Zn (zinc) are mainly found to be slightly enriched using the OSPAR assessment with just one moderately enriched station within the disposal site (Figure A1.2.19). No enrichment was generally observed for stations when assessed against the regional baseline values. Both assessment methods show a slight reduction in concentration for stations within the disposal site (Figure A1.2.12).

In conclusion, the trace metals concentrations sampled in 2019 tend to be much higher than the OSPAR BAC values especially for Hg and Pb. This is generally due to the legacy from the historical and current industrial activities of the area. When assessing those concentrations against the proposed regional baseline values, which were derived by considering for regional variability (Appendix 2), enrichment is still observed but to a reduced level. The temporal change in trace metals concentrations observed infer a general southward drift of metal contamination, although further factors (e.g. hydrodynamic data) would need to be considered to ascertain whether this is a true rationale for the observed shift.



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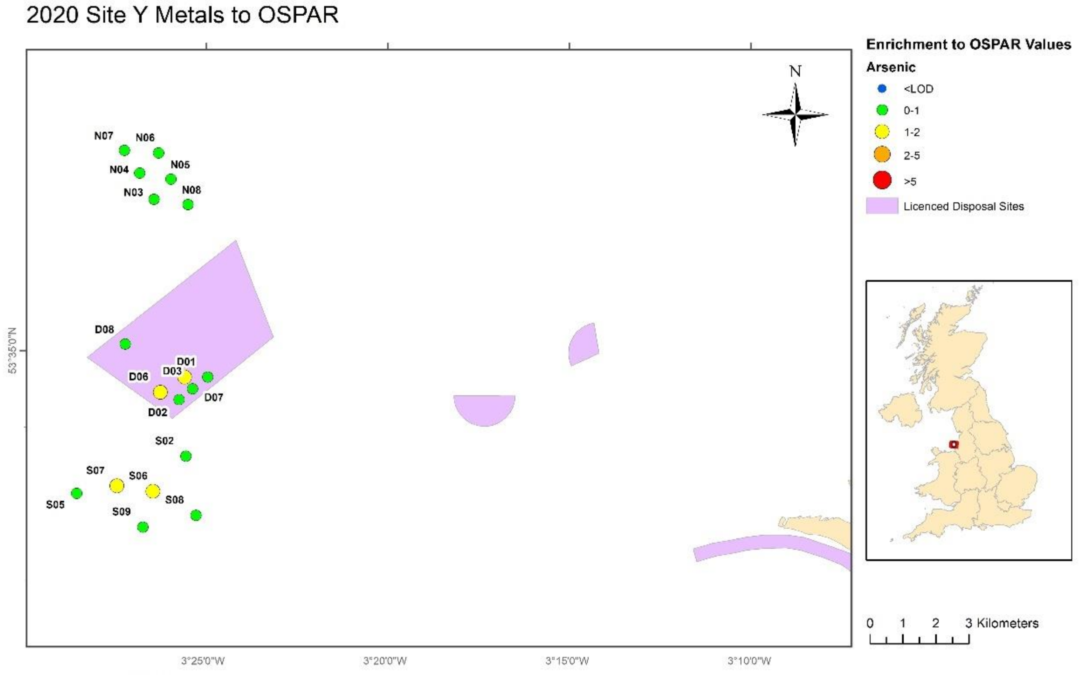

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Figure A1.2.11. Arsenic enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

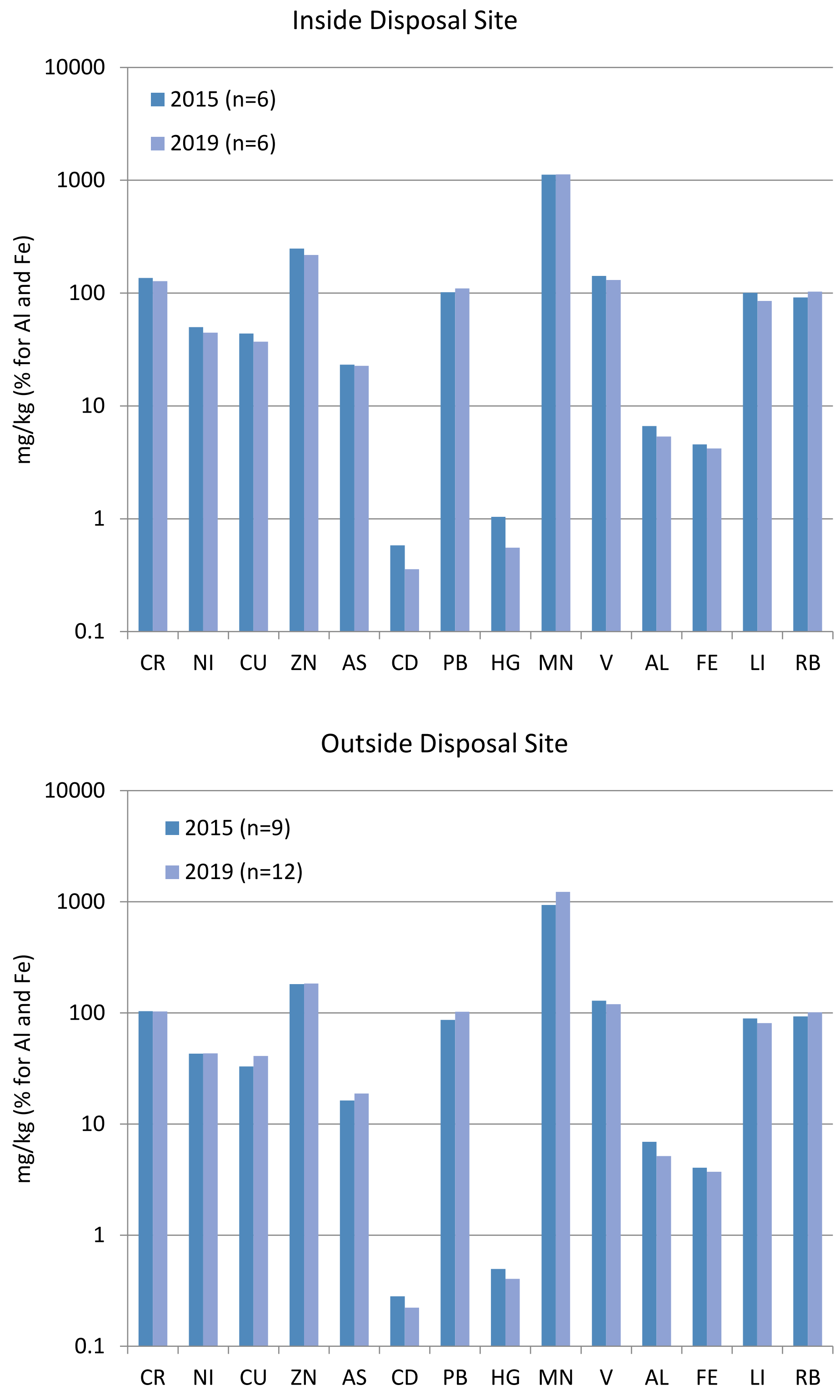
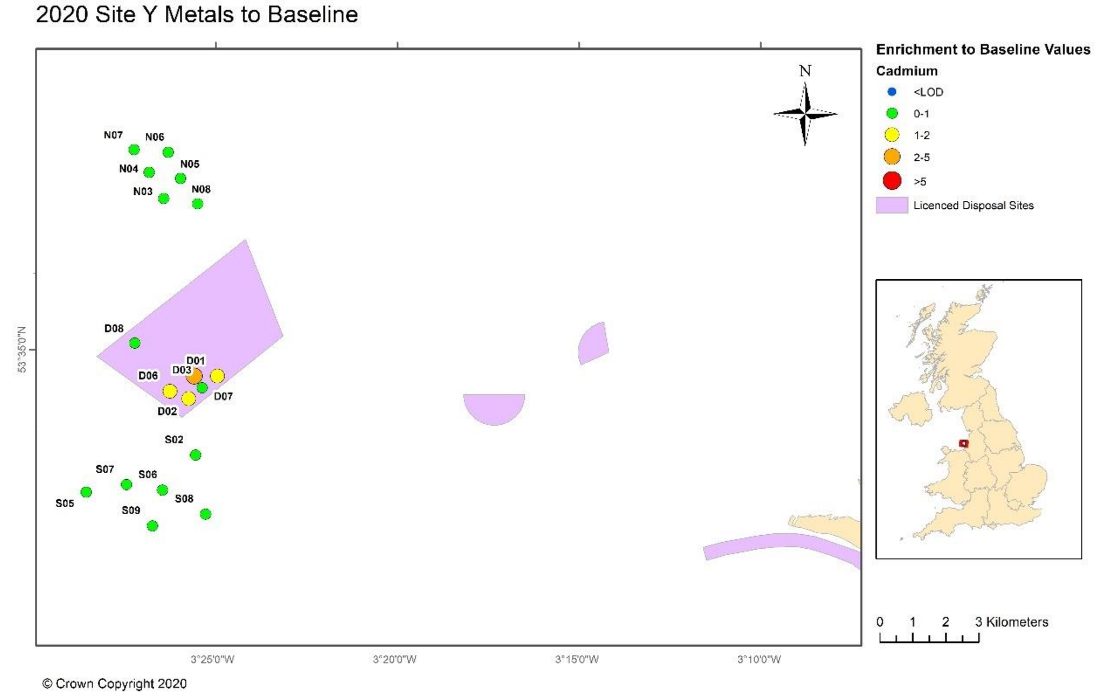


Figure A1.2.12. Trace metals concentrations for stations sampled inside (top) and outside (bottom) the Site Y disposal site in 2015 and 2019.



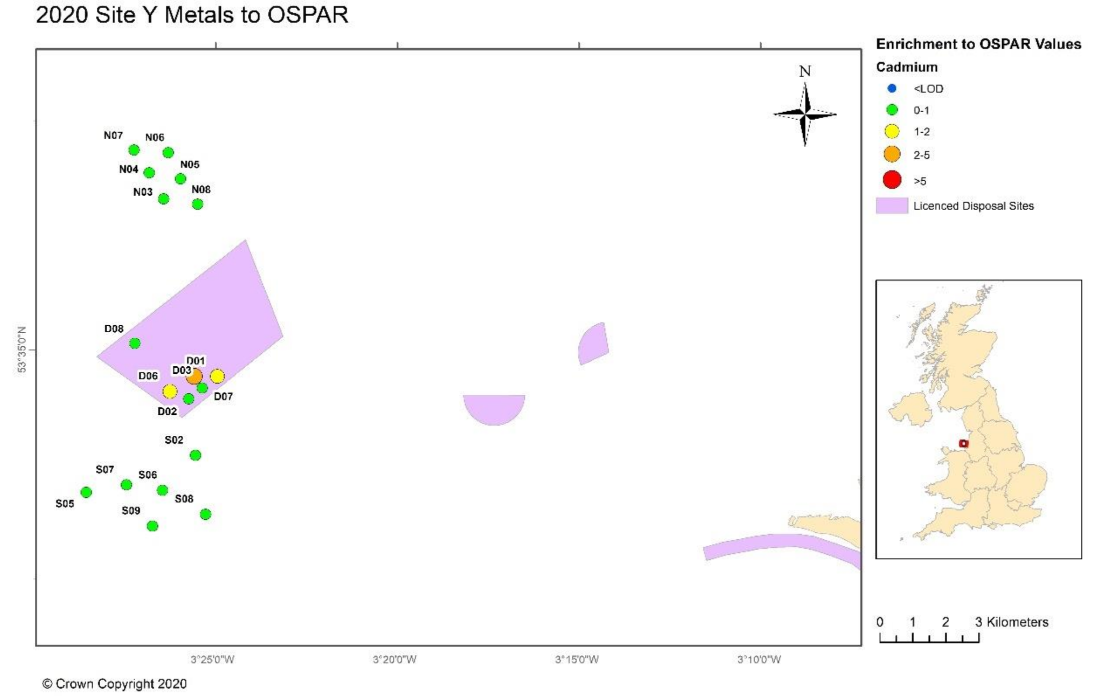
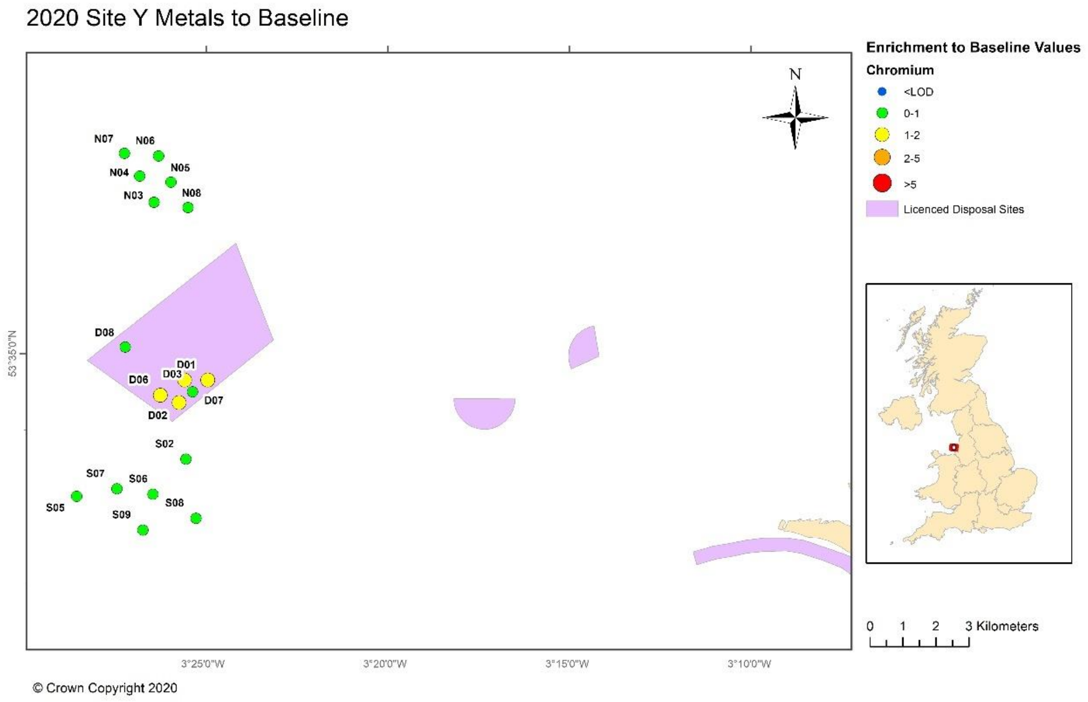


Figure A1.2.13. Cadmium enrichment values to regional baseline values (top) and OSPAR BACs (bottom).



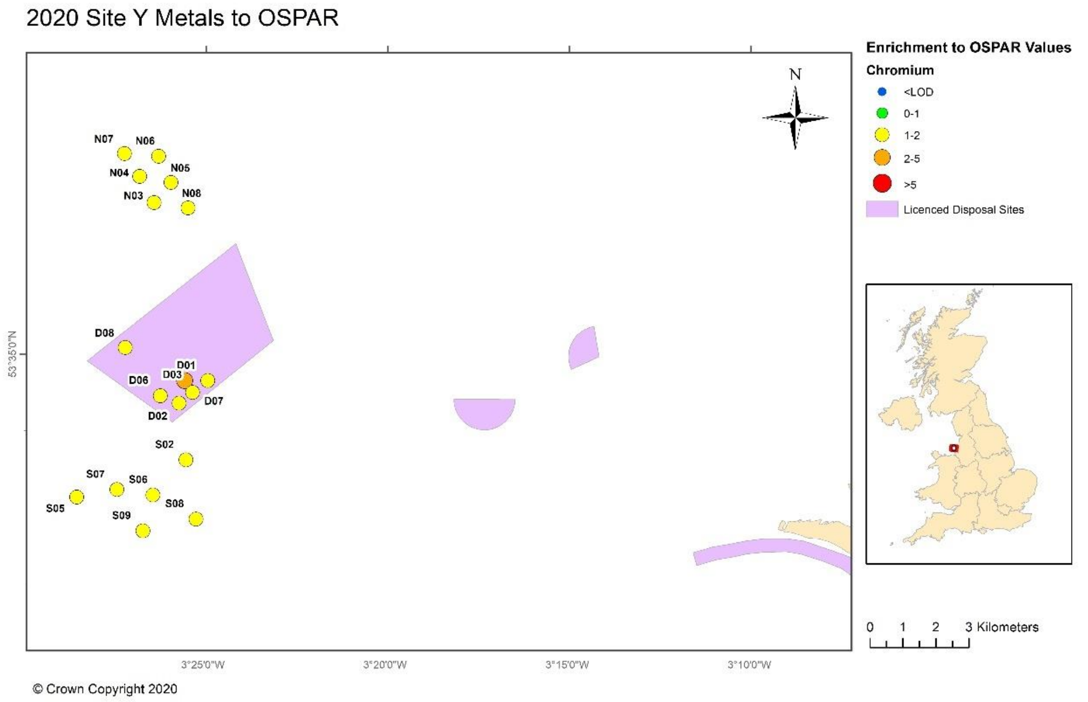
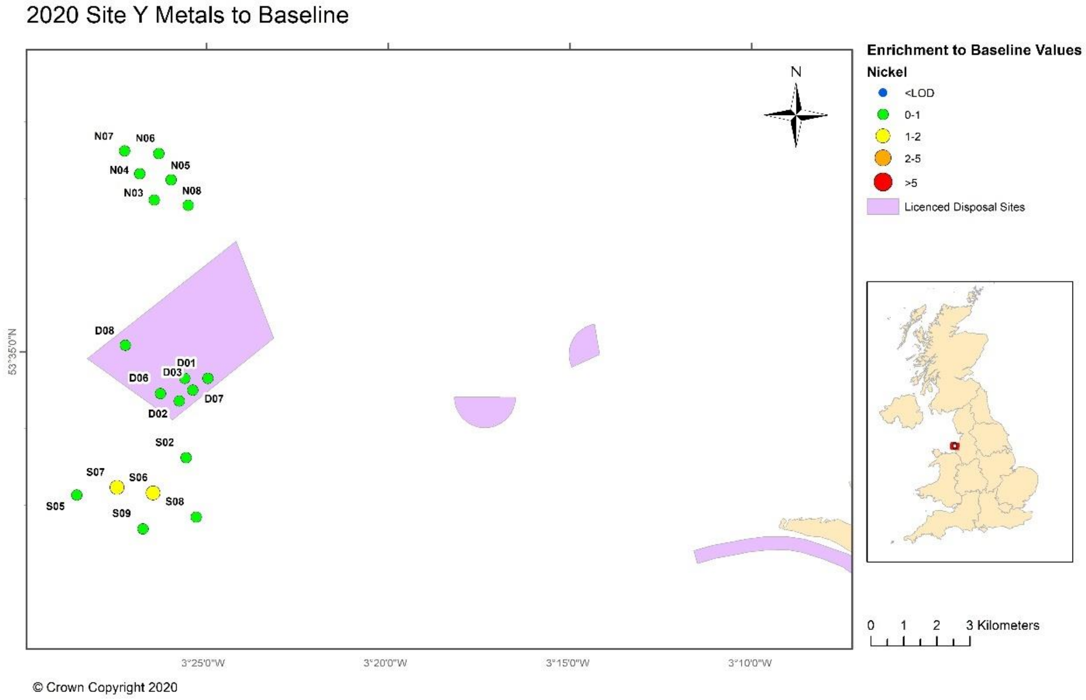


Figure A1.2.14. Chromium enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

Figure A1.2.15. Copper enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

Figure A1.2.16. Mercury enrichment values to regional baseline values (top) and OSPAR BACs (bottom).



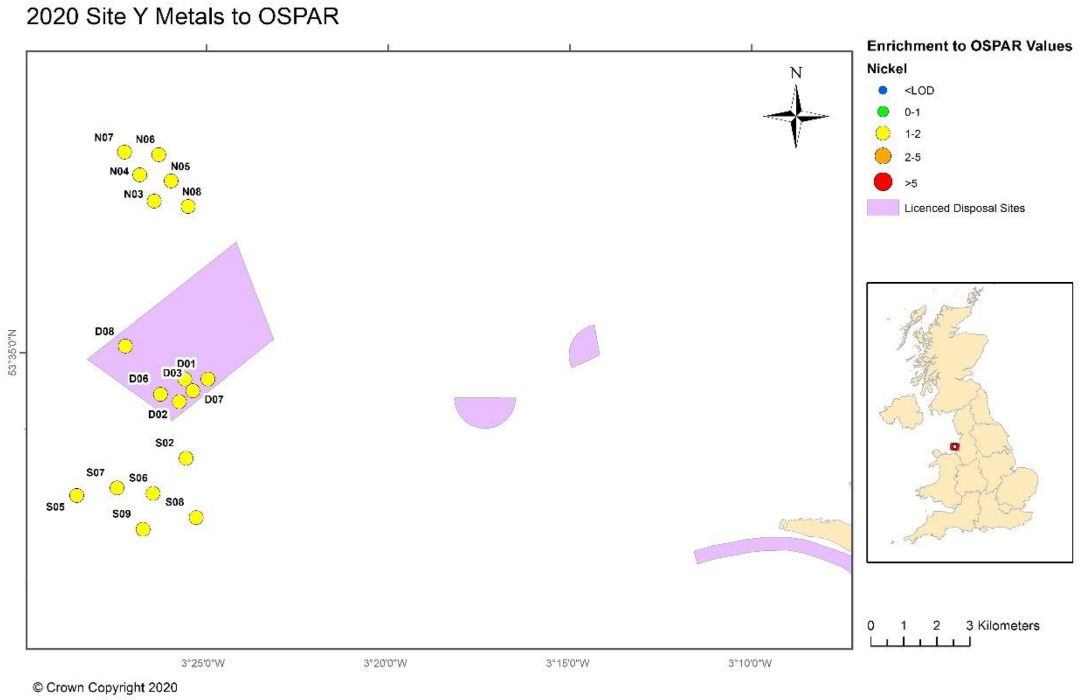
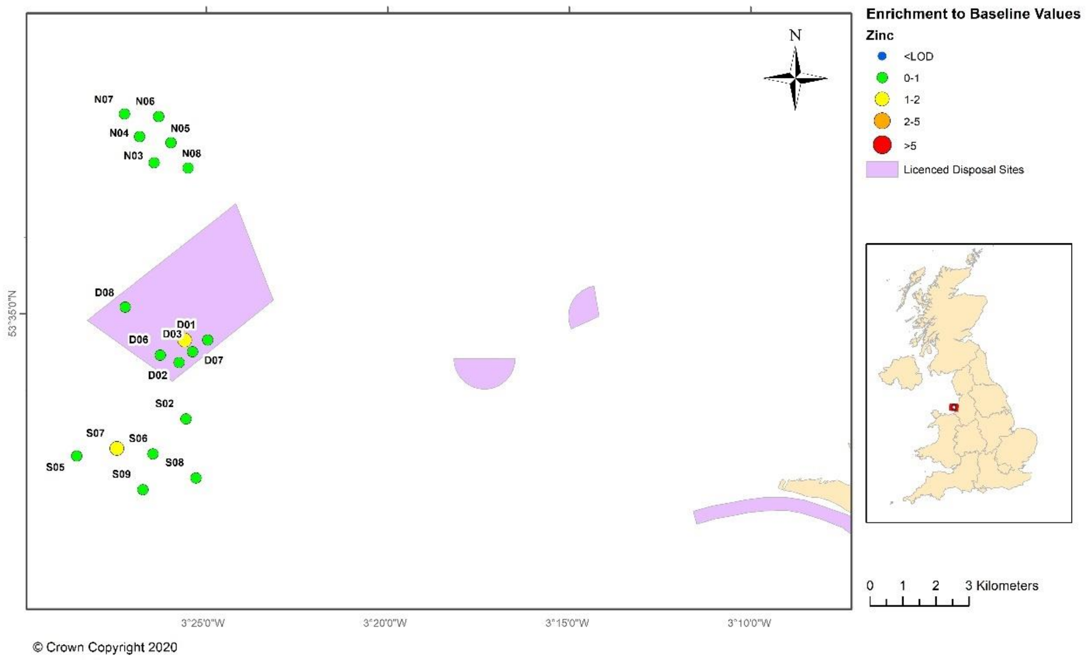


Figure A1.2.17. Nickel enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

Figure A1.2.18. Lead enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

2020 Site Y Metals to Baseline



2020 Site Y Metals to OSPAR

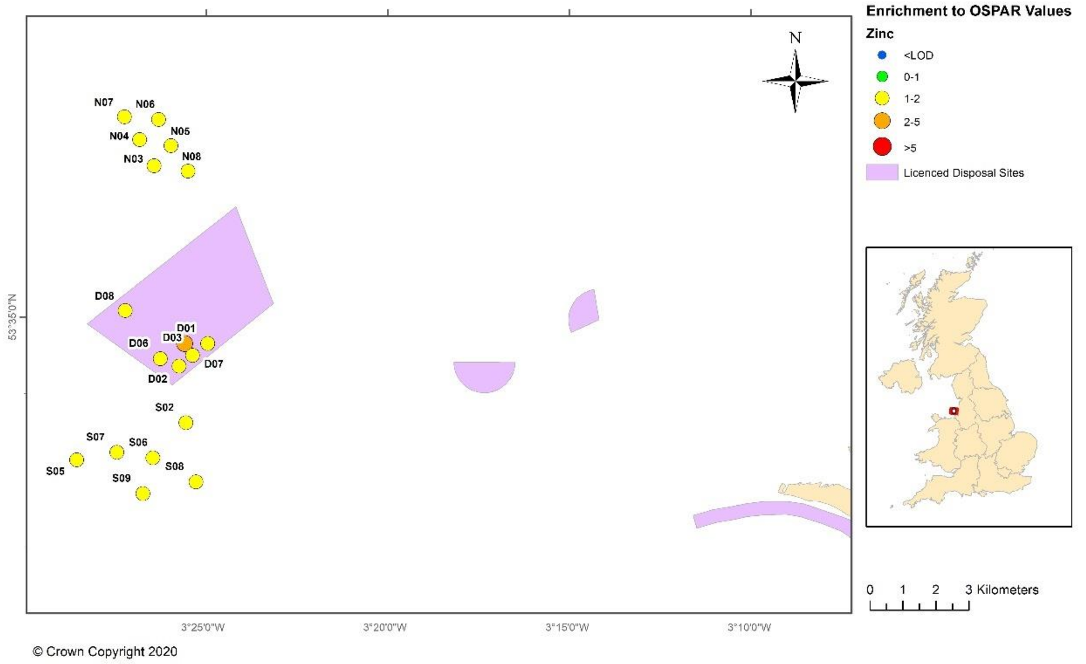


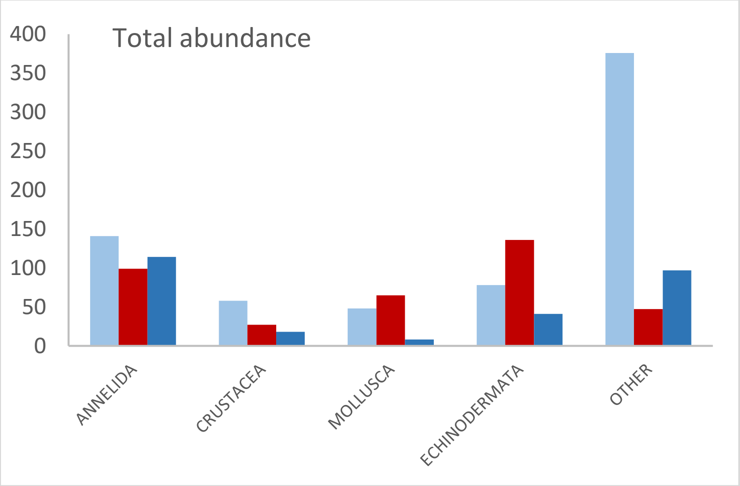
Figure A1.2.19. Zinc enrichment values to regional baseline values (top) and OSPAR BACs (bottom).

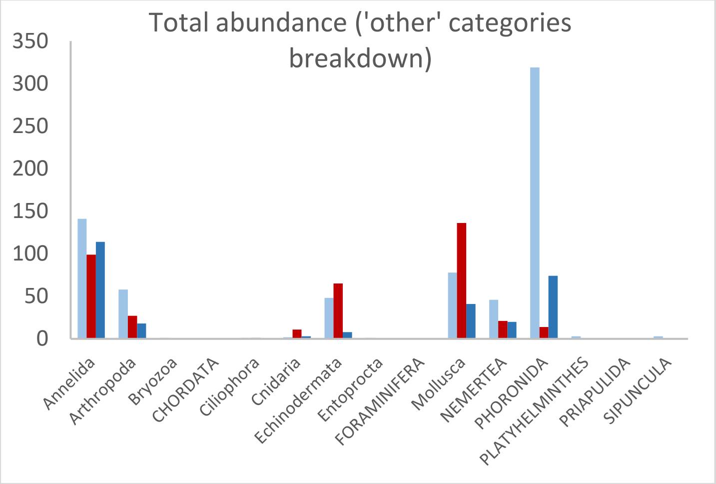
1.2.4 Sediment macrofauna

All macrofaunal samples acquired from the survey were processed by Cefas in accordance with the National Marine Biological Analytical Quality Control (or NMBAQC) scheme (Worsfold et al., 2010). A total of 128 taxa (including colonial epifauna) were recorded from the 18 grab samples (a single replicate was taken at each station) taken at Site Y during the 2019 survey. One hundred and twenty-two free living macrofaunal invertebrate taxa were identified (80 % identified to species level), the most prevalent taxon being the phylum Phoronida (*Phoronis* spp.) which was numerically dominant at the north reference stations in 2019 (Figure A1.2.20). The polychaete *Sthenelais limicola* and the crustacean *Callianassa subterranean* were ubiquitous, being present in 15 and 14 samples respectively. Six taxonomic groups of colonial epifauna were identified (66 % identified to species), with the most prevalent taxa occurring in a maximum of eight samples (the hydrozoan *Lovenella clausa*).

Segmented worms, or annelids, were typically the most abundant macrofaunal invertebrates encountered, with stations within the disposal site typically having a lower abundance of them than either of the reference areas. Molluscan and echinoderm taxa were, however, more abundant within the Site Y disposal site compared to reference areas. Crustacean taxa were typically less abundant in the south reference site and more abundant in the north reference site, while cnidarians were typically more abundant within disposal site stations (Figure A1.2.20).

The 2015 and 2019 macrofaunal datasets were compared to assess any change in univariate metrics and community structure over time. The mean species richness (number of taxa per grab, *S*) of stations within the south reference area has decreased significantly but remained consistent within the north reference area and disposal site (Figure A1.2.21; Table A1.2.7). Total macrofaunal abundance (number of individuals per grab, *N*) within the disposal site and north reference area is more variable in 2019 but not significantly different to that observed in 2015 (Figure A1.2.21). The average total biomass (g) of macrofauna is also highly variable in samples within the disposal site, particularly in 2019, while being consistently low in samples collected from within the south reference area (Figure A1.2.21).





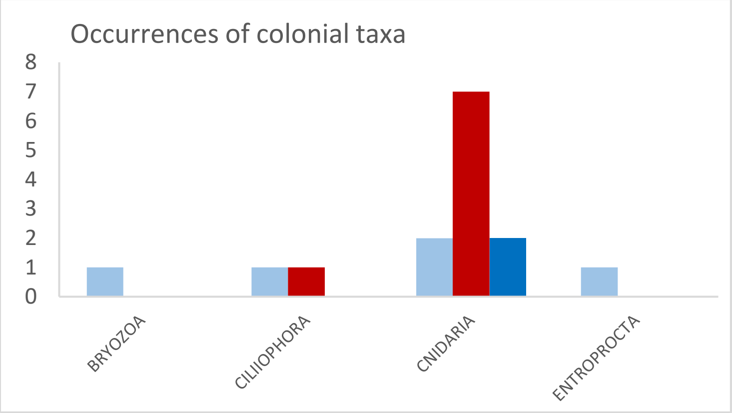


Figure A1.2.20. Bar charts showing the breakdown of abundance (N, per 0.1 m^2 grab) of the taxonomic major groups across the north reference (light blue), Site Y disposal site (red) and south reference area (dark blue) in 2019.

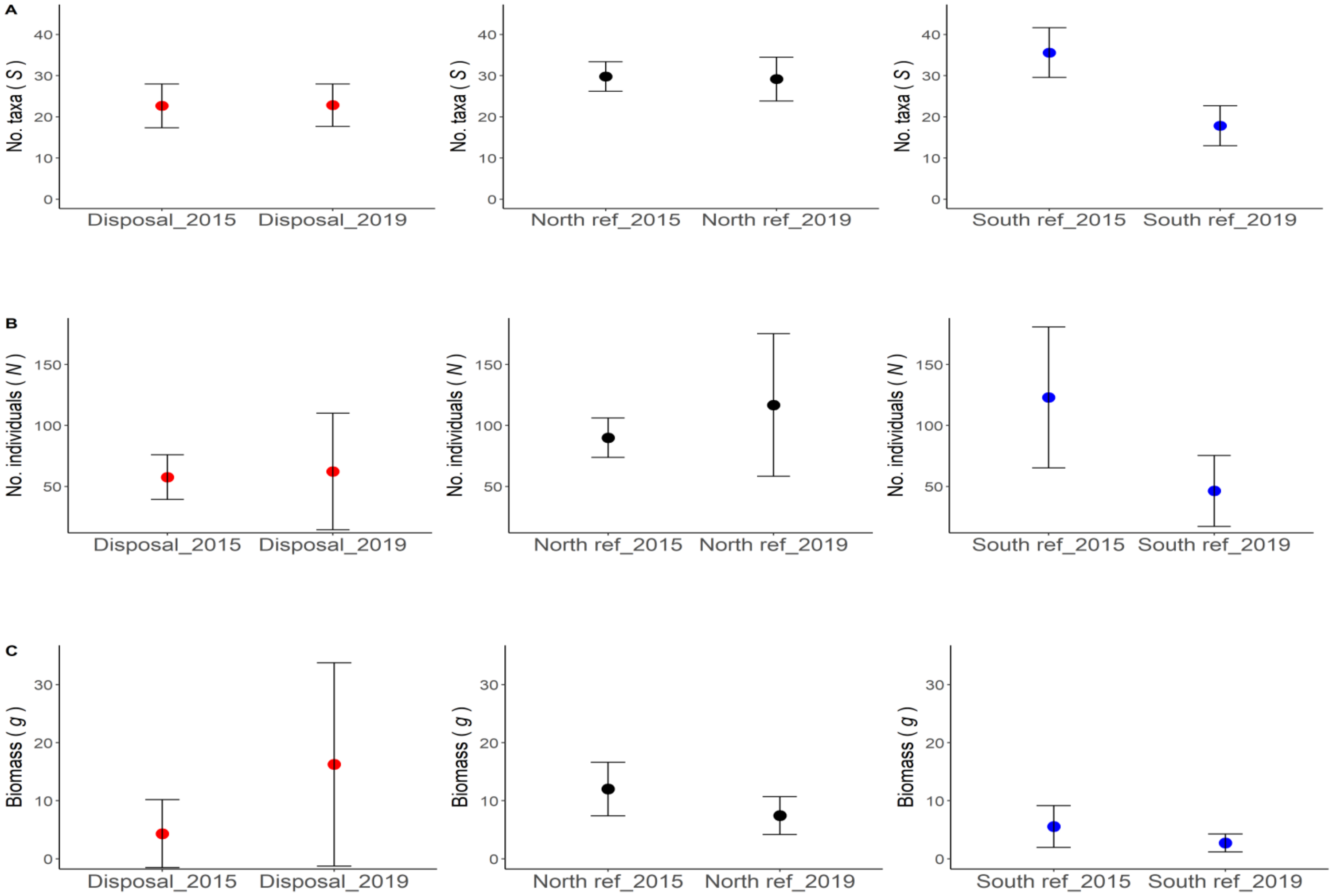


Figure A1.2.21. Mean (± 95% CI) values of (a) number of taxa, (b) number of individuals, and (c) wet biomass per grab (0.1 m^2) for the assemblages sampled during 2015 (left) and 2019 (right).

Table A1.2.7. Summary descriptive statistics showing the richness (S), abundance (N) and total biomass (g) for each treatment site in 2015 and 2019.

		Total number of taxa (*S*)	Total number of individuals (*N*)	Total biomass (g)
2015 Disposal	Range	16-34	29-95	0.4–19.1
	Mean	23	58	4.3
	St. Dev.	6.6	22.9	7.3
	Variance	43.9	525.9	53.3
2015 North reference	Range	25-35	70-111	7.7–19.0
	Mean	30	104	12.0
	St. Dev.	4.1	18.5	5.3
	Variance	16.7	324.5	27.7
2015 South Reference	Range	28-44	50-223	0.6–10.0
	Mean	36	123	5.6
	St. Dev.	6.9	66.0	4.1
	Variance	47.3	4351	17.0
2019 Disposal	Range	17-35	27-182	0.2–58.9
	Mean	23	62	16.3
	St. Dev.	6.5	59.8	21.9
	Variance	41.8	3575.1	479.2
2019 North reference	Range	22-37	46-202	2.9–13.0
	Mean	35	176	7.4
	St. Dev.	6.7	73.0	4.1
	Variance	44.6	5333.0	16.7
2019 South Reference	Range	10-23	15-108	0.5–5.1
	Mean	18	46	2.8
	St. Dev.	6.1	36.3	1.9
	Variance	36.3	1317.5	3.7

Pairwise comparisons (using the ANOSIM test on PRIMER) on the 2019 data implied a separation of benthic community structures between assemblages of the disposal stations and those of both the north and south reference stations (R = 0.32, p<0.001; R = 0.40, p<0.001, for the north and south reference stations respectively). Interestingly, there was higher separation between the two reference area communities (R = 0.59, p<0.001). These results are supported by the locations of the stations on the 2d ordination plot (Figure A1.2.22).

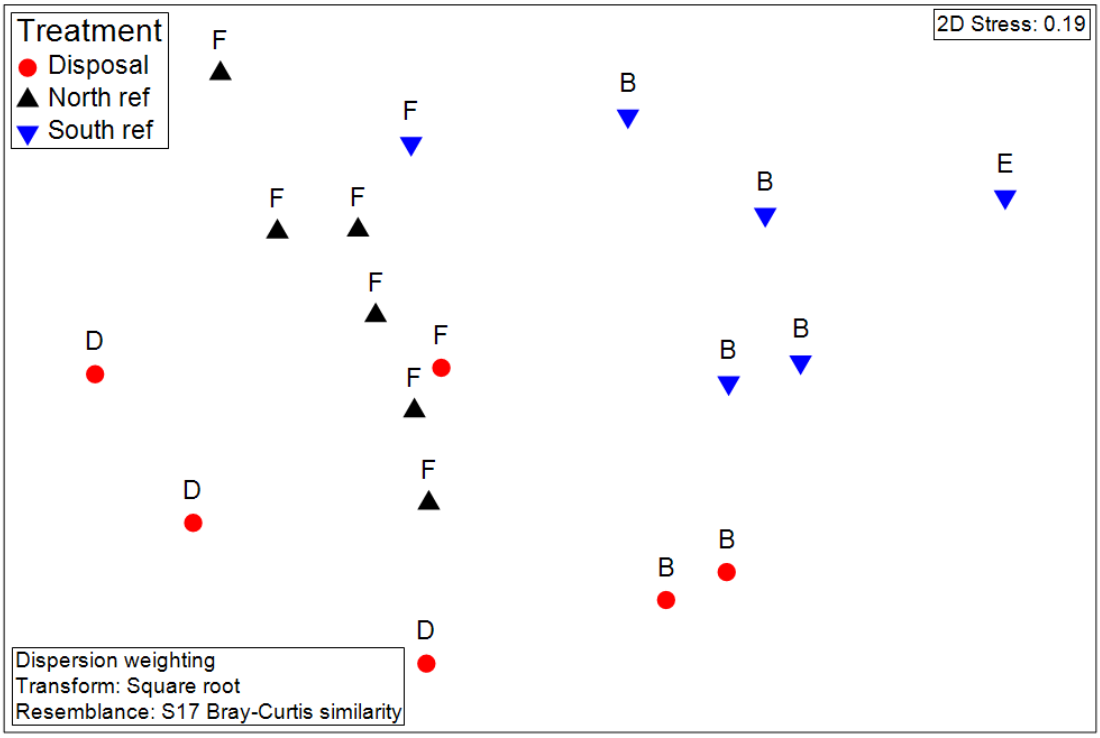


Figure A1.2.22. Non-parametric Multidimensional Scaling (nMDS) ordination plot of the square root-transformed abundance macrofaunal data (colonial macroinvertebrates enumerated as one prior to transformation) showing the separation of benthic communities between disposal and references stations at Site Y, 2019, and group allocation (A-F) following k-R Clustering.

A non-hierarchical flat clustering method, whereby group allocation is redefined iteratively and maximised through the ANOSIM R statistic, was performed in PRIMER to identify statistically different faunal groups. In total, six groups (A-F) were identified (R = 0.85) based on the data obtained from both 2015 and 2019 which differ in their overall community structure (Figure A1.2.23). Station abundance values were summed by their group allocation to help define their characteristics and the macrofaunal metrics (species richness, total abundance and total biomass) were calculated (Table A1.2.8). Group F, the most diverse, numerically abundant group with the highest summed biomass, comprised north reference stations (from both survey events) while the group allocation of stations within the disposal site and south reference stations varied between 2015 and 2019 (Figure A1.2.24). A single station, from within the northwest region of the disposal site, was identified as belonging to Group F following both 2015 and 2019 surveys. The remaining stations within the disposal site were found to have increased species richness, total abundance and biomass in 2019, changing from Groups C and E in 2015 to Groups B and D in 2019 (Figure A1.2.24, Table A1.2.8). Interestingly, the south reference stations typically had decreased species richness, abundance and biomass in 2019 (Figure A1.2.21, Table A1.2.8).

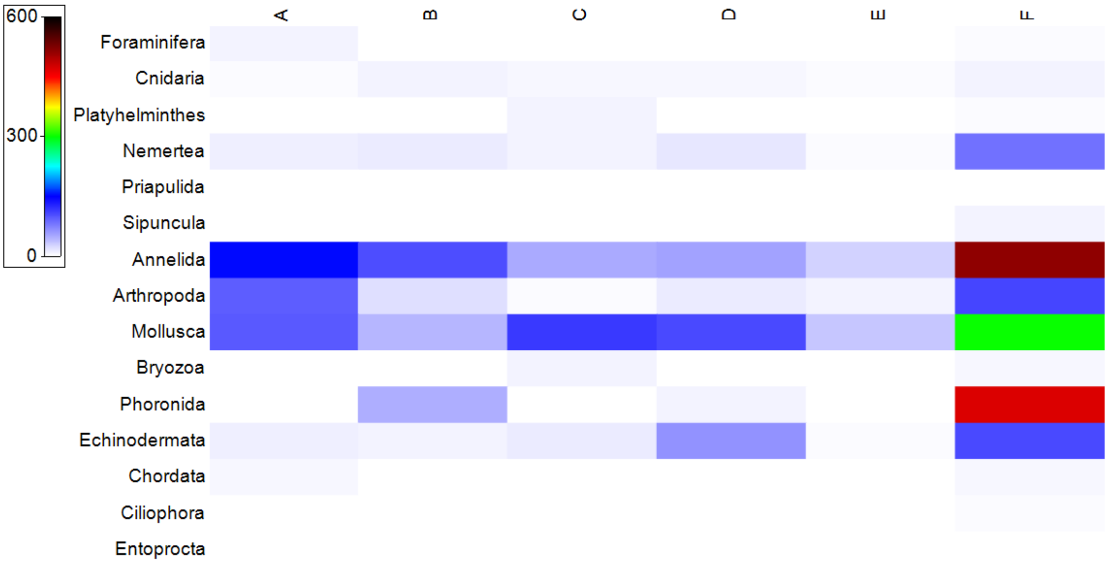


Figure A1.2.23. Shade plot showing the summed abundance values of macroinvertebrates (phyla) by k-R cluster group.

Table A1.2.8. Species richness (S), total abundance (N) and total biomass (g) of the samples allocated to each of six infaunal k-R cluster groups.

Infaunal group	Total number of taxa (S)	Total abundance (*N*)	Biomass (*g*)
A	69	377	17.6
B	55	236	15.4
C	46	206	6.2
D	53	260	77.3
E	37	74	1.2
F	142	1611	154.9

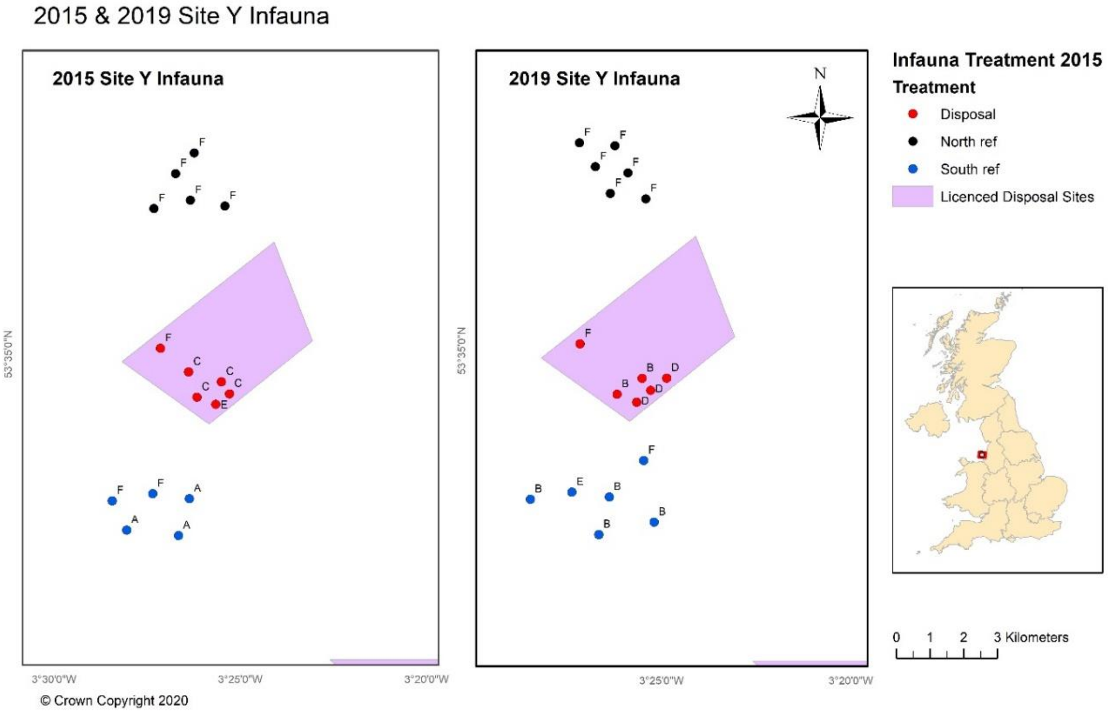


Figure A1.2.24. Map showing the location of the 2015 and 2019 sample points inside each of the treatment areas (north reference, south reference and disposal site) and the k-R group allocation (A-F).

In summary, there were high numbers of *Phoronis* spp. in the north reference stations which were typically absent from the disposal site and south reference stations in 2019. This area also showed evidence of maintaining a consistent assemblage over time. Stations within the disposal site, on average, had slightly lower species richness than those of the north reference but demonstrated higher variability in total abundance and biomass in 2019, with some stations having similar values to those of the north reference stations, when compared to the 2015 data. In 2019, stations from within the south reference site were generally less speciose and comprised lower biomass and abundances of their macrofaunal assemblages.

The 2019 macrofaunal data form a useful baseline for future assessments or, when considered in the context of disposal activity and a time series of macroinvertebrate data collection, contribute to a better understanding of the potential recoverability of Site Y following the previous disposal campaign.

Appendix 2: Assessment methods of contaminants

2.1 PAHs

Sample extraction

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

Method used for assessment

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

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

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

- naphthalene
- monomethyl naphthalenes
- acenaphthene
- acenaphthylene
- fluorene

- phenanthrene
- anthracene

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

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

Although a wider suite of PAHs is routinely determined for both licensing and monitoring purposes, these can be considered as toxicity markers for the PAH as a whole. The ERL and ERM concentrations applied are given in Table A2.1.

Table A2.1. ERL and ERM concentrations for LMW and HMW PAHs in sediments. The limits for LMW PAH are lower than those for HMW PAH as they carry a higher acute toxicity.

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

2.2 Organohalogens

Sample extraction

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

Sample extract clean-up

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

Analysis of PCBs and OCPs by GC-MS/MS

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

Analysis of PBDEs by GC-MS/MS

After addition of internal standard CB200, PBDE concentrations were determined with a Shimadzu 2010plus GC with TQ8030 QQQ-MS/MS in positive electron impact mode (ESI+). The separation of analytes was performed on a 15.0 m × 250 µm, 0.15-µm-film-thickness Rtx-1614 capillary column (Restek). The carrier gas was helium (1.28 ml min^{-1}) and the collision gas was argon. The initial oven temperature was 120°C, held for 1.00 min, then increased to 275°C at 15°C min^{-1}, to 300°C at 50°C min^{-1}, and finally held for 5 min. The injector temperature and source temperature were 340°C and 230°C, respectively. A 2 µl extract was injected in pulsed splitless mode with a purge time of 2 min.

Analysis of BDE209 by GC-MS

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

Quantitation methods

The identification of PCBs and OCPs was based on the retention time of individual standards in the calibration mixtures. Quantitation was performed using internal standards and 9 calibration levels (range 0.1 – 200.0 ng ml^{-1}). The combined PCB and OCP standard solutions contained the following 41 compounds in iso-octane: Hexachlorobenzene; hexachlorobutadiene, alpha-HCH, beta-HCH, gamma-HCH, *p,p'*-DDE, *p,p'*-TDE, *p,p'*-DDT, *o,p'*-DDE, *o,p'*-TDE, *o,p'*-DDT, dieldrin, heptachlor, heptachlor epoxide, endosulfan-I, endosulfan-II, endosulfan sulfate; IUPAC CB101; IUPAC CB105; IUPAC CB110; IUPAC CB118; IUPAC CB128; IUPAC CB138; IUPAC CB141; IUPAC CB149; IUPAC CB151; IUPAC CB153; IUPAC CB156; IUPAC CB158; IUPAC CB170; IUPAC CB18; IUPAC CB180; IUPAC CB183; IUPAC CB187; IUPAC CB194; IUPAC CB28; IUPAC CB31; IUPAC CB44; IUPAC CB47; IUPAC CB49; IUPAC CB52; IUPAC CB66. Concentrations were corrected for the recovery of the $^{13}C_{12}$ labelled recovery standards.

Quantitation for PBDEs was performed using internal standards and 10 calibration levels (range 0.05 – 100.00 ng ml^{-1}). The PBDE standard solutions contained the following 11 compounds in iso-octane: IUPAC BDE17; IUPAC BDE28; IUPAC BDE47; IUPAC BDE66; IUPAC BDE100; IUPAC BDE99; IUPAC BDE85; IUPAC BDE154; IUPAC BDE153; IUPAC BDE138; IUPAC BDE183; plus an additional 13 compounds: IUPAC BDE3; IUPAC BDE7; IUPAC BDE15; IUPAC BDE49; IUPAC BDE71; IUPAC BDE77; IUPAC BDE119; IUPAC BDE126; IUPAC BDE156; IUPAC BDE184; IUPAC BDE191; IUPAC BDE196; IUPAC BDE197; together with the internal standard IUPAC CB200 and recovery standards F-BDE69 and F-BDE-160. Concentrations were corrected for the recovery of the F-BDE recovery standards.

Quantitation of BDE209 was performed using an internal standard and 7 calibration levels (range 0.5 – 500.0 ng ml^{-1}). The BDE209 standard solutions contained IUPAC BDE209 in iso-octane, plus an additional 3 compounds IUPAC BDE206; IUPAC BDE207; IUPAC BDE208; together with the internal standard $^{13}C_{12}$- labelled IUPAC BDE209.

Quality assurance/ quality control procedures

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

Method used for assessment

PCB, OC and BDE concentrations were determined in the sediments and reported on a dry weight basis. The ∑ICES 7 CBs (CB28, CB52, CB118, CB153, CB138, CB170, CB183), and the sum of all 25 measured CBs (∑CBs) were calculated. Where individual congener concentrations were below the limit of detection (LOD) of 0.02 µg kg^{-1}, a value of half the LOD was inserted for calculation of summed concentrations. The ∑DDTs (*p,p'*-DDE, *p,p'*-TDE, *p,p'*-DDT, *o,p'*-DDE, *o,p'*-TDE, *o,p'*-DDT) were calculated. The ∑11 BDEs were calculated. Where individual congener concentrations were below the LOD of 0.02 µg kg^{-1}, a value of half the LOD was inserted for calculation of summed concentrations. For samples analysed prior to 2008, a different LOD of 0.125 µg kg^{-1} applied, resulting in higher values substituted for congeners below LODs. The congener patterns were evaluated, with BDE183 a marker constituent of the octa-BDE technical mix, and the other BDEs constituents of the penta-BDE technical mix. Additionally, BDE209 ("Deca BDE") concentrations were calculated. Where BDE209 concentrations were below the LOD of 0.1 µg kg^{-1}, a value of half the LOD was inserted.

The Total Organic Carbon (TOC) content in the <2 mm fraction determined at a number of representative sampling stations was used to additionally calculate the contaminant concentration normalised to 2.5 % TOC content. The TOC data from the representative stations was used to estimate the TOC content at adjacent stations for which this value was lacking.

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

The current Cefas action limits for dredge disposal are: Action level 1 if ∑ICES7 CBs > 10 µg kg^{-1}, ∑25CBs > 20 µg kg^{-1}, ∑DDT > 1 µg kg^{-1}, dieldrin > 1 µg kg^{-1}, and action level 2 if ∑25CBs > 200 µg kg^{-1}. Concentrations are expressed on a dry weight (dw) basis.

OSPAR in Charting Progress 2 (CP2) have set criteria for Background Assessment Concentrations (BAC) and Environmental Assessment Concentrations (EAC) for the ICES7 CBs in sediments (see Table A2.2). Concentrations are expressed in µg kg^{-1} dry weight normalised to 2.5 % organic carbon. Concentrations below BACs would be considered to have high environmental status. Concentrations significantly below EACs could be considered to have good environmental status and those above, bad environmental status. The station is deemed to have 'bad' environmental status if 'bad' status occurs for more than one ICES7 CB congener.

Table A2.2. OSPAR assessment criteria for CBs in sediment from CP2.

Sediment (µg kg^{-1} dry weight, normalised to 2.5 % TOC)		
Compound	**BAC**	**EAC**
CB28	0.22	1.70
CB52	0.12	2.70
CB101	0.14	3.00
CB118	0.17	0.60
CB138	0.15	7.90
CB153	0.19	40.00
CB180	0.10	12.00

OSPAR MIME have recently adopted the Canadian FEQG (Federal Environmental Quality Guidelines) levels as EAC results for PBDEs, and also calculated BAC values. These thresholds are shown in Table A2.3.

Table A2.3. Canadian FEQG (Federal Environmental Quality Guidelines) levels adopted by OSPAR MIME as EACs thresholds for PBDEs, together with calculated BAC values.

Sediment (µg kg^{-1} dry weight, normalised to 2.5 % TOC)		
Compound	**BAC**	**EAC**
BDE28	0.04	110.00
BDE47	0.04	97.50
BDE66	0.04	97.50
BDE85	0.04	1.00
BDE99	0.04	1.00
BDE100	0.04	1.00
BDE153	0.04	1100.00
BDE154	0.04	1100.00
BDE183	0.04	14000.00
BDE209	0.04	47.50

Concentrations in the samples collected for this report were compared with those collected on previous sampling campaigns from 2002-2012, to investigate temporal trends in sediments at the sampling stations.

2.3 Trace Metals

Methodology

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

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

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

Numerical assessments

Enrichment factors

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

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

Enrichment is arbitrary defined in four levels:
0-1: no enrichment
1-2: slight enrichment
2-5: moderate enrichment
>5: high enrichment

The two assessment methods are briefly presented below (but see Cefas (2011) for a more detailed explanation).

OSPAR BACs

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

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

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

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

Regional baselines

The above-mentioned Background Concentrations (BCs) are based on concentrations recorded in ‘pristine’ areas. There is only one set of values assigned by OSPAR for the whole North Atlantic (http://www.ospar.org). However, trace metal concentrations are known to show regional variation in the UK, largely related to the variable geology around the coast and historical industrial activity in the early 19th Century which has caused localised elevated levels (Ridgeway et al, 2003; Rowlatt and Lovell, 1994; Cefas, 2005). Therefore, for assessing enrichments at disposal sites, Cefas have developed regional baselines utilising various spatial datasets around England and Wales. Recently, an extensive study was carried out on 8 regions defined in the Clean Seas and Environment Programme (CSEMP) (Figure A2.1) and the proposed metals baselines concentration derived from this study have additionally been used in this report as a validation tool to i) compare with OSPAR BACs values, and ii) to assess the credibility of using those proposed baselines values instead of the OSPAR BACs values when studying for metals enrichment. The proposed baselines for the areas are given in Table A2.4, along with the corresponding OSPAR BACs values for each metal (OSPAR, 2006).

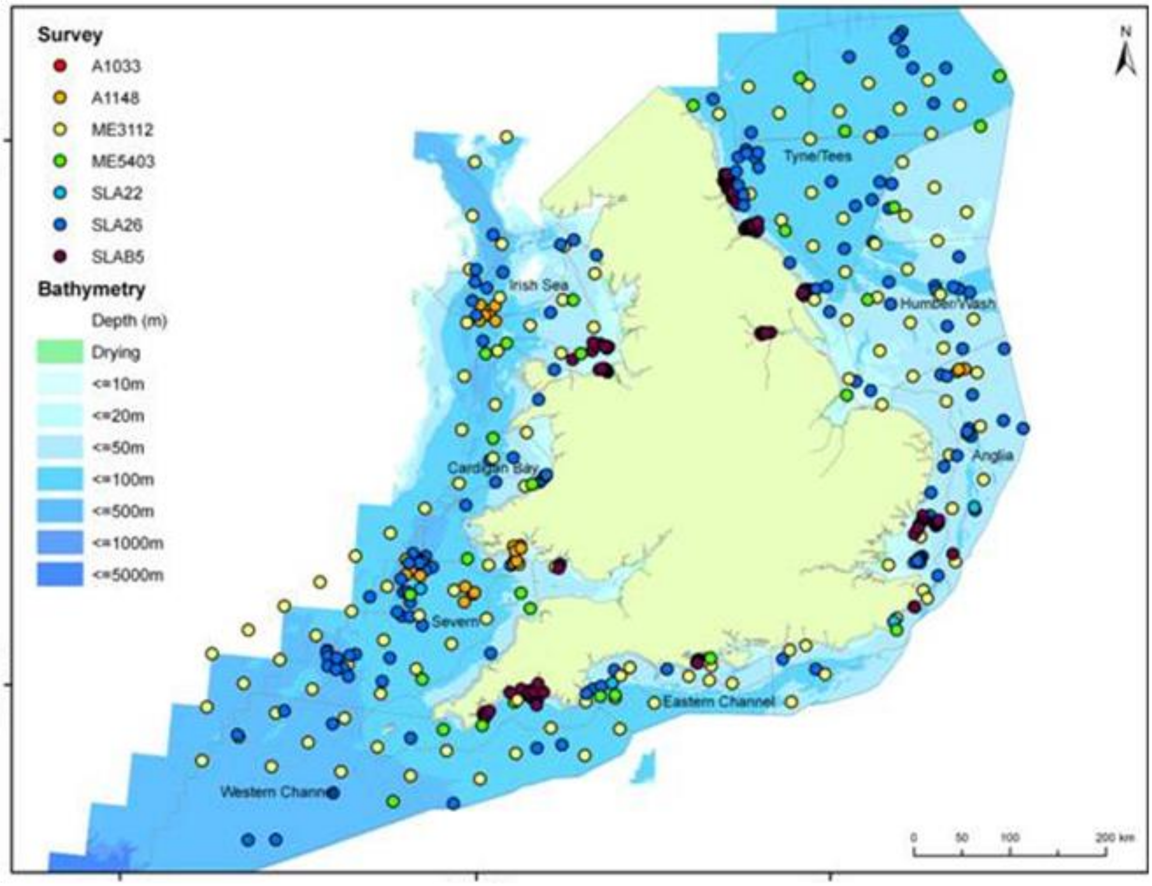


Figure A2.1. Location of stations sampled to provide metals data as part of the regional baseline approach.

Table A2.4. OSPAR BACs (in red) with proposed baselines for all regions covered in disposal site assessment under C6794.

	As (mg kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Anglia	33.0	0.2	115.0	40.0	0.2	56.0	46.0	130.0
Cardigan Bay	26.0	0.3	103.0	26.0	0.1	44.0	73.0	145.0
Eastern Channel	23.0	0.2	90.0	26.0	0.1	31.0	45.0	107.0
Humber Wash	30.0	0.2	109.0	31.0	0.2	44.0	67.0	129.0
Irish Sea	21.0	0.3	115.0	38.0	0.4	47.0	77.0	240.0
Severn	21.0	0.2	81.0	27.0	0.1	36.0	47.0	135.0
Tyne/Tees	27.0	0.3	135.0	29.0	0.4	55.0	131.0	171.0
West Channel	34.0	0.2	105.0	72.0	0.8	50.0	108.0	153.0
OSPAC BAC	25.0	0.3	81.0	27.0	0.1	36.0	38.0	122.0

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Customer focus

We offer a range of multidisciplinary bespoke scientific programmes covering a range of sectors, both public and private. Our broad capability covers shelf sea dynamics, climate effects on the aquatic environment, ecosystems and food security. We are growing our business in overseas markets, with a particular emphasis on Kuwait and the Middle East.

Our customer base and partnerships are broad, spanning Government, public and private sectors, academia, non-governmental organisations (NGOs), at home and internationally.

We work with:

- a wide range of UK Government departments and agencies, including Department for the Environment Food and Rural Affairs (Defra) and Department for Energy and Climate and Change (DECC), Natural Resources Wales, Scotland, Northern Ireland and governments overseas.
- industries across a range of sectors including offshore renewable energy, oil and gas emergency response, marine surveying, fishing and aquaculture.
- other scientists from research councils, universities and EU research programmes.
- NGOs interested in marine and freshwater.
- local communities and voluntary groups, active in protecting the coastal, marine and freshwater environments.

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