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Volume 7B Proposed Development (Offshore) Appendices

Appendix 3-4 Sediment Contamination Baseline

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Volume 7B Appendix 3-4: Sediment Contamination Baseline

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Acronyms and Abbreviations

AL	Action Level
BAC	Background Assessment Concentration
BC	Background Concentration
CCME	Canadian Council of Ministers of the Environment
CPI	Carbon Preference Index
CSEMP	Clean Seas Environment Monitoring Programme
EAC	Environmental Assessment Criteria
EIA	Environmental Impact Assessment
EQS	Environmental Quality Standards
EQSD	Environmental Quality Standards Directive
ERL	Effects Range Low
ERM	Effects Range Median
FEQG	Federal Environmental Quality Guidelines
GC	Gas Chromatography
GC-FID	Gas Chromatography with Flame Ionization Detection
HMW	High Molecular Weight
LMW	Low Molecular Weight
LOD	Limit of Detection
MMO	Marine Management Organisation
MW&SQ	Marine Water and Sediment Quality
OCP	Organochloropesticide
OECC	Offshore Export Cable Corridor

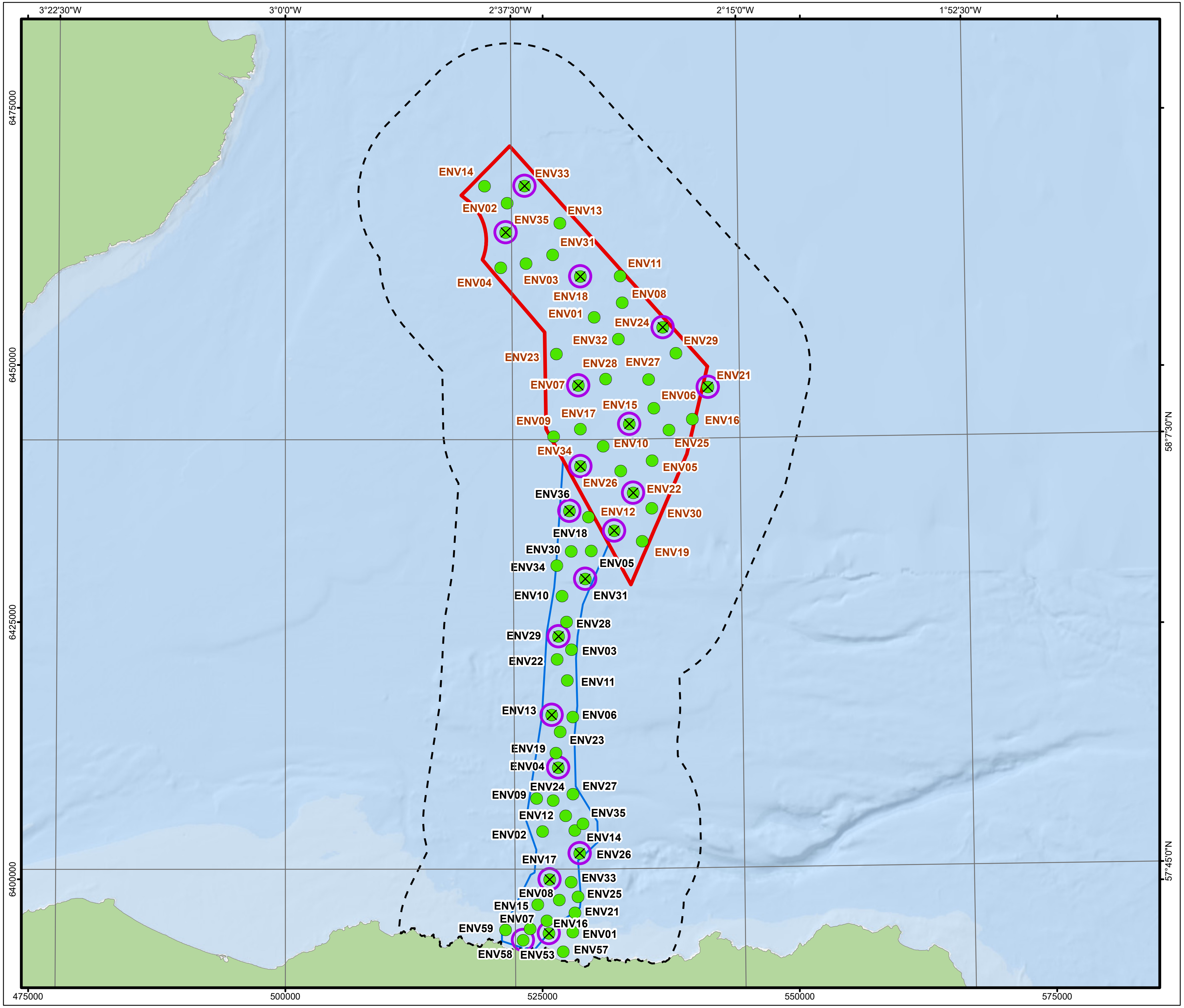
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
OWF	Offshore Wind Farm
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Dipheyl Ether
PCB	Polychlorinated Biphenyl
PEL	Probable Effect Level
SD	Standard Deviation
TEL	Threshold Effect Level
THC	Total Hydrocarbon Content
TOC	Total Organic Carbon
TBT	Tributyltin
UCM	Unresolved Complex Mixture
USEPA	United States Environmental Protection Agency
UVF	Ultraviolet Fluorescence
WFD	Water Framework Directive

1 Introduction

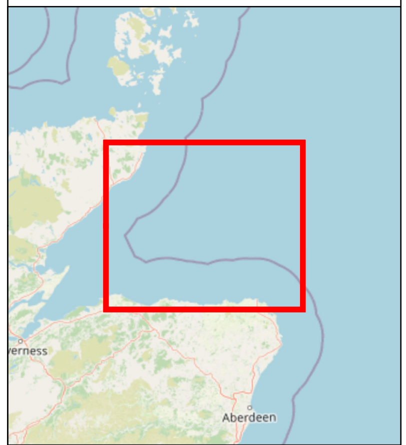
1.1.1.1 This appendix provides a detailed analysis of the baseline environment of the Caledonia Offshore Wind Farm (OWF) in terms of sediment contamination in the Marine Water and Sediment Quality (MW&SQ) Study Area, including:

- Sediment contamination assessment guidelines;
- Total Hydrocarbon Content (THC);
- Polycyclic Aromatic Hydrocarbons (PAHs);
- Polychlorinated Biphenyls (PCBs);
- Polybrominated Diphenyl Ethers (PBDEs);
- Organochloropesticides (OCPs);
- Organotins; and
- Metals.

1.1.1.2 Illustrations of the location of samples stations across the Caledonia Offshore Wind Farm (OWF) (i.e., array area) and the Caledonia Offshore Export Cable Corridor (OECC) are shown in Figure 1-1. The results of this site-specific survey are compared with publicly available regional data, including previous OWF Environmental Impact Assessments (EIAs) and the OSPAR Intermediate Assessment, to provide a robust characterisation of the entire MW&SQ Study Area.



Caledonia OWF
Offshore Export Cable Corridor
10km Zone of Influence
PSA Sample
Chemistry Sample
Water Sample



0 5 10 15 20 km

REV	DATE	DOC STATUS	ORIGIN	REVIEW	APP
01	16/09/2024	Approved	EV	BB	DH

CALEDONIA Offshore Wind Farm
GoBe APEM Group

CONTRACTOR DRAWING NO: UKCAL1_GO_WNF_MWS_MAP_00433
CONTRACTOR REV: 01
GEODETIC PARAMETERS: WGS 84 / UTM zone 30N (EPSG: 32630)
DRAWING TITLE:

Figure 1-1: Site-Specific Survey Locations in the Caledonia OWF Array Area and Caledonia OECC

STATUS: Approved
SCALE: 1:500,000
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2 Sediment Contamination Assessment Guidelines

2.1 Action Levels

2.1.1.1 In the absence of Environmental Quality Standards (EQSs) for sediments, survey sediment contaminant data has been analysed relative to Action Levels (ALs) for the disposal of dredged material. Following the Marine Directorate pre-disposal sampling guidance (Marine Scotland, 2017[1]; note, in 2023, Marine Scotland was renamed Marine Directorate), the assessment of material should be based on these ALs, which are presented in Table 2–1. In the current assessment, these ALs are used to determine whether further assessment is required.

2.1.1.2 Contaminants below Action Level 1 (AL1) are, for dredging projects, not considered to be of concern and thus can be disposed of at sea. Contaminant levels which exceed Action Level 2 (AL2) are not considered suitable for disposal at sea. Those sediments which record concentrations between AL1 and AL2 may be disposed of at sea, but may require some consideration prior to doing so.

2.1.1.3 Whilst the Proposed Development (Offshore) is not a dredging project, it does involve a proposal to dredge, drill and dispose (i.e., disturbance) of seabed sediments within the Caledonia OWF and Caledonia OECC. Therefore, adhering to guidelines regarding the disposal of dredged material will ensure a cautious assessment of potential environmental impacts (IMO, 2014[2]; OSPAR, 2014[3]).

Table 2–1: Action Levels used in sediment contaminant assessment as presented in Marine Scotland (2017[1]).

Contaminant	Action Level 1 (mg/kg; Dry Weight) (ppm)	Action Level 2 (mg/kg; Dry Weight) (ppm)
Arsenic	20	70
Cadmium	0.4	4
Chromium	50	370
Copper	30	300
Lead	50	400
Mercury	0.25	1.5
Nickel	30	150
Zinc	130	600
Organotins (e.g., Tributylin (TBT))	0.1	0.5
Polychlorinated Biphenyls (PCBs) – sum of 25 congeners	0.02	0.18
Polycyclic Aromatic Hydrocarbons (PAHs)*	0.1	-
Total Hydrocarbon Content (THC)	100	-
* Dibenzo(a,h)anthracene (PAH) has an AL1 of 0.01mg/kg dry weight (ppm) (no AL2).		

2.1.1.4 The standard procedure for reviewing PAH concentrations in marine sediment samples is to consider against the Effects Range Low (ERL) and the Effects Range Median (ERM) for a discrete suite of low molecular weight (LMW) and high molecular weight (HMW) PAHs (Gorham-Test *et al*., 1999[4]). This effectively presents a similar AL1 (ERL) and AL2 (ERM) approach to provide context to sediment quality for PAHs and has been applied to support this MW&SQ assessment. The sum of the following PAH concentrations is used in the calculations:

- HMW PAHs: Fluoranthene, Pyrene, Benz[a]anthracene, Chrysene, Benzo(a)pyrene, Dibenz(a,h)anthracene; and
- LMW PAHs: Naphthalene, Acenaphthene, Fluorene, Anthracene, C1-naphthalenes, Acenaphthylene, Phenanthrene.

2.1.1.5 The ERL (equivalent to AL1) for the sum of LMW and HMW PAHs is 552 and 1,700µg/kg, respectively. The ERM (equivalent to AL2) for the sum of LMW and HMW PAHs is 3,160 and 9,600µg/kg, respectively.

2.2 Canadian Marine Sediment Quality Guidelines

2.2.1.1 The Canadian Marine Sediment Quality Guidelines (Table 2–2) have also been used within this assessment to provide context to the sediment contaminant levels reported within the site-specific samples. These Guidelines provide some information for those contaminants not currently reported within the ALs (Table 2–1), specifically PAHs. Developed by the Canadian Council of Ministers of the Environment (CCME), these Guidelines are applied within this Project to provide an indication on the degree of sedimentary contamination and the likely ecological impact.

2.2.1.2 The Guidelines allow the identification of three ranges of chemical contaminants, with regard to biological effects:

- Below the Threshold Effect Levels (TEL): the minimal effect range within which adverse effects rarely occur;
- Between the TEL and Probable Effect Levels (PEL): the possible effect range within which adverse effects occasionally occur; and
- Above the PEL: the probable effect range within which adverse effects frequently occur.

Table 2–2: Canadian Marine Sediment Quality Guidelines for PAHs (CCME, 1999[5]).

Contaminant	Threshold Effect Levels (µg/kg)	Probable Effect Levels (µg/kg)
Acenaphthene	6.71	88.9
Acenaphthylene	5.87	128
Anthracene	46.9	245
Benz(a)anthracene	74.8	693
Benzo(a)pyrene	88.8	763
Chrysene	108	846
Dibenz(a,h)anthracene	6.22	135
Fluoranthene	113	1,494
Fluorene	21.2	144
2-Methylnaphthalene	20.2	201
Naphthalene	34.6	391
Phenanthrene	86.7	544
Pyrene	153	1,398

2.3 OSPAR Assessment Criteria

2.3.1.1 In the absence of ALs for Polybrominated Diphenyl Ethers (PBDEs) in sediment, levels used by OSPAR (OSPAR, 2023[6]), presented in Table 2–3, have been adopted here:

- Background Assessment Criteria (BAC); and
- Federal Environmental Quality Guidelines (FEQGs) also referred to as Environmental Assessment Criteria (EAC).

Table 2–3: OSPAR Assessment Criteria for Polybrominated Diphenyl Ethers (OSPAR, 2020a[7]; OSPAR, 202b[8]; Vinas *et al*., 2023[9]).

PBDE Congener	BAC (mg/kg)	FEQG (mg/kg)
BDE28	0.00005	0.11
BDE47	0.00005	0.0975
BDE66	0.00005	0.0975
BDE85	0.00005	0.001
BDE99	0.00005	0.001
BDE100	0.00005	0.001
BDE126	0.00005	n/a
BDE153	0.00005	1.1
BDE154	0.00005	1.1
BDE183	0.00005	14
BDE209	0.00005	0.0475

3 Sediment Contamination

3.1.1.1 Elevated levels of contaminants can affect flora and fauna in a variety of ways, ranging from cellular effects in individuals to ecosystem effects resulting from changes in population sizes or even the loss of an entire species (UK Marine SACs Project, 2001[10]). Unlike water quality, there are no formal quantitative EQS for sediments. In the absence of any quantified UK standards, common practice for characterising baseline sediment quality conditions is to compare against Als, as is suggested for the disposal of dredged material (Marine Scotland, 2017[1]). Where ALs do not provide comprehensive guidance, other sediment quality guidelines are used in place (See Section 2).

3.1.1.2 The Intermediate Assessment 2017 prepared by OSPAR (2017[11]) reviewed and compared mercury, cadmium, lead, organotin (limited data), PCB, PAH, and PBDE concentrations in sediments between OSPAR contaminant assessment areas (including data collated as part of the Clean Seas Environment Monitoring Programme (CSEMP) assessment). Four monitoring stations in the Moray Firth form part of the Northern North Sea region. The main conclusions drawn from the data for the Northern North Sea are as follows:

- Metals:
  - Mercury and lead concentrations in sediment are at or above the BAC.
  - Lead concentrations are also at or above the ERL value.
  - Mean concentrations of cadmium are below the BAC.
- PCBs:
  - Trend analysis shows PCB concentrations are reducing.
  - PCB congener 118 concentrations in sediments are below the EAC and above the BAC.
- PAHs:
  - Mean PAH concentrations in sediment were statistically significantly below the ERL but not below the BAC.
- PBDEs:
  - PBDE concentrations in sediment are low and often below detection levels.

3.1.1.3 Further to the OSPAR (2017[11]) assessment, there is already a comprehensive base understanding of the volume and type of contamination likely to be present around the MW&SQ Study Area, particularly due to the previous Environmental Impact Assessment Reports (EIARs) carried out for preceding OWFs built in the surrounding area.

3.1.1.4 In the EIA conducted for the most recently consented OWF in the Moray Firth, Moray West, detailed sediment chemistry samples were examined (Moray

West Offshore Wind Farm Ltd, 2018[12]). The analysis of heavy metals in the subtidal samples revealed concentrations well below the respective guidelines, with no samples exceeding ALs or the Canadian Sediment Quality Guidelines. Additionally, PAH concentrations were consistently low, often falling below the limit of detection (LOD) for the analytical tests. However, LODs for Acenaphthene, Acenaphthylene, and Dibenzo(ah)anthracene were slightly higher than the Canadian TEL values. Overall, the survey findings led to the conclusion that there were no indications of unacceptable or significant contamination levels in the vicinity.

3.1.1.5 In the EIA conducted for Moray East, sediment samples were analysed for metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, tin, barium, aluminium), PAHs (16 US EPA Priority Pollutants), total PAH and total petroleum hydrocarbons. Results showed concentrations were below respective guideline values (ALs and Canadian Sediment Quality Guidelines) (Moray Offshore Renewables Limited, 2012a[13]). No adverse environmental effects were anticipated and not considered further in the assessment (Moray Offshore Renewables Limited, 2012b[14]).

3.1.1.6 In the EIA conducted for Beatrice OWF, also within the Moray Firth, the survey findings closely mirror those of Moray West, despite the historical presence of oil and gas exploration and production activities near Beatrice (BOWL, 2012[15]). Organic contaminants (PAHs, n-alkanes, and total alkanes) were present at very low levels or not detected. No heavy metals were present at levels that exceeded ALs. There was no apparent relationship between distribution of any of the metals, including barium, and the distribution of known wellheads (barium compounds, such as barite (barium sulfate), are commonly used as weighting agents in drilling fluids for oil and gas wells). Barium was present at levels ranging from 133 to 273mg/kg, and whilst this may have come from past drilling activities, these levels are lower than published values for North Sea sediments sampled at greater than 5km from oil and gas platforms, and do not suggest gross contamination. This assumption is further supported by a recent decommissioning plan for the Beatrice Field in the Central North Sea (Repsol Sinopec Resources UK Limited, 2018[16]). Contaminant concentrations varied throughout the survey area; elevated concentrations of contaminants were found in the Beatrice Alpha Drilling and Accommodation Platform cuttings pile beneath the platform, and within the surrounding area within 100m, whilst samples from the wider Beatrice area showed the concentrations of contaminants were generally within expected background levels for the Central North Sea. Further indicating a lack of migrating contamination from these oil and gas areas (Repsol Sinopec Resources UK Limited, 2018[16]).

3.1.1.7 Upon comparing the above surveys carried out for the application of previous OWFs, it becomes evident that sediment contamination estimates provided by OSPAR (2017[11]) appear slightly conservative for this specific area, where less prominent sediment contamination has so far been observed. The following sections discuss, in detail, the types of contamination and the site-specific surveys of the Caledonia OWF (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)) and Caledonia OECC (Volume 7B, Appendix 4-2: Environmental Baseline Report (Offshore Export Cable Corridor)).

4 Total Hydrocarbon Content

4.1 Overview

4.1.1.1 The principal sources of hydrocarbons in the marine environment are anthropogenic (McDougall, 2000[17]). However, biosynthetic, and geochemical processes can also be a source for hydrocarbons in the marine environment. THC concentration gives an indication of the total hydrocarbon present within a sediment sample. In the case of site-specific survey output, THC is equivalent to total n-alkane (nC10 to nC37), pristane, phytane, Unresolved Complex Mixture (UCM) and total PAH (all PAHs including alkylated derivatives) concentrations.

4.1.1.2 It has previously been shown that benthic macrofauna suffer adverse effects when THC is in excess of 50µg/g (Kjeilen-Eilertsen *et al*., 2004[18]; UKOOA, 2002[19]; 2005[20]) and as such, this value represents a threshold above which hydrocarbons can be expected to present a 'significant environmental impact'. In addition, Kingston previously reported that benthic macrofauna suffer adverse effects (e.g., reduced diversity), when THC is more than 50µg/g to 60µg/g, where specific sensitive species can experience impacts at levels greater than 10µg/g (Kingston, 1992[21]).

4.1.1.3 THC concentrations give an indication of the total oil in the sediment at each station and can therefore be compared to the ecotoxicological limits outlined above. Analysis of Gas Chromatography (GC) chromatograms can be used to identify the source of hydrocarbons and the extent to which they are weathered. In particular, abundant UCM is ascribed to either degraded or weathered oil residues, and therefore its occurrence in environmental samples is an indicator of oil pollution (Bouloubassi *et al*., 2001[22]). A UCM between nC20 and nC34, centred on nC29 is typical of North Sea sediments, and is generally considered as 'North Sea Background'.

4.2 Caledonia OWF

4.2.1.1 Analysis has been conducted using Gas Chromatography with Flame Ionization Detection (GC-FID) to measure the concentration of THC in sediment samples collected from different stations across the Caledonia OWF (Volume 7B, Appendix 4-1: Environmental Baseline Report (Array Area)). The results showed THC concentration ranging from 2.1µg/g at Station ENV35 to 20.7µg/g at Station ENV21, with an average concentration of 7.0µg/g (± 5.4 SD). The upper concentration of 20.7µg/g at Station ENV21 was identified as a statistically high outlier. Moreover, the concentrations of THC were negatively correlated with mean particle diameter and positively correlated with depth and portion of fines. The highest concentrations of THC were observed in the south of the Caledonia OWF (i.e., in generally deeper waters). Overall, concentrations of THC by ultraviolet fluorescence (UVF) were lower than THC concentrations by GC-FID, where only three Stations recorded concentrations above the LOD (Table 4–1).

4.2.1.2 Concentrations of THC by GC-FID at Station ENV21 was above the outlined 10µg/g threshold and as such could have a potential negative impact on very sensitive benthic macrofauna. However, as mentioned above, THC by UVF were all reported below the 10µg/g threshold.

4.2.1.3 The chromatograms presented a general pattern of low-level, high molecular weight (HMW) n-alkanes and UCM ranging from nC20 to nC36. These distributions are considered typical of background levels of hydrocarbon inputs within the North Sea with historical oil and gas explorations which include a relatively low level UCM distributed between nC20 and nC33.

4.2.1.4 Hydrocarbons in the molecular weight range nC24 to nC36 commonly originate from terrestrial plant sources (Harborne, 1999[23]) or may represent the residue of highly weathered and biodegraded petrogenic material including natural seeps, shipping discharge and oil and gas exploration and extraction (Bouloubassi *et al*., 2001[22]; McDougall, 2000[17]). The results of the THC profile is characteristic of background concentrations of n-alkanes in North Sea sediments, and it is indicative of sedimentary biogenic hydrocarbons from a terrestrial plant source (Tran *et al*., 1995[24]). The UCM accounted for 43% to 79% of THC across the Caledonia OWF, indicating that generally hydrocarbons were weathered with some fresher inputs.

4.2.1.5 THC values across the Caledonia OWF were below published threshold values. Of note, Station ENV21 which was slightly above the level at which some sensitive species may be impacted (Kingston, 1992[21]). Overall, the faunal community is not expected to be significantly influenced by THC concentrations.

Table 4–1: Summary of sediment hydrocarbon analysis of samples collected within the Caledonia OWF.

Sample Station	THC by UVF	THC by GC-FID	UCM by GC-FID	n-alkanes by GC-FID			CPI by GC-FID	Isoprenoids by GC-FID		
				nC10-20	nC21-37	nC10-37		Pristane	Phytane	Pr/Ph Ratio
ENV07	<1	3.6	1.6	0.004	0.055	0.059	1.9	<1	<1	0.004
ENV12	1.2	8.8	5.1	0.019	0.171	0.190	3.5	0.004	<1	0.047
ENV15	<1	7.6	4.1	0.017	0.111	0.128	4.3	0.005	<1	0.019
ENV18	<1	3.1	2.0	0.010	0.033	0.044	2.4	0.002	<1	0.001
ENV21	2.8	20.7	14.2	0.086	0.451	0.537	4.0	0.026	<1	0.275
ENV22	1.0	5.2	4.1	0.024	0.101	0.125	3.3	0.007	0.003	0.060
ENV24	<1	8.4	4.7	0.014	0.080	0.094	2.8	0.007	<1	0.012
ENV33	<1	3.3	2.1	0.015	0.036	0.051	3.4	0.003	<1	NC
ENV34	<1	7.6	4.4	0.026	0.107	0.134	3.4	0.006	<1	0.033
ENV35	<1	2.1	1.2	0.001	0.015	0.016	NC	0.002	<1	NC
Summary Statistics										
Minimum	NQ	2.1	1.2	0.001	0.015	0.016	NC	NQ	NQ	NQ
Maximum	2.76	20.7	14.2	0.086	0.451	0.537	4.3	0.026	2.7	0.275
Mean	NC	7.0	4.3	0.022	0.116	0.138	NC	NC	NC	NQ

Sample Station	THC by UVF	THC by GC-FID	UCM by GC-FID	n-alkanes by GC-FID			CPI by GC-FID	Isoprenoids by GC-FID		
				nC10-20	nC21-37	nC10-37		Pristane	Phytane	Pr/Ph Ratio
Standard Deviation	NC	5.4	3.7	0.024	0.127	0.150	NC	NC	NC	NQ
Concentrations expressed as µg/g dry sediment. NQ: Not quantified due to concentrations below LOD. NC: Not calculated due to concentrations below LOD.										

4.3 Caledonia OECC

4.3.1.1 Analysis has been conducted using GC-FID to measure the concentration of THC in sediment samples collected from different stations across the Caledonia OECC (Volume 7B, Appendix 4-2: Environmental Baseline Report (Offshore Export Cable Corridor)). The results showed THC concentration ranged from 2.8µg/g at the shallowest station (ENV58) up to 18.7µg/g at the deepest station (ENV26) with a mean of 10.7µg/g (± 4.6SD). The data suggest that concentrations of THC were positively correlated with fines and TOC. Similar to the Caledonia OWF, concentrations of THC by UVF were lower than THC concentrations by GC-FID, where only three Stations recorded concentrations above the LOD (Table 4–2).

4.3.1.2 Concentrations of THC by GC-FID at six of the nine stations (ENV04, ENV17, ENV26, ENV29 ENV36 and ENV53) were marginally above the 10µg/g threshold and as such have a potential for negative impacts on sensitive benthic macrofauna. Of note, concentrations of THC by UVF were below the threshold of 10µg/g.

4.3.1.3 The chromatograms generally presented a pattern comparable to samples collected in the Caledonia OWF of low-level, HMW n-alkanes and unresolved complex mixtures (UCM) ranging from nC20 to nC36. These distributions are considered typical of background levels of hydrocarbon inputs within the North Sea with historical oil and gas explorations which include a relatively low level UCM distributed between nC20 and nC33.

4.3.1.4 The results of the THC profile are characteristic of background concentrations of n-alkanes in North Sea sediments, and it is indicative of sedimentary biogenic hydrocarbons from a terrestrial plant source (Tran *et al*., 1995[24]). The UCM accounted for 62% to 94% of THC across the Caledonia OWF, indicating that generally hydrocarbons were weathered with some fresher inputs.

4.3.1.5 Overall, THC concentrations along the Caledonia OECC were generally below the published thresholds indicating the faunal community is not expected to be significantly influenced by THC concentrations.

Table 4–2: Summary of sediment hydrocarbon analysis of samples collected within the Caledonia OECC.

Sample Station	THC by UVF	THC by GC-FID	UCM by GC-FID	n-alkanes by GC-FID			CPI by GC-FID	Isoprenoids by GC-FID		
				nC10-20	nC21-37	nC10-37		Pristane	Phytane	Pr/Ph Ratio
ENV04	<1	11.3	8.1	0.035	0.283	0.318	3.4	0.011	<0.001	NC
ENV13	<1	6.0	3.7	0.012	0.069	0.081	4.9	0.003	<0.001	NC
ENV17	4.1	12.9	8.2	0.033	0.331	0.364	3.7	0.010	<0.001	NC
ENV26	4.2	18.7	13.1	0.057	0.421	0.478	3.2	0.022	0.004	5.5
ENV29	4.7	14.0	9.5	0.047	0.314	0.361	3.0	0.012	0.003	4.4
ENV31	<1	9.2	6.4	0.027	0.175	0.202	3.6	0.007	0.002	4.0
ENV36	<1	11.4	7.4	0.040	0.211	0.251	4.2	0.010	0.002	5.7
ENV53	<1	10.1	9.5	0.003	0.016	0.018	NC	0.001	<0.001	NC
ENV58	<1	2.8	1.8	0.006	0.014	0.020	NC	0.001	<0.001	NC
Summary Statistics										
Minimum	NQ	2.8	1.8	0.003	0.014	0.018	NQ	0.001	NQ	NQ
Maximum	4.7	18.7	13.1	0.057	0.421	0.478	4.9	0.022	0.004	5.7
Mean	NC	10.7	7.5	0.029	0.204	0.232	NC	0.009	NC	NC
Standard Deviation	NC	4.6	3.3	0.019	0.147	0.164	NC	0.006	NC	NC

Sample Station	THC by UVF	THC by GC-FID	UCM by GC-FID	n-alkanes by GC-FID			CPI by GC-FID	Isoprenoids by GC-FID		
				nC10-20	nC21-37	nC10-37		Pristane	Phytane	Pr/Ph Ratio
Concentrations expressed as µg/g dry sediment. NQ: Not quantified due to concentrations below LOD. NC: Not calculated due to concentrations below LOD.										

5 Polycyclic Aromatic Hydrocarbons

5.1 Overview

5.1.1.1 PAHs are classed as priority hazardous substances and ubiquitous persistent, bio-accumulative and toxic compounds under the Water Framework Directive (WFD) in the related EQS Directive (2008/105/EC amended by 2013/39/EU). The Canadian Marine Sediment Quality Guidelines (TELs and PELs values) provide the most reliable standardised estimates of the potential toxicity of individual PAHs in marine sediments, as outlined in Section 2.2.

5.1.1.2 The concentrations at which individual PAHs produce toxic effects vary widely (Long *et al*., 1995[25]) and are dependent on their type and bioavailability. Values for the toxicity of individual aromatics may be misleading since individual PAHs are rarely found in isolation. More sensitive estimates of the potential toxicity of PAHs in marine sediments are ERL and ERM concentrations for total LMW, total HMW and total PAHs. Long *et al*. (1995[25]) gives ERL concentrations for LMW and HMW PAHs of 0.55 and 1.70µg/g, respectively. ERM concentrations are 3.16 and 9.60µg/g for LMW and HMW PAHs, respectively. The ERL and ERM concentrations for total PAH concentration in sediments are 4.022 and 44.792µg/g, respectively. These concentrations are not actual thresholds of toxicity but delineate concentration ranges with associated probabilities of toxicity.

5.2 Caledonia OWF

5.2.1.1 The total PAH concentrations ranged from 0.001µg/g to 0.275µg/g across the Caledonia OWF, except for Station ENV33 and ENV35 that were below even the LOD. The molecular mass indices identified the presence of pyrogenic PAHs (i.e. likely from grass, wood or coal combustion). Results also indicate that PAHs were from petrogenic (e.g. petroleum) sources with a mixture of sources present at Station ENV21. Overall, concentrations of PAHs were very low, with no exceedance of either the Canadian or US Environmental Protection Agency (USEPA) guidelines for PAH concentrations in sediment (shown in Table 5–1). Moreover, total PAH concentrations were below their respective ERL values (Long *et al*., 1995[25]), further indicating that toxic effects to fauna by PAHs are unlikely.

Table 5–1: Summary of PAH concentrations from sediment samples across the Caledonia OWF.

PAH	Canadian Guidelines		Sample Stations									
	TEL Value	PEL Value	ENV07	ENV12	ENV15	ENV18	ENV21	ENV22	ENV24	ENV33	ENV34	ENV35
Acenaphthene	6.71	88.9	<LOD	<LOD	<LOD	<LOD	0.002	<LOD	<LOD	<LOD	<LOD	<LOD
Acenaphthylene	5.78	128	<LOD	<LOD	<LOD	<LOD	0.001	<LOD	<LOD	<LOD	<LOD	<LOD
Anthracene	46.9	245	<LOD	<LOD	<LOD	<LOD	0.003	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo[a]anthracene	74.8	693	<LOD	0.001	<LOD	<LOD	0.012	0.003	<LOD	<LOD	<LOD	<LOD
Benzo[a]pyrene	88.8	763	<LOD	0.002	<LOD	<LOD	0.015	0.003	<LOD	<LOD	0.001	<LOD
Benzo[b]fluoranthene	-	-	0.001	0.006	0.002	<LOD	0.023	0.005	0.002	<LOD	0.004	<LOD
Benzo[e]pyrene	-	-	0.001	0.007	0.003	<LOD	0.025	0.005	0.002	<LOD	0.005	<LOD
Benzo[ghi]perylene	-	-	<LOD	0.003	0.002	<LOD	0.014	0.003	0.001	<LOD	0.002	<LOD
Benzo[k]fluoranthene	-	-	<LOD	0.004	0.002	<LOD	0.018	0.004	0.002	<LOD	0.003	<LOD
C1-naphthalenes	-	-	<LOD	0.001	0.002	<LOD	0.008	0.003	<LOD	<LOD	0.001	<LOD
C1-phenanthrenes	-	-	<LOD	0.002	0.001	<LOD	0.012	0.005	<LOD	<LOD	0.001	<LOD

PAH	Canadian Guidelines		Sample Stations									
	TEL Value	PEL Value	ENV07	ENV12	ENV15	ENV18	ENV21	ENV22	ENV24	ENV33	ENV34	ENV35
C2-naphthalenes	-	-	<LOD	0.003	0.003	<LOD	0.016	0.003	0.002	<LOD	0.002	<LOD
C3-naphthalenes	-	-	<LOD	0.001	0.001	<LOD	0.008	0.003	<LOD	<LOD	0.001	<LOD
Chrysene	108	846	<LOD	0.002	<LOD	<LOD	0.014	0.003	<LOD	<LOD	0.001	<LOD
Dibenzo[ah]anthracene	6.22	135	<LOD	0.001	<LOD	<LOD	0.005	0.001	<LOD	<LOD	<LOD	<LOD
Fluoranthene	113	1,494	<LOD	0.002	<LOD	<LOD	0.026	0.005	<LOD	<LOD	0.002	<LOD
Fluorene	21.2	144	<LOD	<LOD	<LOD	<LOD	0.002	<LOD	<LOD	<LOD	<LOD	<LOD
Indeno[1,2,3-cd]pyrene	-	-	0.002	0.009	0.004	0.001	0.031	0.006	0.003	<LOD	0.006	<LOD
Naphthalene	34.6	391	<LOD	<LOD	<LOD	<LOD	0.003	0.001	<LOD	<LOD	<LOD	<LOD
Perylene	-	-	<<LOD	<LOD	<LOD	<LOD	0.004	<LOD	<LOD	<LOD	<LOD	<LOD
Phenanthrene	86.7	544	<LOD	0.001	<LOD	<LOD	0.015	0.004	<LOD	<LOD	0.001	<LOD
Pyrene	153	1,398	<LOD	0.002	<LOD	<LOD	0.020	0.004	<LOD	<LOD	0.001	<LOD
Total	-	-	0.004	0.047	0.019	0.001	0.275	0.060	0.012	N/A	0.033	N/A

PAH	Canadian Guidelines		Sample Stations									
	TEL Value	PEL Value	ENV07	ENV12	ENV15	ENV18	ENV21	ENV22	ENV24	ENV33	ENV34	ENV35
Concentrations from Sample Stations converted from ng/g dry weight sediment to ug/g dry weigh sediment to allow comparisons with guideline levels.												

5.3 Caledonia OECC

5.3.1.1 The total PAH concentrations ranged from 0.009µg/g to 0.146µg/g across the Caledonia OECC, except for Station ENV53 and ENV58 that were below even the LOD. The molecular mass indices identified the presence of pyrogenic PAHs (i.e., likely originating from grass, wood or coal combustion) at all stations. Results indicate that PAHs were also from petrogenic sources (e.g., petroleum) in low concentrations. Overall, concentrations of PAHs were very low, with no exceedance of either the Canadian or USEPA guidelines for PAH concentrations in sediment (shown in Table 5–2). Total PAH concentrations were below their respective ERL values (Long *et al*., 1995[25]), further indicating that toxic effects to fauna by PAHs are unlikely.

Table 5–2: Summary of PAH concentrations from sediment samples across the Caledonia OECC.

PAH	Canadian Guidelines		Sample Station								
	TEL Value	PEL Value	ENV04	ENV13	ENV17	ENV26	ENV29	ENV31	ENV36	ENV53	ENV58
Acenaphthene	6.71	88.9	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Acenaphthylene	5.78	128	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Anthracene	46.9	245	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Benzo[a]anthracene	74.8	693	0.002	<LOD	0.002	0.005	0.003	0.002	0.002	<LOD	<LOD
Benzo[a]pyrene	88.8	763	0.003	<LOD	0.003	0.007	0.005	0.003	0.003	<LOD	<LOD
Benzo[b]fluoranthene	-	-	0.008	0.002	0.006	0.016	0.012	0.007	0.008	<LOD	<LOD
Benzo[e]pyrene	-	-	0.008	0.002	0.006	0.017	0.013	0.007	0.009	<LOD	<LOD
Benzo[ghi]perylene	-	-	0.005	<LOD	0.004	0.009	0.007	0.004	0.004	<LOD	<LOD
Benzo[k]fluoranthene	-	-	0.006	0.002	0.005	0.013	0.009	0.005	0.005	<LOD	<LOD
C1-naphthalenes	-	-	0.003	<LOD	0.002	<LOD	0.003	0.002	0.002	<LOD	<LOD
C1-phenanthrenes	-	-	0.003	<LOD	0.003	0.006	0.005	0.003	0.003	<LOD	<LOD
C2-naphthalenes	-	-	0.004	0.002	0.004	0.010	0.006	0.003	0.004	<LOD	<LOD
C3-naphthalenes	-	-	0.003	<LOD	0.002	0.005	0.004	0.002	0.002	<LOD	<LOD

PAH	Canadian Guidelines		Sample Station								
	TEL Value	PEL Value	ENV04	ENV13	ENV17	ENV26	ENV29	ENV31	ENV36	ENV53	ENV58
Chrysene	108	846	0.003	<LOD	0.003	0.006	0.004	0.003	0.002	<LOD	<LOD
Dibenzo[ah]anthracene	6.22	135	<LOD	<LOD	<LOD	0.003	0.002	<LOD	<LOD	<LOD	<LOD
Fluoranthene	113	1,494	0.004	<LOD	0.004	0.009	0.006	0.005	0.003	<LOD	<LOD
Fluorene	21.2	144	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Indeno[1,2,3-cd]pyrene	-	-	0.008	0.002	0.007	0.020	0.015	0.008	0.010	<LOD	<LOD
Naphthalene	34.6	391	<LOD	<LOD	<LOD	0.002	<LOD	<LOD	<LOD	<LOD	<LOD
Perylene	-	-	0.003	<LOD	0.004	0.007	0.002	<LOD	<LOD	<LOD	<LOD
Phenanthrene	86.7	544	0.002	<LOD	0.002	0.005	0.003	0.002	0.002	<LOD	<LOD
Pyrene	153	1,398	0.003	<LOD	0.003	0.007	0.005	0.004	0.003	<LOD	<LOD
Total	-	-	0.069	0.009	0.061	0.146	0.108	0.059	0.062	<LOD	<LOD
Concentrations from Sample Stations converted from ng/g dry weight sediment to ug/g dry weigh sediment to allow comparisons with guideline levels.											

6 Polychlorinated Biphenyls

6.1 Overview

6.1.1.1 PCBs are toxic and persistent synthetic organic compounds that are known to bioaccumulate in marine sediment, where they may be trapped in lower layers unless the sediments are disturbed. A report published by Marine Scotland (2020[26]) found PCB concentrations in biota (fish and shellfish) and sediment in the four Scottish biogeographic regions generally remain below the threshold at which adverse effects occur in marine life, but above BACs. Mean concentrations were stable or decreasing in the assessed areas over the assessment period (1999 to 2018) (Marine Scotland, 2020[26]).

6.2 Caledonia OWF

6.2.1.1 PCB concentrations from sediment samples collected from the Caledonia OWF were all below the LOD, indicating that toxic effects to fauna by PCBs are unlikely, even with the disturbance of sediment.

6.3 Caledonia OECC

6.3.1.1 PCB concentrations from sediment samples collected from the Caledonia OECC were all below the LOD, indicating that toxic effects to fauna by PCBs are unlikely, even with the disruption of sediment.

7 Polybrominated Diphenyl Ethers

7.1 Overview

7.1.1.1 PBDE concentrations in sediment can be compared to OSPAR Background BACs and EAC which were primarily developed for the assessment of contaminant concentrations. BACs are used to make precautionary tests of whether observed concentrations are 'near background' or 'close to zero' in the case of man-made substances (i.e., PBDEs). PBDEs with concentrations below the BAC fulfil the ultimate aim of the OSPAR Hazardous Substances Strategy of approaching the natural background concentration. EACs were developed to assess whether concentrations of contaminants are likely to have adverse biological effects on the marine environment. For PBDEs, the Canadian Federal Environmental Quality Guidelines (FEQGs) adapted for use in Construction Environmental Management Plan (CEMP) assessments (OSPAR, 2020[7]) were used as EAC equivalents. Hence, adverse effects on marine organisms are rarely observed when concentrations are below the FEQG.

7.2 Caledonia OWF

7.2.1.1 Concentrations of PBDEs in sediment collected across the Caledonia OWF were recorded below the LOD with the exception of PBDE 209 which ranged from 0.31ng/g to 2.01ng/g (Table 7–1). The results of the survey highlighted that PBDE 209 concentrations exceeded OSPAR (2020[7]) BAC values at three Stations. However, all concentrations were below the FEQG guidelines (Vinas *et al*., 2023[9]). Therefore, toxic effects to fauna by PBDEs in the Caledonia OWF are unlikely, even with the disturbance of sediment.

Table 7–1: Concentration of PBDE 209 identified when normalised to 2.5% TOC from sediment samples across the Caledonia OWF.

Sample Station	PBDE 209 (ng/g dry weight)
ENV07	<LOD
ENV12	1.16
ENV15	<LOD
ENV18	<LOD
ENV21	0.31
ENV22	0.51
ENV24	2.01
ENV33	<LOD
ENV34	<LOD
ENV35	0.37
BAC Value (OSPAR, 2020[7])	0.5
FEQG Value (Vinas *et al*., 2023[9])	47.5

7.3 Caledonia OECC

7.3.1.1 Contamination of PBDEs in sediment collected across the Caledonia OECC were recorded below the LOD with the exception of PBDE 209 which ranged from below the LOD at Station ENV58 to 1.86ng/g at Station ENV31 (Table 7–2). Analysis of survey results showed that PBDE 209 at Stations ENV04, ENV13, ENV26 and ENV31 exceeded the OSPAR (2020[7]) BAC. However, concentrations were all well below the FEQGs. Therefore, toxic effects to fauna by PBDEs in the Caledonia OECC are unlikely, even with the disturbance of sediment.

Table 7–2: Concentration of PBDE 209 identified when normalised to 2.5% TOC from sediment samples across the Caledonia OECC.

Sample Station	PBDE 209 (ng/g dw)
ENV04	0.80
ENV13	0.71
ENV17	0.61
ENV26	1.53
ENV29	0.28
ENV31	1.86
ENV36	0.39
ENV53	0.23
ENV58	<LOD
BAC Value (OSPAR, 2020[7])	0.5
FEQG Value (Vinas *et al*., 2023[9])	47.5

8 Organochloropesticides

8.1 Overview

8.1.1.1 OCPs are synthetic pesticides widely used all over the world. They belong to the group of chlorinated hydrocarbon derivatives, which have vast application in the chemical industry and in agriculture. These compounds are known for their high toxicity, slow degradation, and bioaccumulation (Jayaraj *et al*., 2017[27]).

8.2 Caledonia OWF

8.2.1.1 Results from a site-specific survey showed OCPs present in sediment samples collected across the Caledonia OWF were generally below the LOD, with the exception of dieldrin at Station ENV15 (0.1ng/g) and p,p'-Dichlorodiphenyldichloroethane at Station ENV33 (0.1ng/g). There are currently no ALs for OCPs (Marine Scotland, 2017[1]) and toxic effects to fauna in the Caledonia OWF are not anticipated.

8.3 Caledonia OECC

8.3.1.1 Results from a site-specific survey showed OCPs present in sediment samples collected across the Caledonia OECC were generally below the LOD, with the exception of dieldrin at Station ENV04. There are currently no ALs for OCPs (Marine Scotland, 2017[1]) and toxic effects to fauna in the Caledonia OECC are not anticipated.

9 Organotins

9.1 Overview

9.1.1.1 Organotin compounds are man-made metallic tin complexes with hydrocarbon substituents with historical applications in food packages, pesticides, wood preservatives, antifouling, and anticorrosion paints. According to the OSPAR Intermediate assessment, mean concentrations of TBT have measurably reduced in the Southern North Sea and are very low or undetectable elsewhere (OSPAR, 2017[11]).

9.2 Caledonia OWF

9.2.1.1 Organotin concentrations found in sediment samples collected across the Caledonia OWF were all below the LOD at all sampled stations. Therefore, toxic effects to fauna are not anticipated.

9.3 Caledonia OECC

9.3.1.1 Organotin concentrations found in sediment samples across the Caledonia OECC were all below the LOD at all sampled stations. Therefore, toxic effects to fauna are not anticipated.

10 Metals

10.1 Overview

10.1.1.1 Metals constitute a significant source of pollution in marine environments, originating from both natural and anthropogenic sources. Within the water column, biogeochemical processes govern the existence of heavy metals in particulate or dissolved form. Additionally, some proportion of metals get deposited in marine sediment which act as a major sink for metal pollution. Metals are taken up by marine biota through seawater or through food chain, which may adversely affect them by altering their abundance, diversity, and physiology. As detailed in paragraph 3.1.1.4 and subsequent sections, the EIAs for the Moray East, Moray West and Beatrice OWFs identified no metals exceeding ALs, nor were any present in concentrations that would be likely to affect surrounding faunal communities.

10.2 Caledonia OWF

10.2.1.1 A site-specific survey of the Caledonia OWF showed that chromium, copper, nickel and zinc were positively correlated with fines and negatively correlated with sands, meaning that fluctuations in metal concentrations were influenced by variations in sediment particle size and the resultant adsorption properties. These four metals additionally demonstrated positive correlations with TOC and N-alkalines. Alternatively, mercury was below the LOD in all samples with the exception of Station ENV12 which recorded a concentration of 0.02ug/g. Concentrations of metals were all well below their respective ALs (Table 10–1), indicating that toxic impacts are unlikely to occur.

Table 10–1: Summary statistics of sediment metal contamination from samples collected across the Caledonia OWF.

Metal	AL1	AL2	Minimum	Maximum	Mean	Standard Deviation
Arsenic	20	70	1.9	10.9	4.6	2.8
Cadmium	0.4	4	0.07	0.34	0.14	0.08
Chromium	50	370	6.0	11.8	9.3	1.7
Copper	30	300	3.0	6.5	3.9	1.0
Mercury	0.25	1.5	NQ	0.02	NC	NC
Nickel	30	150	2.6	9.0	4.9	2.0
Lead	50	400	3.0	7.8	3.9	1.5
Zinc	130	600	6.3	19.3	11.7	4.5
Concentrations expressed as ug/g dry weight sediment. NQ – not qualified due to concentrations below the LOD. NC – Not calculated due to concentrations below the LOD.						

10.3 Caledonia OECC

10.3.1.1 A site-specific survey of the Caledonia OECC showed that arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc were positively correlated with depth and finer sediment, indicating that fluctuations in metal concentrations were influenced by variations in sediment particle size and resultant adsorption properties. These five metals also demonstrated positive correlations with TOC and low molecular weight n-alkanes. Concentrations of metals were all well below their respective ALs (Table 10–2), indicating that toxic impacts are unlikely to occur.

Table 10–2: Summary statistics of sediment metal contamination from samples collected across the Caledonia OECC.

Metal	AL1	AL2	Minimum	Maximum	Mean	Standard Deviation
Arsenic	20	70	2.1	5.4	3.2	1.1
Cadmium	0.4	4	NQ	0.12	NC	NC
Chromium	40	370	6.1	14.7	10.1	2.9
Copper	40	300	3.0	5.9	3.9	1.0
Mercury	0.3	1.5	NQ	0.01	NC	NC
Nickel	20	150	3.3	9.8	6.1	2.3
Lead	50	400	2.1	6.2	3.9	1.4
Zinc	130	600	10.6	24.8	15.8	4.6
Concentrations expressed as ug/g dry weight sediment. NQ – not qualified due to concentrations below the LOD. NC – Not calculated due to concentrations below the LOD.						

11 Sediment Contamination Conclusions

11.1.1.1 All contaminants were below their respective guideline thresholds (Table 11–1), frequently falling below the LOD. Consistent with findings from the Moray West, Moray East and Beatrice OWFs, the survey results indicate no evidence of unacceptable or significant contamination levels within the MW&SQ Study Area.

Table 11–1: Summary of sediment contamination in the Caledonia OWF and Caledonia OECC relative to threshold guidelines.

Contaminant Type	Contamination Summary Relative to Threshold Guidelines
THC	No exceedance of AL1 (Marine Scotland, 2017[1]). No exceedance of threshold values (Kjeilen *et al*., 2004[18]; UKOOA, 2002[19]; 2005[20]).
PAH	No exceedance of: ▪ TEL/PEL values (CCME, 1999[5]) ▪ ERL/ERM values (Long *et al*., 1995[25])
PCB	No exceedance of AL1 (Marine Scotland, 2017[1]). Below the LOD at all stations.
PBDE	All PBDEs were recorded below the LOD, except PBDE 209, which was: ▪ Above the BAC at three Stations in the Caledonia OWF and four Stations in the Caledonia OECC (OSPAR, 2020a[7]) ▪ Below FEQGs (OSPAR, 2020b[8])
OCP	There are currently no ALs for OCPs (Marine Scotland, 2017[1]). Below the LOD at most stations.
Organotins	No exceedance of AL1/AL2 (Marine Scotland, 2017[1]). Below the LOD at all stations.
Metals	No exceedance of AL1/AL2 (Marine Scotland, 2017[1]).

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