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A review of the distribution and ecological importance of seabed communities in the deep waters surrounding Scotland

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Summary

The Scottish Government's Programme for Scotland 2017-18 included a commitment to 'evaluate options to create a deep-sea national marine reserve'. The designation of a deep-sea reserve would complement the existing marine protected area (MPA) network in Scottish waters and provide a legal framework for the protection of additional deep-sea marine habitats and species against emerging threats.

Marine Scotland and JNCC have recently undertaken a scoping exercise to identify the deep-sea features of interest and evaluate options for creating a deep-sea national marine reserve to the north-west and north of Scotland in waters deeper than 800 metres. The 'study area' for the potential deep-sea marine reserve is divided into two distinct biogeographic areas either side of the Wyville-Thomson Ridge with different hydrographic and thermal regimes resulting in distinct community types north and south.

Numerous deep-sea habitats and species could be appropriate for spatial protection, many of which are already Priority Marine Features (PMFs) or correlate with existing PMF descriptions.

This review is not exhaustive, but it presents or describes the ecological characteristics and main data sources for the following features of interest within the study area:

1. Deep-sea sedimentary habitats, specifically the Priority Marine Features 'Offshore subtidal sands and gravels' and 'Offshore deep-sea muds', including burrowing communities.

2. Distribution of associated biodiversity, specifically the northern feather star (*Leptometra celtica*) and sea pens including the tall sea pen (*Funiculina quadrangularis*).

Data for sedimentary habitat distribution are available for most of the area within the Faroe-Shetland Channel to the north of the Wyville-Thomson Ridge giving a good resolution of seabed features and their associated communities. In the western part of the study area south of the Wyville-Thomson Ridge, survey data are generally scarcer with increasing distance from existing MPAs or topographical features, for which multiple data sets often exist. An overview of the known deep-sea sedimentary species and communities throughout the study area is given as well as their ecological functions and some of the benefits humans derive from them. Functional links and associations with other PMFs are presented and the resilience of deep-sea habitats and communities to human impacts is discussed.

Of particular interest in this review are seapens and feather stars. Broad descriptions are provided of the biology and distribution of both groups, drawing on data from the northeast Atlantic wherever possible. Specific attention is paid to the northern feather star (*Leptometra celtica*) and the tall sea pen (*Funiculina quadrangularis*).

Confidence in the data and reports used to compile the review are provided in an accompanying spreadsheet.

Contents

1 Introduction and scope

The Scottish Government's Programme for Scotland 2017-18[1] included a commitment to 'evaluate options to create a deep-sea national marine reserve'. The designation of a deep-sea reserve would complement the existing marine protected area (MPA) network in Scottish waters and provide a legal framework for the protection of additional deep-sea marine habitats and species against emerging threats.

Marine Scotland and the Joint Nature Conservation Committee (JNCC) have recently undertaken a scoping exercise to identify the deep-sea features of interest and evaluate options for creating a deep-sea national marine reserve to the northwest and north of Scotland in waters deeper than 800m (Figure 1). Numerous deep-sea habitats and species could be appropriate for protection in the potential deep-sea marine reserve, many of which are listed on some or all of the following lists: the Scottish Priority Marine Feature[2] (PMF) list, the Scottish Biodiversity[3] list, the OSPAR Threatened and/or Declining species and habitats[4] list, and ICES' Vulnerable Marine Ecosystems (VME)[5] list. The appropriateness of the features for spatial protection will be evaluated depending upon the level of evidence available to confirm their presence and relative importance in the study area.

The features of interest for assessment within the study area and covered by this literature review are:

1. Deep-sea sedimentary habitats, specifically the Priority Marine Features 'Offshore subtidal sands and gravels' and 'Offshore deep-sea muds', including burrowing communities.

2. Associated biodiversity, specifically the northern feather star (*Leptometra celtica*) and sea pens including the tall sea pen (*Funiculina quadrangularis*).

Development of the deep-sea component of the Marine Habitat Classification for Britain and Ireland[6] occurred following the creation of the Scottish PMF list. Consequently, most of the listed PMF components are unlikely to be relevant to deep-sea systems. The JNCC correlations table[7] clarifies the links between PMFs and other classification systems. Whilst any eventual designated feature would be the PMF, the correlating JNCC marine habitat deep-sea classification, EUNIS, OSPAR Threatened and/or Declining habitats and species and/or ICES Vulnerable Marine Ecosystems (VME) would be considered as components of the designated feature. An overview of these correlations is provided in the following section.

The current study area for the proposed deep-sea national marine reserve includes a spatial overlap with ten MPAs (Figure 1). These MPAs are listed in Table 1 along with the habitats and species for which they are designated. The study area is divided into 'northern' and 'western' areas based on distinct biogeographical differences described in further detail in section 2.2.

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[1] Available at: http://www.gov.scot/Publications/2017/09/8468/8
[2] For more information see: https://www.snh.scot/professional-advice/safeguarding-protected-areas-and-species/priority-marine-features-scotlands-seas
[3] For more information see: http://www.biodiversityscotland.gov.uk/advice-and-resources/scottish-biodiversity-list/
[4] For more information see: https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-species-habitats
[5] For more information see: http://www.ices.dk/marine-data/data-portals/Pages/vulnerable-marine-ecosystems.aspx
[6] For more information see: http://jncc.defra.gov.uk/page-6998
[7] For more information see: http://jncc.defra.gov.uk/page-6767

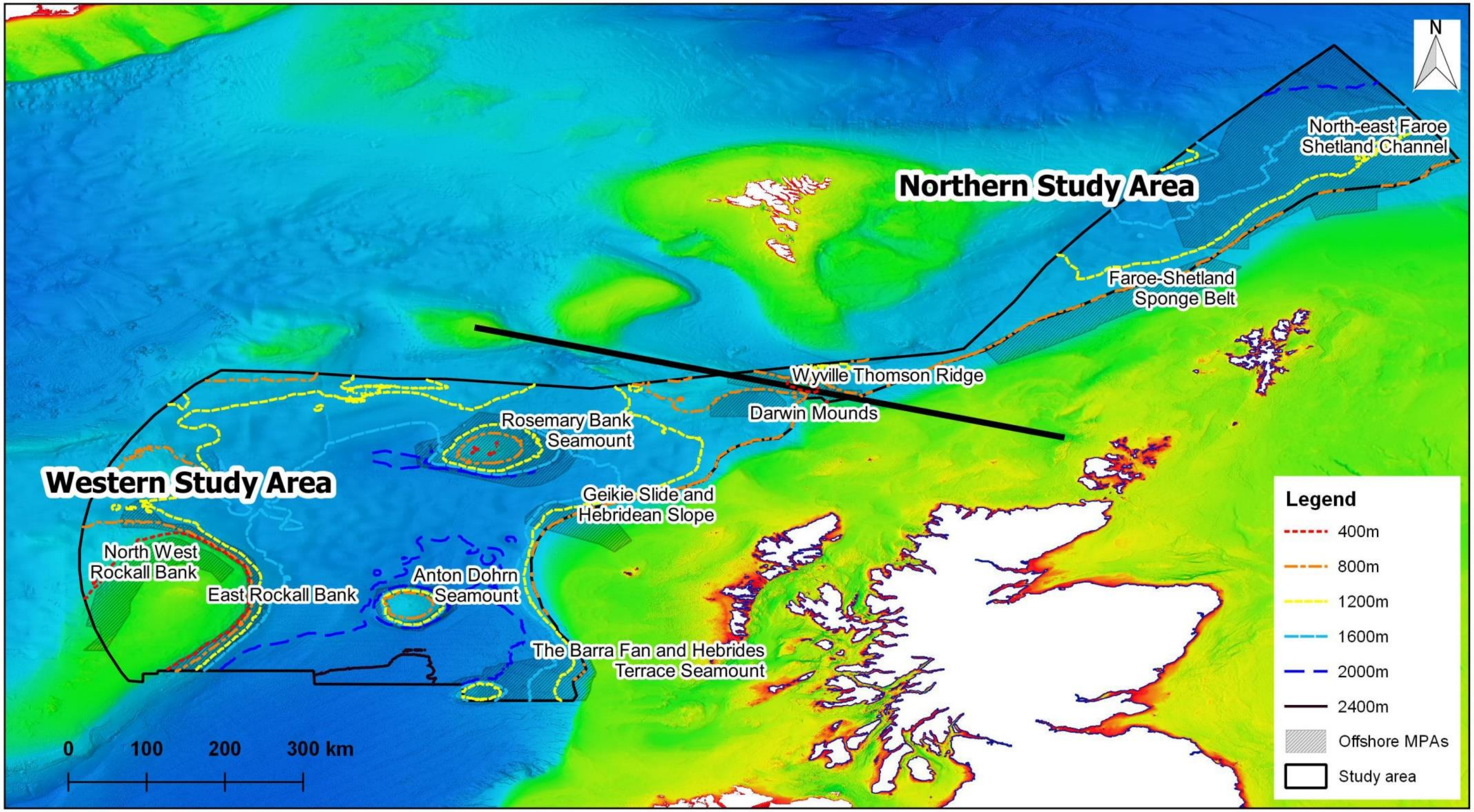

Figure 1: Marine Protected Areas (MPAs) located within the study area. Also shown is the division into the two distinct 'northern' and 'western' biogeographic zones, northeast and southwest of the Wyville Thomson Ridge. (Bathymetry data source EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM).

Evidence already exists that certain MPAs within the study area contain the sedimentary habitats and species of interest to this review (JNCC 2018a-j). Evidence is already available with respect to the biological communities within these MPAs; providing summaries of that evidence is not the objective of this review.

The purpose of this review is to provide information on: where the features of interest listed above are present outwith the existing MPAs, drivers of their distribution, their functional significance and their biological diversity.

Table 1: Existing MPAs overlapping with the study area, and their designated features of interest. Source: JNCC (2018a-j).

Site name	**Designation type**	**Designated feature**	
		Annex I	**Priority Marine Feature**
Anton Dohrn Seamount	Special Area of Conservation	Reefs (bedrock, biogenic, stony)	-
Geikie Slide and Hebridean Slope	Nature Conservation MPA		Burrowed mud Continental slope Offshore Subtidal sands and gravels Offshore deep-sea muds Slide deposit and slide scars representative of the Geikie Slide Key Geodiversity Area
Rosemary Bank Seamount	Nature Conservation MPA		Deep-sea sponge aggregations Iceberg plough mark fields, slide scars, sediment drifts, sediment wave fields and the seamount scour moat Seamount communities Seamounts
Barra Fan and Hebrides Terrace Seamount	Nature Conservation MPA		Continental slope *Hoplostethus atlanticus* - Orange roughy Burrowed mud Seamount communities Offshore deep-sea muds Offshore subtidal sands and gravel Seamounts
North-west Rockall Bank	Special Area of Conservation	Reefs (biogenic, stony)	
Darwin Mounds	Special Area of Conservation	Reefs (biogenic)	
East Rockall Bank	Special Area of Conservation	Reefs (bedrock, biogenic, stony)	
Faroe Shetland Sponge Belt*	Nature Conservation MPA		*Arctica islandica* - Ocean quahog Continental slope Continental slope channels, iceberg plough marks, prograding wedges and slide deposits and Sand wave fields and sediment wave fields Deep-sea sponge aggregations Offshore subtidal sands and gravels Sand wave fields and sediment wave fields
North-east Faroe-Shetland Channel	Nature Conservation MPA		Continental slope West Shetland Margin Palaeo-depositional, Miller slide and Pilot Whale Diapirs Key Geodiversity Areas

Site name	Designation type	Designated feature	
		Annex I	Priority Marine Feature
			Deep-sea sponge aggregations Offshore subtidal sands and gravels Offshore deep-sea muds
Wyville Thomson Ridge	Special Area of Conservation	Reefs (bedrock, stony)	-

*The Faroe Shetland Sponge Belt Nature Conservation MPA extends to a depth of 800m and therefore lies immediately adjacent to the present study area. There is therefore likely to be some considerable overlap between the taxa and habitats recorded in the deeper parts of this MPA as it transitions into the adjoining study area; it has been included here for this reason.

2 Deep-sea sedimentary habitats

This section provides a synopsis of present knowledge regarding deep-sea sedimentary habitats within the study area (Figure 1). It gives an introduction to their physical structure and composition and the depth ranges and geographical areas over which modelling and / or survey data suggest they occur. Oceanographic conditions driving sediment distributions are discussed as is present knowledge on their associated biodiversity, and their ecological and functional significance. The known functional links of deep-sea sedimentary habitats with other Scottish PMFs are presented. A summary of the main human impacts occurring within the habitats and communities also addresses their known sensitivities and resilience to those impacts.

As noted in the introduction, the relevant components on the Scottish PMF list relate to shallower sea areas. Table 2 summarises the correlations between Scottish PMFs and other classification systems, including the JNCC Deep-sea Habitat Classification which includes the broad-scale deep-sea sedimentary habitats discussed herein, thereby justifying their conservation status as PMF habitats or species.

Table 2: Summary of correlations between Scottish Priority Marine Features and other classification systems for deep-sea habitats.

Priority Marine Feature	PMF Component species	OSPAR	EUNIS Classification (Level 3)	JNCC Deep-sea Classification (15.03)	
Offshore subtidal sand and gravels	N/A	N/A	A6.2 Deep sea mixed substrata*	M.ArMB.Co	Arctic mid bathyal coarse sediment
				M.ArLB.Co	Arctic lower bathyal coarse sediment
				M.ArUA.Co	Arctic upper abyssal coarse sediment
				M.AtUB.Co	Atlantic upper bathyal coarse sediment
				M.AtMB.Co	Atlantic mid bathyal coarse sediment
				M.AtLB.Co	Atlantic lower bathyal coarse sediment
				M.AtUA.Co	Atlantic upper abyssal coarse sediment
				M.AtMA.Co	Atlantic mid abyssal coarse sediment
				M.AtLA.Co	Atlantic lower abyssal coarse sediment
				M.AAUB.Co	Atlanto-Arctic upper bathyal coarse sediment
				M.ArMB.Mx	Arctic mid bathyal mixed sediment
				M.ArLB.Mx	Arctic lower bathyal mixed sediment
				M.ArUA.Mx	Arctic upper abyssal mixed sediment
				M.AtUB.Mx	Atlantic upper bathyal mixed sediment
				M.AtMB.Mx	Atlantic mid bathyal mixed sediment
				M.AtLB.Mx	Atlantic lower bathyal mixed sediment
				M.AtUA.Mx	Atlantic upper abyssal mixed sediment
				M.AtMA.Mx	Atlantic mid abyssal mixed sediment
				M.AtLA.Mx	Atlantic lower abyssal mixed sediment
				M.AAUB.Mx	Atlanto-Arctic upper bathyal mixed sediment
			A6.3 Deep sea sand	M.ArMB.Sa	Arctic mid bathyal sand
				M.ArLB.Sa	Arctic lower bathyal sand
				M.ArUA.Sa	Arctic upper abyssal sand
				M.AtUB.Sa	Atlantic upper bathyal sand
				M.AtMB.Sa	Atlantic mid bathyal sand
				M.AtLB.Sa	Atlantic lower bathyal sand
				M.AtUA.Sa	Atlantic upper abyssal sand
				M.AtMA.Sa	Atlantic mid abyssal sand
				M.AtLA.Sa	Atlantic lower abyssal sand
				M.AAUB.Sa	Atlanto-Arctic upper bathyal sand
			A6.4 Deep-sea muddy sands*	M.ArMB.Sa	Arctic mid bathyal sand
				M.ArLB.Sa	Arctic lower bathyal sand
				M.ArUA.Sa	Arctic upper abyssal sand

Priority Marine Feature	PMF Component species	OSPAR	EUNIS Classification (Level 3)	JNCC Deep-sea Classification (15.03)	
				M.AtUB.Sa M.AtMB.Sa M.AtLB.Sa M.AtUA.Sa M.AtMA.Sa M.AtLA.Sa M.AAUB.Sa	Atlantic upper bathyal sand Atlantic mid bathyal sand Atlantic lower bathyal sand Atlantic upper abyssal sand Atlantic mid abyssal sand Atlantic lower abyssal sand Atlanto-Arctic upper bathyal sand
Offshore deep-sea muds	N/A	N/A	A6.5 Deep sea mud	M.ArMB.Mu M.ArLB.Mu M.ArUA.Mu M.AtUB.Mu M.AtMB.Mu M.AtLB.Mu M.AtUA.Mu M.AtMA.Mu M.AtLA.Mu M.AAUB.Mu	Arctic mid bathyal mud Arctic lower bathyal mud Arctic upper abyssal mud Atlantic upper bathyal mud Atlantic mid bathyal mud Atlantic lower bathyal mud Atlantic upper abyssal mud Atlantic mid abyssal mud Atlantic lower abyssal mud Atlanto-Arctic upper bathyal mud
Burrowed mud	Tall seapen (*Funiculina quadrangularis*) Seapen and burrowing megafauna communities**	Seapen and burrowing megafauna communities**	N/A	M.AtUB.Mu.SpnMeg M.AtMB.Mu.SpnMeg	Sea pens and burrowing megafauna on Atlantic upper bathyal mud Sea pens and burrowing megafauna on Atlantic mid bathyal mud
Northern feather star (*Leptometra celtica*)	N/A	N/A	N/A	N/A	N/A

*The features will be included in the JNCC correlations table version 2.3 to be published in January 2019.

**OSPAR definition: Plains of fine mud, at water depths ranging from 15 – 200m or more, which are heavily bioturbated by burrowing megafauna; burrows and mounds may form a prominent feature of the sediment surface with conspicuous populations of seapens, typically *Virgularia mirabilis* and *Pennatula phosphorea*. The burrowing crustaceans present may include *Nephrops norvegicus*, *Calocaris macandreae* or *Callianassa subterranea*. In the deeper fjordic lochs which are protected by an entrance sill, the tall sea-pen *Funiculina quadrangularis* may also be present. The burrowing activity of megafauna creates a complex habitat, providing deep oxygen penetration.

2.1 Range and Distribution

As outlined in Section 1.1, specifically two Priority Marine Features (and their correlating deep-sea sedimentary habitats) are under consideration here; 'Offshore subtidal sands and gravels' and 'Offshore deep-sea muds', the latter including burrowed-mud communities. Where the term 'continental slope' is used it refers to the continental slope within the study area, unless stated otherwise. This section considers the physical composition of the sediments and the drivers of their distribution before presenting data on their range and distribution within the study area.

'Sands and gravels' are separated from 'muds' on the basis of their physical constitution of particle sizes. The Folk Classification is typically used to determine the differences in sediment types and is explained by Long (2006) for its use by the British Geological Survey and its reclassification for UKSeaMap (2016). Muds are typically defined as being <5% gravel with a sand:mud ratio of 4:1 or less. Sands and muddy sands have <5% gravel and a sand:mud ratio between 4:1 and 9:1. Sediments with >5% gravel are either 'mixed sediments' or 'coarse sediments' depending on the mud fraction.

Marine Scotland's Feature Activity Sensitivity Tool (FeAST[8]) is used for determining potential management requirements for Nature Conservation MPAs; it provides useful, broad definitions of Scotland's marine habitats and their associated communities (Marine Scotland 2018). Table 3 provides a summary of the FeAST marine sediment and habitat definitions in relation to the deep-sea 'muds' and 'sands and gravels' discussed in this review.

Table 3: Summary or the broad habitat and community descriptions for the deep-sea available from the Marine Scotland's Feature Activity Sensitivity Tool (2018). Source: Marine Scotland (2018).

Feature Name	Description
Deep-sea muds	Considered as a type of offshore deep-sea mud habitat. Seabed sediments on the continental slope and abyssal plain ranging from fine silty muds to sandy muds that can host a range of animals both within and on the seabed such as polychaete worms, sea urchins and star fish.
Burrowed mud*	Soft muddy sediments peppered with the burrows of burrowing animals such as the Dublin Bay prawn and populated with other animals such as sea pens and anemones.
Deep-sea muddy sands	Considered as a type of offshore subtidal sand and gravel habitat. Muddy sands on the continental slope and abyssal plain that may host a range of animals such as sea spiders, sea urchins and polychaete worms as well as sea pens.
Deep-sea sands	Considered as a type of offshore subtidal sand and gravel habitat. Sandy habitats on the continental slope and abyssal plain that may host a range of animals such as sea urchins, star fish and anemones.
Deep-sea mixed sediments	Considered as a type of offshore subtidal sand and gravel habitat. Mixed sediments from gravel and cobbles to finer sands on the continental slope and abyssal plain that can host a range of animals such as sponges, bryozoans, polychaete worms and sea urchins.
Coral gardens	Aggregations of soft and hard coral species, found on both hard and soft-bottomed seabeds.

*Note: this description is more applicable to inshore / shallow shelf seas rather than deep-sea burrowed muds.

Water depths within the study area range between 800m and approximately 2,500m at the deepest point, between the Rockall Bank and the Hebrides Terrace Seamount (see bathymetry contours in Figure 1). The deep-sea areas to the west and north of Scotland support large expanses of mud and fine clay with a variety of coarse sediments present in places (Baxter *et al* 2011). The distribution of sediment types within the study area is influenced by the presence of various geological features e.g. seamounts, the continental slope, ridges, troughs and banks and their associated oceanic currents (Inall & Sherwin

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[8] For more information see: http://www.marine.scotland.gov.uk/feast/

2006). Strategic Environmental Assessments (SEAs) of different sea areas have been completed within the UK to facilitate decision-making with respect to development and environmental protection. SEA Area 7 (SEA7) includes the study area to the west of Scotland whilst SEA Area 4 (SEA4) includes the study area north-east of the Wyville-Thomson Ridge and is largely defined by the Faroe-Shetland Channel. Inall and Sherwin (2006) and Holmes *et al* (2002) provide descriptions of the currents and bathymetry, and the geology (including sediments) respectively throughout the SEA7 region. Holmes *et al* (2003), Masson (2003) and Bett (2012) provide similar summaries for the SEA4 region. In both regions, the reports acknowledge the influence of topographic features over the prevailing currents and consequently, the sediment types present. In particular, Holmes *et al* (2002) provide a vast bibliography of the data available for SEA7 at the time, which for seabed surveys details the data available between 1976 and 2002. A summary of the main currents throughout Scotland’s offshore areas is provided in Baxter *et al* (2011).

In general, deep-sea, subsurface currents are weaker when compared with surface flows but are intensified around topographic features such as seamounts, the continental slope and the Rockall Bank (Holmes 2006; Baxter *et al* 2011). In deeper areas, away from large topographic features and with low or negligible currents, finer, muddy sediments are present (Holmes 2006). The highly varied topography in the region of the Faroe-Shetland Channel results in complex current patterns, which in turn influence sediment distribution patterns. Within the Faroe-Shetland Channel, stronger currents are present as the channel narrows toward the Wyville-Thomson Ridge; this results in coarser sediments being located at greater depths compared with the deep sea to the west of Scotland (Masson 2003; Holmes 2006; Bett 2012). Hughes *et al* (2003) note that low sediment deposition rates in the Faroe-Shetland Channel also play a role in determining which sediments are present. Overall, there is a trend of increasing mud content from the southwest to the northeast within the Faroe-Shetland Channel. These sediment distribution patterns and the influence of topographic features are illustrated by the British Geological Survey data (Figure 2 - Figure 5 in Appendix 1) showing higher percentages of sands and gravels around such features as the Rockall Bank, the continental slope and around the Wyville Thomson Ridge.

Several geological sedimentary features exist in Scottish offshore waters with some already designated as interest features in existing MPAs (see Table 1). These features may take the form of slide deposits, iceberg plough marks, sediment drifts, sediment wave fields, sand contourites and barchan sand dune fields[9], mud diapirs[10] / mounds and sediment plains. Within the Faroe-Shetland Channel including the approach to the Wyville-Thomson Ridge, Bett (2012) illustrates the distribution of the known sedimentary physical features. Below 800m these include contourite deposits, barchan sand dunes, gravel / cobble deposits, landslide debris (mud blocks) and mud diapirs and mud mounds. Masson (2003) provides a detailed chart of survey sampling results and sonar survey interpretations across the entire SEA4 / Faroe-Shetland Channel area (both within and outwith existing MPAs) which details the known presence of the seabed sedimentary features and associated bed currents. A further generalised map within Masson (2003) illustrates the presence of sands, gravels and muds throughout the area, correlating well with other datasets described in the following sections of this report (Sections 2.1.1 - 2.1.4).

Sediment distribution in the deep-sea areas to the west of Scotland within the SEA7 area is described by Davies *et al* (2006): sediments along the Hebridean slope show a general decrease in grain size with increasing depth and were described as being thickest within the

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[9] Barchan sand dunes are crescent-shaped and can be found in high-energy areas. The ‘horns’ of the crescent face down current. The dunes may be up to 120m across and the slopes can support abundant fauna such as seapens and anemones.

[10] Mud diapirs are vertical intrusions of mud through fractures or zones of weakness of over-lying brittle rock layers. The resulting structures can be mushroom-shaped, mound-like or elongated ‘dykes’ depending on the geological materials involved.

eastern Rockall Trough and along the Hebridean slope and thinnest in the western Rockall Trough and on the Rockall Plateau (Davies *et al* 2006). During a survey to locate rocky reef features on the Rockall Bank, Howell *et al* (2009) also recorded this gradation in sediment type, identifying mud habitats at the base of the bank in ~1,100 – 1,600m depth. Along the continental slope, Davies *et al* (2006) described sediments as changing from sands at 700m to silty mud and mud between 700 – 1,000m depth with gravel patches being rare and cobbles and boulders even rarer. Sediments extending into the Rockall Trough are described as being mainly mud with some areas of coarse sand and gravel (Davies *et al* 2006); the authors provide photographic evidence of the trends of decreasing grain size with depth.

Data from many of the seabed surveys undertaken within the study area are available to view and download as complete datasets online with some used to contribute to the production of broadscale habitat maps of European and UK seas. Many of these data originate from the SEA4 and SEA7 survey initiatives described above; the main datasets available are described below.

2.1.1 British Geological Survey data

British Geological Survey (BGS) data are available for multiple surveys undertaken throughout the study area, comprising sampling techniques such as grabs, corers, boreholes or shallow dredges. The surveys were predominantly part of the Strategic Environmental Assessment (SEA) programme. The BGS states that "*these are primarily shallow geology and geophysics data collected as either part of regional or local mapping work, or provided to the BGS by third parties*." The BGS also manages data for the Marine Environment Data and Information Network (MEDIN). MEDIN is a partnership of UK organisations committed to improving access to marine data and facilitating data sharing. BGS is the accredited data archive centre (DAC) for geology, geophysics and backscatter. BGS datasets can be viewed using the GeoIndex service which provides data available from a number of sources, each of which is catalogued and traceable to its source, thereby providing confidence in the data.

BGS sea bed sediment data for mud, sand and gravel fractions were extracted for the study area and are presented in Figure 2 - Figure 5 (Appendix 1). In all figures, the BGS data illustrate the higher sand and gravel fractions in areas proximal to distinct geological features where prevailing currents are likely to be higher. In deeper, low-energy waters such as the central Rockall Trough (and outside existing MPAs), mud fractions dominate the sample data (Figure 5). Figure 2 shows the available data for the north-eastern part of the Faroe-Shetland Channel. Whilst few data are available for the deepest parts of the Norwegian basin, these are provided in Masson (2003) and available via the Geodatabase of Marine Features in Scotland (GeMS) (see below); much of this area is already designated as the Northeast Faroe-Shetland Channel Nature Conservation MPA (Figure 1 and Table 1). For a relatively small area of the Northeast Faroe Slope on the extremity of the Fugloy Ridge and outside of the Northeast Faroe-Shetland Channel Nature Conservation MPA, no BGS data exist. However, Masson (2003) provides data on this slope habitat which consists of a mix of sand / gravel lag deposits, relict landslide scars and buried landslide deposits.

The coarser sediments reported from the south-western end of the Faroe-Shetland Channel (Masson 2003; Holmes 2006; Bett 2012) are visible in the BGS data, which show higher gravel and sand fractions as the Channel narrows toward the Wyville-Thomson Ridge, across the Ridge itself and toward the Darwin Mounds SAC (Figure 3 and Figure 4, Appendix 1). These data provide good coverage of the study area within the Faroe-Shetland Channel outside the existing MPAs and correlate well with the data and illustrations provided in Masson (2003).

In the western part of the study area within SEA7 the BGS data cover an extensive area within the southern and western Rockall Trough, including around the George Bligh Bank. Fewer sample data exist for the north and northeast section of this part of the study area, particularly the following broadscale areas (Figure 5, Appendix 1):

- north, east and west of the Rosemary Bank Seamount;
- the Hebridean Slope between the Darwin Mounds SAC and Geikie Slide and Hebridean Slope NCMPA; and
- between the Anton Dohrn and Rosemary Bank Seamounts.

2.1.2 Marine Environmental Mapping Programme (MAREMAP)

The data held by BGS is also being used to provide the foundations for the Marine Environmental Mapping Programme (MAREMAP) outputs shown on the MAREMAP portal (MAREMAP 2018). MAREMAP was launched in 2010 and is a joint initiative led by the BGS, the National Oceanography Centre (NOC) and the Scottish Association for Marine Science (SAMS) with partners from the University of Southampton, Channel Coastal Observatory, the University of Plymouth, the Maritime and Coastguard Agency, the Centre for Environment, Fisheries & Aquaculture Science and Marine Scotland. The project aims to use combined expertise to update existing marine maps and target areas of strategic, economic or biological importance (MAREMAP 2018).

Much of the available MAREMAP data to the west of Scotland correspond to shelf seas and nearshore areas at present. Offshore, deep-sea data are available only for two areas within the study area; the Anton Dohrn seamount and the George Bligh Bank. MAREMAP data for the Anton Dohrn seamount confirm those available through other sources, namely that the sediments around the base of the seamount are sands and gravels, becoming muds with increasing depth and distance from the seamount. MAREMAP data for the George Bligh Bank show sands and muddy sands to the south between the George Bligh Bank and the East Rockall Bank SAC. To the east of the George Bligh Bank, sands and gravels graduate into mud habitat with increasing depth into the Rockall Trough (MAREMAP 2018).

Within the SEA4 area MAREMAP provides data for the entire Faroe-Shetland Channel area, north of the Wyville Thomson Ridge. The data are presented as sediment types based on Folk classifications (Section 2.1). They correspond well with those presented through the BGS (Section 2.1.1) and UKSeaMap (Section 2.1.4), again showing gradation from sands and gravels in the southwest of the area to muds toward the northeast in the Norwegian basin (UKSeaMap 2016).

All MAREMAP data are available to view at http://www.maremap.ac.uk/view/search/searchMaps.html.

2.1.3 Geodatabase of Marine Features in Scotland

The Geodatabase of Marine Features in Scotland (GeMS) is managed and held by Scottish Natural Heritage. GeMS holds point and polygon datasets containing seabed habitat data for inshore and offshore areas of Scotland's seas which match the definitions of habitats on the PMF list. The database is updated annually or if new data become available. All data held in the GeMS database are verifiable and traceable, providing confidence in the data quality. Available GeMS data relevant to the sedimentary habitats under investigation in this report are displayed in Figure 6, Appendix 1; a further breakdown of particle size data for many of the same data points within SEA4 is provided in Hughes *et al* (2003).

GeMS data for the northern study area reflect those described above. Muds are shown to be present in the northeast of the area and graduate into offshore subtidal sands and gravels as the channel narrows toward the southwest approaching the Wyville-Thomson Ridge.

In the western study area most of the GeMS point data lie within existing MPAs for which there is already documented evidence of the physical habitats present (see Table 1 and references therein). There are however, some data for areas outside existing MPAs for burrowed mud habitats below 800m along the Hebridean Slope. Two of these areas are immediately north of both the Barra Fan and Hebrides Terrace Seamount and Geikie Slide and Hebridean Slope Nature Conservation MPAs. A further cluster of burrowed mud habitat data points is present along the Hebridean Slope approximately halfway between the Geikie Slide and Hebridean Slope Nature Conservation MPAs and the Darwin Mounds SAC. The positions of all these burrowed mud habitats correspond with the survey areas reported by Hughes (2014) and likely originate from the surveys reported therein.

2.1.4 EUSeaMap and UKSeaMap data

The EMODnet seabed habitat portal provides access to data on Europe’s seas (Populus *et al* 2017). The broad-scale habitat map referred to as EUSeaMap has been created by this project and after the first two phases it now covers all European basins including the present study area. The project remains in a state of development with completion expected in 2020 (EMODnet 2018). The EUSeaMap habitat maps available are based on predictive mapping which uses existing maps as well as substrate, energy, depth and salinity data from historical and contemporary surveys to produce the outputs by matching modelled physical parameters to EUNIS physical habitat descriptions. A description of the project’s history, methods, data sources, quality control and confidence assessments is provided by Populus *et al* (2017). The sources of the various survey data available range from government agencies and departments, academic institutions to industries exploring the seafloor for energy and/or minerals. As mentioned previously, the survey data do not cover the entire area, therefore the absence of data from any single area does not imply the absence of those habitats or communities of interest in this report.

Directly related to the EUSeaMap project is the UKSeaMap 2016 project which has been generated by the JNCC as a “*by-product of the 2013-2016 activities of the EMODnet Seabed Habitats 2013-2016 consortium*” (JNCC 2018k). UKSeaMap 2016 is a broad-scale EUNIS seabed habitat map for the UK continental shelf created from outputs of the EMODnet Seabed Habitats project, often at a higher resolution than EUSeaMap, dependent on the availability of underlying data. UKSeaMap includes the offshore areas beyond the continental slope at a coarser resolution. A technical report detailing the methods used to construct the UKSeaMap 2016 is not yet available from the JNCC. However, it supersedes previous UK-wide broad-scale seabed habitat maps, including EUSeaMap 2012, UKSeaMap 2010, MESH 2008 and UKSeaMap 2006. It has built on the work of these projects and uses the most recent available data and methods. McBreen and Askew (2011) provide technical detail on the methods used to develop the UKSeaMap 2010 benthic substrate layers including how the Folk classification system relates to the EUNIS substrate types, which remains relevant to the latest version. Outputs from the UKSeaMap 2016 are provided in Figure 7 - Figure 9, Appendix 1 and described here.

In the northern study area (Faroe Shetland Channel to Wyville Thomson Ridge) UKSeaMap2016 shows the same patterns of sediment distribution as in the previously described datasets (Figure 7). In the northern and deeper Norwegian basin area, the substrates are dominated by muds and an area of mixed sediments. As the Channel narrows toward the Wyville Thomson Ridge the substrate changes to sandy muds and muddy sands, through sands to mixed and coarse sediments. The data again illustrate the presence of sands and coarse sediments along the southern edge of the Faroe-Shetland Channel.

In the western study area, the UKSeaMap2016 data show the substrate type along the Hebridean Slope to comprise a mixture of mud, sandy muds and muddy sands with occasional coarser sediments on the upper slope (Figure 8). These data correspond well with the survey evidence provided in Hughes (2014) and described above in reference to the GeMS database (Section 2.1.3). A larger area of sand and coarse sediment exists in the north-eastern section of this part of the study area toward the Darwin Mounds and Wyville Thomson Ridge.

West of the Hebridean Slope the low energy and deep-water environment of the Rockall Trough results in the vast majority of the area being designated as sandy-mud and muddy-sand habitat, again with sands and coarser sediments being located around the larger geological features such as seamounts and banks and within the narrow channel between the George Bligh Bank and East Rockall Bank. North of the George Bligh Bank, bands of mixed and coarse sediments are predicted to be present.

It is noted that the predictive maps generated by UKSeaMap and EUSeaMap projects provide information on the likely physical habitats throughout the area. The maps rely on expert interpolation from widely spread point samples and acoustic survey transects. To this end, both EUSeaMap and UKSeaMap conduct confidence assessments in the data used to generate the final outputs. A substrate confidence assessment for the UKSeaMap2016 substrates is provided in Figure 9 (Appendix 1). The assessment provides an indication as to the sea areas where substrate confidence is greatest and those where it is lowest. Overall, areas scoring highly were often (but not always) within and around existing MPAs. Only very few areas received low confidence scores (visible in dark blue in Figure 9) but it should be noted that these scores relate only to the likely physical substrates and not the biological habitats and communities which might be present.

Gage (2002) stated that whilst there are known broad-scale, depth-related changes of sediments and biota, local-scale heterogeneity in sediment type, hydrodynamics and topography occurs along the continental slope. This variation creates challenges with respect to predicting continental slope habitat types from broadscale data, as illustrated along the continental slope off Norway by Buhl-Mortensen *et al* (2012); pockets of coarser sediments or rocky habitat should not be ruled out from the margins of or within the Rockall Trough. Greater survey effort would be required to detect and map the presence or absence of such pockets of coarser sediment or rocky habitat with higher confidence than exists at present.

2.2 Biology and ecology

2.2.1 Biodiversity

Ecological data on, and understanding of Scotland’s deep-sea environment are relatively limited compared with the shallower shelf seas, hindered not least by the relative difficulties and costs in accessing these environments (Baxter *et al* 2011). Bett (2003) noted the taxonomy of the deep-water fauna in the Faroe-Shetland Channel was significantly incomplete (as is typically the case in any deep-sea area) with around half the macrofauna species collected during benthic surveys (1996-2002) being unable to be recorded to species level at that time. Significant advances have since been made, and the benthos were at least as well understood as any other deep-sea areas by 2003 (Bett 2003). Where targeted surveys have been undertaken around features of interest throughout the study area, including many of the existing MPAs listed in Table 1, reliable and detailed data exist on the occurrence of physical habitat types and their associated biological communities, whilst advances in benthic taxonomy continue. Assessments of deep-sea benthic communities made under the SEA4 and SEA7 programs reviewed the literature available at the time; those reviews have been used in the following sections to provide an overview of the biological communities present or likely to be present in sedimentary habitats within the study area. More recent reports have provided biotope definitions for deep-sea communities and physical habitats both within and outwith existing MPAs within the study area (Howell *et al* 2010, 2014). Although incomplete, Figure 6 (Appendix 1) provides an indication of the spread of biological data available within the study area; of note is the paucity of data within the wider Rockall Trough area.

The ecology of deep-sea sedimentary habitats will be influenced by sediment type, current regime and temperature. As noted above in section 2.1, some general rules can be applied to the likely occurrence of deep-sea sediments and their associated communities based on factors such as depth and current regime. However, in a summary of the biological communities of the Faroe-Shetland Channel, Bett (2012) noted that the dynamic current regime, complex thermal regime and enhanced seafloor heterogeneity (all of which vary with depth) contribute to the Channel being a highly atypical marine area about which textbook generalisations should not be made. Bett (2012) also reviewed the various classification schemes that have sought to categorise the deep-sea habitats of the NE Atlantic. Of these, Dinter (2001) incorporated environmental variables such as temperature, considered likely to influence the communities present. With respect to the present study area, the Faroe-Shetland Channel was classified as ‘Arctic deep’ and ‘Boreal’ owing to the ingress of colder (<5°C) northern waters below ~600m depth. Waters in the western study area were classed as ‘Boreal’, ‘Boreal-Lusitanian’ and ‘Atlantic deep’. These different deep-sea ‘Arctic’ and ‘Atlantic’ biozones (and associated confidence scores) are shown in Figure 10 and Figure 11 (Appendix 1) as derived from the UKSeaMap2016 / EMODnet biotope classifications. On the basis that the deep-sea faunas to the north and south of the Wyville-Thomson Ridge are considered distinct (Hughes *et al* 2003), current knowledge on the biodiversity of the sedimentary communities is presented separately below.

In their description of deep-sea benthos Davies *et al* (2006) describe the different size spectra of benthic fauna. From largest to smallest these are classed as megafauna, macrofauna and meiofauna. A species falls into one or other category based on taxonomic definitions and/or sampling and analysis techniques; one exception is the xenophyophores – large, single-celled protozoans and members of the meiofauna (described further below). The following sections give an overview of the faunal diversity in each of the biogeographically different deep-sea sedimentary habitats to the north and south of the Wyville Thomson Ridge (as illustrated in Figure 1 above and in Figure 11, Appendix 1). These area-wide descriptions do not attempt to map species distributions but provide background information on the various communities known to occur in deep-sea sediments within the study area, particularly outside of existing MPAs where data are available. Buhl-Mortensen *et al* (2010) provide detailed descriptions and images of the biodiversity typical of the deep-sea ecosystem in the northeast Atlantic.

Northern study area - Faroe-Shetland Channel

Many detailed surveys have been carried out within the Faroe-Shetland Channel (SEA4 region) since the late 1990s to characterise the region’s seabed geology and ecology. The surveys involved collaboration between offshore industries, academics and Government agencies (Hughes *et al* 2003). Several reports are available that summarise the main findings of those surveys and describe the biological communities present (Bett 2003; Hughes *et al* 2003; Masson *et al* 2003; Gates *et al* 2011; Bett, 2012). Bett (2012) and Hughes (2003) synthesised results from five surveys in particular within SEA4 between 1996 and 2002 to describe the benthic communities.

Bett (2012) used the data from the SEA4 surveys to propose biotopes for the habitats and communities present. The data were derived from many of the same survey locations as those indicated by the GeMS data and demonstrate clear relationships with depth, sediment type and temperature regime. Below 600m in the Faroe-Shetland Channel the hydrographic regime was described as ‘Arctic water with a highly stable thermal regime’ below 0°C. There was further variation in faunal composition below 1200m. Hughes *et al* (2003) reported macrofaunal abundance to reach a maximum at 700 – 800m within the Faroe-Shetland Channel before decreasing again at depths to 1,000m. Total biomass peaked at 350-450m with values differing little between 500 – 1,000m.

In total, eight biotopes were proposed for the SEA4 area, of which four ‘cold water’ biotopes characterised the two depth bands within the present study area (Bett 2012). Dominant families were mostly polychaetes which comprised >40% of the individuals sampled per station, and were characterised by Oweniidae, Paraonidae, Cirratulidae, Maldanidae and Amphinomidae, together with the sipunculid family Golfingiidae. Other fauna present included amphipods, bivalves, acorn worms and holothurians (sea cucumbers). Median faunal density ranged between 1,500 and 2,500 individuals m^{-2} across the four biotopes. Summary descriptions of the four biotopes proposed for waters >800m depth are reproduced below with full descriptions and illustrations available in Figure 28 of Bett (2012).

SEA4 BIOTOPE III

CIRRATULIDAE-MALDANIDAE-MALDANIDAE IN ARCTIC SAND AND MUDDY SAND (600-1,200M)
Deep-water biotope (600-1,200m) of the Faroe-Shetland / Faroe Bank Channels (West of Shetland); Arctic waters; sand and muddy sand substratum (predominantly S/mS); macrobenthos characterised by Cirratulidae and Maldanidae, distinguished from other UK SEA area 4 biotopes by abundance of Maldanidae.

SEA4 BIOTOPE IV

OWENIIDAE-CAPITELLIDAE-MALDANIDAE IN ARCTIC MUD AND SANDY MUD (>1,200M)
Deep-water biotope (>1,200m) of the Faroe-Shetland / Faroe Bank Channels (West of Shetland); Arctic waters; mud and sandy mud substratum (predominantly mS/sM); macrobenthos characterised by Oweniidae and Capitellidae, distinguished from other UK SEA area 4 biotopes by abundance of Maldanidae.

SEA4 BIOTOPE VII

CIRRATULIDAE-OWENIIDAE-THYASIRIDAE IN ARCTIC MUD AND SANDY MUD (600-1,200M)
Deep-water biotope (600-1,200m) of the Norwegian Basin (North of Shetland); Arctic waters; mud and sandy mud substratum (predominantly mS); macrobenthos characterised by Cirratulidae and Oweniidae, distinguished from other UK SEA area 4 biotopes by abundance of Thyasiridae (bivalves).

SEA4 BIOTOPE IX

CAPITELLIDAE-OWENIIDAE-MYRIOTROCHIDAE IN ARCTIC MUD AND SANDY MUD (>1,200M)
Deep-water biotope (>1,200m) of the Norwegian Basin (North of Shetland); Arctic waters; mud and sandy mud substratum (predominantly sM/M); macrobenthos characterised by Capitellidae and Oweniidae, distinguished from other UK SEA area 4 biotopes by abundance of Myriotrochidae (holothurians).

Bett (2012) assumed that sediment gravel content was largely <5% throughout the Faroe-Shetland Channel but noted that gravels, cobbles or boulder-sized fractions could be found anywhere within the SEA4 area, sometimes providing 100% cover; such habitats cannot be sampled for macrobenthos by standard methods (grabs, corers *etc*) so infaunal data are not available.

Two areas within SEA4 presently lying outside existing MPAs contain ‘deep gravel and cobble pavements’ (Bett 2012). The first lies in 1,000 – 1,500m on the northeast extremity of the Fugloy Ridge (see also Masson (2003) in section 2.1.1) whilst the second is in 800 – 1,200m along the southern edge of the Faroe Plateau. Both areas are subject to elevated near-bottom currents leading to exposed gravels, cobbles and boulders. In turn, these support diverse epifaunas including octocorals, sponges and echinoderms with crinoids having been recorded along the southern edge of the Faroe Plateau (Bett 2003). Further detail on crinoid distribution is given in sections 3.1 and 3.2.

Howell *et al* (2010) describe additional communities within the Faroe-Shetland Channel. Sabellid worm communities with ophiuroids and white encrusting sponges can be found on substrates ranging from muddy-sands to mixed cobbles, pebbles and sand between 111 – 1027m. Cyclostome bryozoans with ophiuroids and white encrusting sponges were recorded from 549 – 820m on mixed sediments of sand, gravel, pebbles, cobbles and boulders. A further biotope found between 343 – 867m, including from within the Faroe-Shetland Channel and Wyville-Thomson Ridge (associated with coarse mixed substrates of pebble, cobble and gravel) was termed ‘Boreal-*ostur*’ and characterised by a white encrusting sponge, squat lobsters (*Munida* spp.), brachiopods, ophiuroids, serpulid worms and other various massive and encrusting sponge taxa. Full taxa lists for all the biotopes described above are provided in Howell *et al* (2010) along with other supporting references; positional data were not given.

Bett (2012) also provides descriptions of the fauna associated with ‘contourites and other deep-sand features’ known to be present in the Faroe-Shetland Channel between 800 – 1,200m. Whilst some contourites exist within the Northeast Faroe-Shetland-Channel Nature Conservation MPA in the north of the study area, others are present in the southern areas adjacent to the Faroe-Shetland Sponge Belt Nature Conservation MPA and north of the Wyville-Thomson Ridge SAC. These sandy habitats are recorded as supporting unusual communities of surface-dwelling acorn worms, abundant populations of stalked sponges and very abundant populations of sabellid worms; burrows are also apparent in the seabed images available (Bett 2003). Barchan sand dunes are recorded between the southern deep gravel area and an area of contourites to the north of the Wyville-Thomson Ridge SAC (see Figure 37 in Bett (2012)). These areas are known to support an abundance of seapens and anemones; Bett (2012) notes that these habitats are of limited occurrence, relatively poorly understood and may therefore warrant a degree of conservation protection. Further detail on seapen distribution and reference to figures showing their known distribution is given in sections 3.3 and 3.4.

Howell *et al* (2010) recorded communities characterised by dense *Lanice* beds or Edwardsid anemones at depths to 951m and 899m respectively in sandy substrate within the Faroe-Shetland Channel. Exact location data were not provided but lists of additional taxa associated with the communities are provided.

Deep-sea mud habitats in the northeast ‘mouth’ of the North-East Faroe-Shetland Channel Nature Conservation MPA are known to include ‘burrowed muds’ as evidenced by seabed images (Bett 2003) but these are not listed as a designated PMF of the MPA. Finally, within the northern study area, Bett (2012) gives a description of the mud diapirs, noting that they support little distinct fauna. Whilst the diapirs are probably of geological interest rather than biological, more ‘exotic’ communities such as those associated with active mud volcanoes may occur since they are known to exist in Norwegian waters (Bett 2003). Where exposed rock exists within the mud structures, epifauna adapted to hard substrata can colonise and may influence the surrounding communities to some extent.

Hughes *et al* (2003) provide detail on the distribution of the families and species recorded with depth within the northern study area. They note (as for the distribution of sediment types in the area (see Section 2.1)) that the dominant influence on the ecology of the Faroe-Shetland Channel floor is the unique hydrography which causes the sediment types to range from coarse sands to sandy muds. The authors also recognise the importance of seabed temperatures on the region's ecology e.g. different polychaete species dominate in warmer *vs*. colder environments, the latter occurring below 800m. Within the deepest zone assessed (700 – 2,315m) the number of macrofaunal species recorded was significantly correlated with depth; details of depth-related changes in polychaete species patterns are provided in Hughes *et al* (2003).

The SERPENT project, "*Scientific and Environmental ROV Partnership using Existing iNdustrial Technology, is a collaboration between world leading scientific institutions and companies associated with the oil and gas industry*" (Gates *et al* 2011). The SERPENT website details the locations of the surveys and provides links to numerous project reports and publications although at present, none specifically address habitat and community / species distribution patterns[11]. Cruise reports for five ROV surveys undertaken in 2009 and 2010 provide information on some of the taxa and habitats observed within the study area, which correspond to those already described above (Gates *et al* 2011). The relevant sites are all in the Faroe-Shetland Channel and are: Rosebank North 1, Rosebank 5, South Uist, Tornado and Lagavulin.

OSPAR data for Threatened and Declining Habitats and Species, available through EMODnet cite a number of records for deep-sea sponge aggregations (OSPAR 2010a) within the northern study area at the southwestern end of the Faroe-Shetland Channel. The records are cited as 'uncertain' which might only mean that the positional accuracy is in doubt, rather than the presence of the feature itself (EMODnet 2018). No other OSPAR data overlap with the northern study area.

Western Study Area

As stated previously, several large bathymetric features characterise the western study area within SEA7, these are: the Rockall Trough, the Rockall Bank, the George Bligh Bank the Wyville Thomson Ridge, the Anton Dohrn, Rosemary Bank and the Hebrides Terrace seamounts and the continental slope. These large geological features contain a number of different benthic habitats and communities already described in site summary documents for existing MPAs (Table 1).

Biodiversity of deep-sea sedimentary habitats in the western study area varies between the continental slope and the floor of the Rockall Trough. Davies *et al* (2006) provide a synthesis of the knowledge of the biological communities inhabiting these areas and the broad-scale and local-level patterns that are known to exist, based on data between the 1970s and 2005. Compared with other deep-sea regions, the western study area is relatively well-understood with much research being driven by industries interested in commercial exploitation of fisheries and hydrocarbons as well as smaller studies by academic research institutions and minor industry players (Davies *et al* 2006).

Davies *et al* (2006) state that "*the north-east Atlantic Ocean falls mainly within a biogeographic region described as the Atlantic Deep-Sea Province (ADSP), which has relatively homogenous oceanic conditions*" (particularly when compared with the northern study area). The megafaunal communities in the study area are representative of the wider regional north-east Atlantic Ocean and similar to those observed within the nearby Porcupine Seabight and Porcupine Abyssal Plain (Davies *et al* 2006). Davies *et al* (2006) cite reports that demonstrate how deep-sea megafaunal communities within the study area exhibit "*strong linear decreases in abundance and biomass with increasing water depth*" with

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[11] The SERPENT Project website: http://www.serpentproject.com/

maximum diversity usually occurring between 1,800 – 2,300m depending on taxonomic group.

The relatively homogenous conditions of the western study area compared with the Faroe-Shetland Channel result in predictable, broad-scale distribution patterns of megafaunal species with depth. Some overlap evidently occurs and variation is dependent on local conditions and individual species tolerances Davies *et al* (2006). The authors state that the most likely factors which "*may affect local species composition are topographically-influenced hydrodynamic processes that can alter currents, re-suspend sediment and organic matter and change sedimentary processes*" (Davies *et al* 2006). In brief, the communities within various depth bands are described in Table 4. Further descriptions of depth-related community changes are given in Gage *et al* (2000).

Table 4: Broad deep-sea sedimentary community descriptions within the SEA7 area, after Davies *et al* (2006).

Depth band (m)	Community description
800 – 1,000	Communities may be characterised by burrowed muds and include ophiuroids, anemones and cut-throat eels.
1,000 – 1,400	Communities can be characterised by the hexactinellid sponge *Pheronema carpenteri* which is often restricted to this depth band and can overlap with high abundances of the ophiuroid *Ophiocten gracilis.*
1,000 – 1,400	In areas with high surface productivity and particle flux, multinucleate xenophyophores may also occur.
1,500 – >2,000	High abundances of the octocoral *Acanella arbuscula* and ophiuroids

Xenophyophores mentioned in Table 4 are large protozoans (single-celled organisms) found exclusively within or on deep-sea sediments and rock surfaces. Their large, elaborate tests (skins) can be in excess of 25cm across and are created by agglutinating sediments. Within the study area xenophyophores can be a major component of the benthic community, with some species such as *Reticulammina* sp. attaining densities of several thousand 100m^{-2} (Davies *et al* 2006). Howell *et al* (2014) also report xenophyophore fields associated with sand, gravel and mixed substrates from the East Rockall Bank between depths of ~860 – 1,440m. Narayanaswamy *et al* (2013) recorded xenophyophores during a survey of the George Bligh Bank. Providing habitat for fauna such as bryozoans, anemones, crustaceans, meiofauna and Foraminifera means that xenophyophores can increase biodiversity on a local scale (Hughes (2004) cited in Davies *et al* 2006; Howell *et al* 2014).

During the 2005 SEA7 surveys to depths ~1,330m, habitats of muddy and coarse substrata were recorded from the George Bligh Bank (north of the East Rockall Bank SAC) (Narayanaswamy *et al* 2013). Community composition was reported as similar to that recorded elsewhere in the deep northeast Atlantic and included seapens in coarse sediments, cerianthid anemones, hexactinellid sponges, corals, xenophyophores, crinoids, holothurians, crustaceans, eels, bony fish, rays and sharks. Complete taxa lists for each transect are provided by the authors. Further detail on the known distribution of crinoids is given in sections 3.1 and 3.2. The Deeplinks project conducted video transects over areas of the George Bligh Bank in 2016 and recorded similar taxa to those listed above and coarse sediment habitats among bedrock, boulders and coral rubble (see Howell *et al* 2016, for specific taxa).

On the Rockall Bank, Howell *et al* (2014) reported various soft-sediment biotopes, many matching the descriptions given for the SEA7 area by Davies *et al* (2006). Aggregations of the xenophyophores were reported from sands and muds containing cerianthid and halcampoid / Edwardsid anemones, crustaceans between ~860 – 1,440m depth. In the same depth band, a community characterised by sponges, corals and ascidians on mixed substrates as well as boulders and ledges was recorded. Howell *et al* (2014) provide a full list (with descriptions) of 29 biotopes determined during the JC060 MAREMAP surveys including those associated with sedimentary habitats for the North-West Rockall Bank SAC, the East Rockall Bank SAC, Darwin Mounds SAC and beyond, into the the Hatton-Rockall Basin, the latter being outside existing MPAs and outside the present study area. The survey was the first dedicated habitat mapping exercise of the MAREMAP initiative and further work will generate more knowledge of the diversity of such habitats.

Davies *et al* (2006) give descriptions of survey stations along the Hebridean Slope. Stations situated at 885m or shallower contained mainly *Ophiocten gracilis*, whilst the dominant taxa on fine sediments at ~1,300m were the octocoral *Acanella arbuscula*, pennatulids (sea pens) such as *Kophobelemnon stelliferum* and hexactinellid sponges such as *Hyalonema* sp. At depths of ~1300m, active bioturbation of sediments was observed by echiuran (acorn) worms and additionally burrows were visible (potentially from squat lobster species), as were glass sponges. At depths ~2,000m communities comprised octocorals such as *Acanella arbuscula* and ophiuroids such as *Ophiomusium lymani*. Gage (1986) also describes echinoderms, particularly *O. gracilis* as dominating the benthic fauna throughout the Rockall Trough.

Hughes (2014) and Hughes *et al* (2014) examined still images of megafaunal communities taken from surveys during 1988-1998 along the Hebridean Slope. They provide a schematic of the lower, mid and upper bathyal zones and the associated biological communities that were identified. The survey areas in the north and the south included sites presently outwith any designated MPAs but within the present study area.

The images analysed by Hughes (2014) confirmed the presence of the brittlestar *Ophiocten gracilis* at high densities between 600m and ~1,000m. Ophiuroid assemblages are distinct communities occurring within rippled sandy seabed throughout the Rockall Trough (Gage 1986; Howell *et al* 2010). Within this depth band the northern survey sites had some stations with a noticeable gravel fraction which supported a sparse mobile epifauna of urchins, small hermit crabs and squat lobsters with sessile epifauna including cerianthid anemones, and brachiopods on cobbles and boulders. The same depth band at the southern survey sites supported high densities of cerianthid anemones, urchins, holothurians, sea stars, hermit crabs and neogastropods, as well as fish including the eel *Synaphobranchus kaupii*, halibut, morids, alfonsinos and small grenadiers.

Xenophyophores were recorded by Hughes (2014) over rippled sands at the northern survey sites between 1,000 – 1,100m with lower numbers at the southern sites; these zones supported hermit crabs, sea cucumbers, urchins, eels, rays and chimaeras. Burrowed muds (also an OSPAR Threatened and Declining Habitat) were recorded from ~1,300 – 1,600m at both the northern and southern survey sites (see GeMS data in Figure 6, Appendix 1), with the burrows attributed to squat lobsters. Feeding signs of acorn worms and sea stars were also recorded as well as sparse records of sea cucumbers, sea stars, stalked sponges and further xenophyophores. Fish including eels, grenadiers and big-eye rocklings were present at these depths. Bioturbated sediments on the floor of the Rockall Trough at ~2,060m supported further brittlestar and octocoral species as well as acorn worms, sea cucumbers, sea pens, anemones and grenadiers (Hughes 2014; Hughes *et al* 2014).

Sedimentary habitats can also support *Lophelia pertusa* reefs in some locations. Davies *et al* (2006) and Howell *et al* (2014) give descriptions of such associations of *L. pertusa* with sand and gravel habitats among the Darwin Mounds (where they are closely associated with xenophyophores) and mud mounds. Although locations of the latter were outwith the study area, their presence within it cannot be discounted. Davies and Guinotte (2011) predicted that *Lophelia pertusa* reefs are quite likely to occur throughout the wider continental slope ecosystem but without detailed survey data the task of quantifying the presence of these habitats is confounded.

Deep sedimentary habitats are also known to support sponge communities. The sedimentary habitats to the west of the Rosemary Bank Seamount support sponges at depths >1,500m (ICES 2013, 2015). OSPAR data for Threatened and Declining Habitats and Species within the western study area are available through EMODnet. Surveys undertaken between 1995 and 1999 in the Rockall Trough recorded "*soft bottom bamboo coral gardens*", a habitat identified as part of the OSPAR classification "coral gardens" (OSPAR 2010b). In the Rockall Trough the dominant corals are the bamboo corals *Acanella normani* and *A. arbuscula* with 25 records at essentially four locations within the study area (Figure 12, Appendix 1), occurring at depths greater than 1,200m on Atlantic mid bathyal and lower bathyal burrowed mud (OSPAR 2010b).

Davies *et al* (2006) (and references therein) describe deep-sea, sedimentary macrofaunal communities in the northeast Atlantic as being composed of "*polychaetes (bristle worms), small-bodied peracarid crustacean orders such as Cumacea, Tanaidacea, Amphipoda and Isopoda, molluscs such as Gastropoda, Bivalvia, and Scaphopoda and other worm groups such as the Nemertea, Sipuncula, Pogonophora, Priapulida, Echiura and Enteropneusta. Other fauna, which are not large enough to constitute the megafauna and are described as the macrofauna are species of Porifera, pycnogonids, brachiopods, epifaunal entoprocts, ophiuroids, porcellanasterid asteroids, apodous holothurians and small tunicates*".

The Benthic Boundary Layer Experiment (BENBO, funded by the UK Natural Environment Research Council) found that on a broad scale, macrofaunal communities are polychaete-dominated accounting for ~55-58% of the abundance and 57-79% of biomass. A study of benthic polychaetes (Paterson & Lambshead 1995, cited in Davies *et al* (2006) on the Hebridean Slope observed the peak in polychaete diversity to occur at ~1,500m before declining toward the floor of the Rockall Trough. Following polychaetes, peracarid crustaceans, bivalves and small bryozoans are most abundant. The majority of polychaete species are infaunal, living within the sediment, but some species live on the surface and feed within the sediment:water interface (Davies *et al* 2006).

Davies *et al* (2006) describe the Nematoda (roundworms) as most abundant within deep-sea, sedimentary metazoan (multi-celled) meiofaunal communities in the northeast Atlantic, accounting for 89-95% of the meiofauna. Other less abundant phyla include the Harpacticoida (copepods), the Ostracoda (seed or mussel shrimp) and the rarer Kinorhyncha (spiny crown worms), Tardigrada (water bears) and Loricifera (brush heads). Single-celled foraminiferans are an often-overlooked component of the meiofauna and can account for up to 50% of all meiofauna retrieved in samples from the north-east Atlantic. The meiofaunal communities of the western study area are generally representative of the wider north-east Atlantic (Davies *et al* 2006).

Deep-sea biotopes

The sections above outline the general knowledge about the biodiversity of deep-sea sedimentary habitats within the SEA7 and SEA4 regions of the study area. A list with community definitions of deep-sea biotopes identified in UK EEZ waters is available in the deep-sea section of the Marine Habitat Classification of Britain and Ireland (Parry *et al* 2015), the hierarchy for which can be viewed at http://jncc.defra.gov.uk/marine/biotopes/hierarchy.aspx.

At the time of writing core records for the deep-sea, sedimentary biotopes were not publicly available through the Marine Recorder database. Biotope assignations for, and descriptions of the sedimentary habitats and communities known to occur within each MPA in the study area are available in the multiple site and survey reports in the evidence sections of the JNCC's Offshore MPA Site Information Centres (JNCC 2018l).

Vulnerable Marine Ecosystems and OSPAR Habitats

The International Council for Exploration of the Seas (ICES) and the North Atlantic Fisheries Organisation (NAFO) operate a joint expert Working Group on Deep-water Ecology (WGDEC). Amongst other tasks, the group's more recent annual reports (ICES 2011-2017b) summarise new information on the known distribution of Vulnerable Marine Ecosystems (VMEs) within the North Atlantic and give details of the various surveys undertaken; these are summarised in Table 5. The ICES WGDEC reports also give details of new VME records on hard substrata within the study area and within existing MPAs although these are beyond the scope of the present study and not cited here. VME indicator species and communities can form hotspots of biodiversity on the deep-sea floor as the organisms themselves and sediments immediately around them often support an increased faunal diversity and abundance (Danovaro *et al* 2009; Davies *et al* 2006). Many of the ICES VME definitions overlap with the 'OSPAR list of Threatened and Declining Species and Habitats'. Further details of the biology and distribution of the OSPAR species and communities that can be associated with deep-sea sedimentary habitats such as '*Lophelia pertusa* reefs', 'coral gardens', 'deep-sea sponge aggregations' and 'seapens and burrowing megafaunal communities' are provided in OSPAR background documents (OSPAR 2009, 2010a, 2010, 2010c).

Table 5: Surveys reported within ICES' annual WGDEC reports detecting VME communities and indicator species likely to be in sedimentary habitats within the study area (ICES 2011, 2012, 2013, 2014, 2015, 2016, 2017).

WGDEC Report	Location	Survey	VMEs recorded
2017	>1,000m adjacent to the Ymir Ridge	Marine Scotland anglerfish survey #0416S	Gorgonian coral, seapen, sponges
2017	900-1,000m, Faroe-Shetland Channel	Marine Scotland MOREDEEP survey #1316S	Sponge and soft coral species
2016	>1,000m along the Hebridean Slope and between the Hebridean Slope and Rosemary Bank Seamount	Marine Scotland deep water slope survey #12155, September 2015	Cup corals, gorgonian corals, black corals, seapens and sponges
2015	900-1,000m, southern Faroe-Shetland Channel	Marine Scotland Science survey #1314S	Seapens, sponges and soft corals
2011-2014	WGDEC reports for 2011-2014 did not report new records of VMEs in deep-sea sedimentary habitats within the study area. WGDEC reports were not consulted prior to 2011 because new records were not reported within the UK EEZ prior to this time.		

2.2.2 Ecological functions and services

Much of the continental slope habitat and deep-sea floor throughout the study area consists of muds, sands and gravels (see section 2.1); such sediments contain numerous infaunal species with occasional hotspots of biodiversity (see section 2.2.1). Deep-sea habitats and their associated species cover ~65% of the global seafloor and have a number of ecological functions which provide ecosystem services and processes of benefit to humans (Fletcher *et* *al* 2011; Thurber *et al* 2014). Throughout the deep sea the biological, physical, and chemical properties of the ecosystem operate in combination, forming complex processes that result in globally important ecosystem services (ICES 2015). Although our understanding of many of these ecosystem functions remains relatively limited, recent research projects and reports have sought to identify the various supporting, provisioning, regulating and cultural services provided by deep-sea habitats and species (HERMES 2016; Danovaro *et al* 2009; Freiwald *et al* 2004; OSPAR 2009, 2010a-c; Thurber *et al* 2014).

Balmford *et al* (2008) identified three categories of ecosystem goods and services, which were adapted by Fletcher *et al* (2011) to make them applicable to the marine environment. The three key categories can be summarised as:

- **Core ecosystem processes -** basic ecosystem processes supporting ecological functions including:
    - production,
    - biogeochemical cycling,
    - ocean ventilation and convection,
    - atmospheric and ecological teleconnections,
    - sedimentary regimes.

- **Beneficial ecosystem processes -** specific ecological processes that directly underpin benefits to people including:
    - physical habitats for species,
    - food web dynamics,
    - speciation and genetic variation,
    - larval supply and species dispersal.

- **Beneficial ecosystem services -** products of ecosystem processes that directly impact human wellbeing including:
    - fisheries,
    - natural products,
    - research, knowledge and education,
    - recreation and culture.

Several of the processes above can be related to deep-sea sedimentary habitats and their associated communities. The following sections summarise the key services and processes outlined in the studies cited above which can be consulted directly for further detail.

Core ecosystem processes

Primary production from sunlight does not occur within the sedimentary habitats under review here. However, primary production is possible within the microbial communities inhabiting deep-sea sediments. Understanding of the microbial ecology of the deep-sea sediments remains limited but they are considered to support the largest fractions of bacteria, Archaea and viruses on Earth with a potentially high diversity. Data on **chemoautotrophic production** rates in deep-sea sediments is very limited; however, the overall contribution of chemosynthetic primary production in deep-sea ecosystems could be much higher than previously thought (Corinaldesi 2015).

Microbial communities can also play a role in the **cycling and retention mechanisms** of carbon, nitrogen, silica, sulphur, phosphorous and methane in the deep sea although the species responsible have yet to be identified (Danovaro *et al* 2008; Thurber *et al* 2014; Corinaldesi 2015). Coldwater corals at 600m on the Rockall Bank have been shown to make a significant contribution toward processing organic carbon (ICES 2015) so it is possible that those found below 800m within the study area will carry out similar functions. Even viruses can exert a significant influence on food webs and consequently the flux of carbon and energy through the deep-sea ecosystem (Brandt 2008).

Suspension feeders such as sponges extract food from the water and expel it as pseudofaeces which is then available to benthic feeders; this process enhances **biogeochemical cycling** and likely plays a role in **climate regulation** by extracting carbon from the water column and eventually transferring it to the sediments (Fletcher *et al* 2011). Current estimates are that the deep sea worldwide has already absorbed a quarter of all the carbon released by human activity (Thurber *et al* 2014).

OSPAR (2010c) gives an overview of 'seapen and burrowing megafauna' communities and separates them from coral gardens on the basis that the associated burrowing megafauna create a more complex habitat. It is noted that the burrowing megafauna are key to the designation of this habitat type owing to their function of oxygenating the bed sediments. **Bioturbation** by both megafauna and macrofauna mixes sediments vertically and can create micro-scale currents across and within the seafloor, particularly where resident organisms ventilate the burrows. These currents help to draw nutrients, oxygen and contaminants deeper and more quickly into sediments and thereby enhance waste absorption and detoxification processes (Fletcher *et al* 2011). Persistent organic pollutants, oils, micro-plastics and sewage can sometimes be removed by bioremediation, itself facilitated by bioturbation (Thurber *et al* 2014).

Where bioturbation occurs on large scales in the North Sea it has been shown to result in the burial of large quantities of fresh, organic carbon which might assist in **climate regulation**; such habitats are also important sites for **nutrient exchange** between the water column and sediments (Fletcher *et al* 2011; Thurber *et al* 2014). Seasonal plankton blooms at the surface (Billet *et al* 1983; Duineveld *et al* 2007) have been linked to the supply of organic carbon to the deep sea. Billet *et al* (2010) recorded major increases in density of the sea cucumber *Amperima rosea*, as well as community-wide increases in all size fractions from meiofauna to megafauna at the same time. These community changes were related to large-scale fluxes in organic matter to the seafloor of the Porcupine abyssal plain and would result in the processing and burial of organic carbon.

The occurrence of biodiversity hotpots within sedimentary habitats such as coral gardens and sponge aggregations can play a number of ecological roles including **secondary production** as sponges can account for a large proportion of the biomass present (Fletcher *et al* 2011). The three-dimensional structure formed by these habitats can alter near-bed **hydrodynamic regimes**, aggregate organic matter and alter sediment characteristics (Thurber *et al* 2014).

Diversity itself has been directly and positively related to efficient ecosystem functioning in a range of deep-sea habitats particularly on continental slope sediments, including those in UK waters (Danovaro *et al* 2008; Thurber *et al* 2014). Biodiversity enhances the ability of deep-sea sedimentary ecosystems to exploit primary production originating from the photic zone via the uptake and recycling of organic detritus deposited to the seafloor and channelling it to higher trophic levels (Billet *et al* 2010; Thurber *et al* 2014). A more diverse ecosystem is also more resilient and adaptable to environmental variability (Thurber *et al* 2014).

Beneficial ecosystem processes

Lophelia pertusa reefs have been reported from sedimentary habitats such as those within the Darwin Mounds SAC. Where they occur within sedimentary habitats, both sponge beds and *L. pertusa* reefs can provide **habitat** for colonisation by other species such as anemones, hydroids and bryozoans. The physical structures of these communities allow for more complex **food web dynamics** as they serve as **nursery areas** for juvenile organisms, **refuges** for prey species, and subsequently as hunting grounds for predators (Fletcher *et al* 2011; Thurber *et al* 2014) with fish abundances around cold water corals off Ireland being seven times higher than in non-coral areas (ICES 2015). The structure of the habitats allows mobile taxa such as brittlestars and anemones to gain elevation to feed in potentially higher water flows above the sediment surface (Davies *et al* 2006; Fletcher *et al* 2011; Thurber *et al* 2014; WGDEC 2015).

Buhl-Mortensen *et al* (2010) reviewed the structural attributes and biotic effects of the habitats that corals, seapens, sponges and xenophyophores offer other organisms; their importance as **substrata** increased with depth as the complexity of the surrounding habitat and food supply declined (see also section 3.3.2 with respect to seapens). Bongiorni *et al* (2010) demonstrated how living and even dead deep-sea hard corals can promote higher meiofaunal diversity in surrounding sediments along continental margins (including along the Rockall Bank), perhaps due to the increased structural complexity that they provide. The authors concluded that as the higher diversity in sediment meiofauna is associated with "*exponentially higher ecosystem functioning"* owing to the **trophic link** the meiofauna provide between the microbial and macro/megafaunal communities. In a global study, northeast Atlantic deep-sea sediments were shown to contain some of the highest nematode diversity, which was used as a proxy for overall benthic biodiversity (Danovaro *et al* 2008)[12]. The authors estimated that a loss in biodiversity could lead to exponential declines in key **deep-sea ecosystem biogeochemical processes** and even their possible collapse.

Hexactinellid sponge aggregations on open sediments have been linked to increased macrofaunal abundance and richness, particularly where they create large deposits of sponge spicules (from dead sponges) which can stabilise sediments and encourage settlement of other species (OSPAR 2010a; Fletcher *et al* 2011).

In addition to the structural attributes provided by xenophyophores they may also trap larvae passively within their tests, either creating nursery areas or concentrating prey populations and attracting predators; the increased abundance of species within xenophyophore habitats creates further opportunity for reproduction (Davies *et al* 2006). Regionally xenophyophores form an important component of the deep-sea community and have been described as one of the key benthic faunal assemblages in the SEA7 area (Lamont & Gage 2002).

Burrowed muds also provide **habitat** and contribute to **food web dynamics** as the species creating / inhabiting burrows (squat lobsters, anemones, brittlestars, shrimps, fish or worms) can be found in the stomachs of benthic-feeding fish species, some of which will be exploited by **commercial fisheries** (Fletcher *et al* 2011).

Megafaunal burrowing species can create shifting-mosaics of habitat patches with varying levels of disturbance which can influence local meiofaunal and macrofaunal **species diversity**. The species occurring in these habitats can form burrows, furrows and feeding tracks, and deposit faecal pellets; all of these features can persist over long periods in low-energy environments and offer a range of functions including **refuge, feeding, mating, nursery and social areas** (Davies *et al* 2006). Both inhabited and uninhabited burrows formed by macro and megafauna can promote microbial growth and further enhance **diversity and abundance**.

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[12] The authors provide multiple reasons for using nematodes as a proxy for benthic biodiversity and functioning based on: their high species richness; distinct and easily recognisable feeding types; life strategies (which make it easy to identify functional diversity traits); and they cite comparative studies that have linked nematode diversity to that of higher meiofaunal taxa and foraminiferan and macrofaunal diversity.

In relation to megafauna, Fletcher *et al* (2011) state that the "*deep-sea bed itself is not thought to be associated with **high species diversity** but has errant megafauna dominated by echinoderms and to a lesser extent decapods, or bottom-dwelling fish*". The authors do note however that **bacterial diversity** can be novel and can dominate sedimentary habitats; such undiscovered diversity is being exploited by biotechnology industries. The bacteria themselves also become a food source for benthic infaunal species, although Corinaldesi (2015) suggests they are not a significant food source for higher trophic levels.

Beneficial ecosystem services

Deep-sea **commercial fish stocks** are increasingly targeted owing to diminishing stocks in shallower seas (Fletcher *et al* 2011). Within the study area prior to the EU ban on fishing below 800m, black scabbardfish (*Aphanopus carbo)*, birdbeak dogfish (*Deania calceus)*, orange roughy *(Hoplostethus atlanticus)*, rabbit fish (Chimaeridae), blue ling (*Molva dypterygia*), roundnose grenadier (*Coryphaenoides rupestris)* and anglerfish (*Lophius piscatorius)* were all exploited (ICES 2017b).

With so little known about the deep-sea, opportunities for **research**, **education** and **public engagement** are huge. Deep-sea sponges are considered to contain many compounds likely to be of use in the pharmaceutical and anti-fouling industries and are collected as part of that research (OSPAR 2010a; Fletcher *et al* 2011; Thurber *et al* 2014). However, several authors note that impacts from activities such as **bottom-trawling, bioprospecting, mining or the energy sector** are so widespread that it is likely that many deep-sea habitats surveyed have already deviated from a pristine status (Roberts *et al* 2000; Bett 2003; Benn *et al* 2010; OSPAR 2010a; Hughes 2014).

2.2.3 Functional links and associations with other Priority Marine Features

'Offshore deep-sea muds' and 'offshore subtidal sands and gravels' throughout the study area have a number of known or probable associations and / or functional links with existing PMF habitats and species, as listed in Tyler-Walters *et al* (2016); these are outlined in brief below with references to further details.

Seabed habitat PMFs

- Burrowed muds – Sections 2.1 and 2.2 have outlined the known occurrences of burrowed muds within the study area; further burrowed mud habitat is likely to exist in areas where soft sediments are present. Seapen species that might occur in burrowed mud habitats include *Kophobelemnon stelliferum* and *Umbellula encrinus* as well as the tall seapen *Funiculina quadrangularis*. As outlined in section 2.2.2, burrowing megafauna associated with this habitat help to oxygenate the sediments, increase nutrient, energy and particle flux between the sediment and water interface and can enhance waste absorption and detoxification.

- Cold-water coral reefs – Although many coldwater coral reefs are associated with hard substrata, the reef-forming coral *Lophelia pertusa* has been recorded from sedimentary habitat within the study area (see section 2.2.1, Davies *et al* 2006; Howell *et al* 2014) with modelling studies also suggesting it may occur throughout the continental slope area (Davies & Guinotte 2011). Increased sediment meiofaunal diversity immediately around hard coral structures can enhance trophic interactions and contribute to food web functioning and energy flux (Bongiorni *et al* 2010).

- Coral gardens – Coral gardens are highly diverse habitats and can occur on both hard and soft substrates (OSPAR 2010b; Tyler-Walters *et al* 2016); verified records exist from the Rockall Trough (Figure 6 and Figure 12, Appendix 1). As a habitat they provide structure, secondary production, habitat, increase biodiversity and can modify near-bed currents (see section 2.2.2).

- Deep-sea sponge aggregations – Over sedimentary habitats, deep-sea sponge aggregations consist primarily of the glass sponges (Hexactinellida), with the giant sponges (Demospongia) more often associated with hard substrates. Sponges can provide structure/substrate upon which other taxa may climb or colonise and increase biodiversity. Where sponges are dense, spicules falling to the seabed from dead specimens can modify the substrate making it more suitable for colonisation by other taxa. Sponges play roles in biogeochemical cycling and can alter near-bed current regimes which, in turn may increase habitat complexity and diversity (see section 2.2.2).

Limited-mobility species PMFs

- Northern feather star, *Leptometra celtica* – A description of this species and its known presence within the study area is provided in section 3.2. It can be found in sediment, shell, gravel or bedrock habitats to depths in excess of 1,000m. It feeds on plankton and suspended organic particles thereby contributing to food webs, biogeochemical cycles and energy flux.

Mobile species PMFs

Many of the fish species listed below are commercially important species linked directly to deep-sea sedimentary habitats, which may be used as feeding, reproductive or nursery areas. Roundnose grenadiers and black scabbardfish are important pelagic predators feeding on shrimps, cephalopods and small fish such as whiting, scombrids and argentines (FAO 2018a-c; Ribeiro Santos 2013) whilst blue ling feed on benthic fish species of flatfish, gobies and rockling (FAO 2018b). The vertical feeding migrations of roundnose grenadiers and black scabbardfish may also play an important role in transferring nutrients, carbon and energy from shallow waters to benthic habitats where they become available to other organisms and processes (Roberts 2002).

- Anglerfish, *Lophius piscatorius* – Sandy and muddy substrates provide habitat for anglerfish which have been recorded to depths of at least 1,100m (Tyler-Walters *et al* 2016). Anglerfish is an important commercial species and is targeted along the continental slope and in shelf waters.

- Atlantic halibut, *Hippoglossus hippoglossus* – Atlantic halibut is classified as ‘Vulnerable’ in the northeast Atlantic and ‘Endangered’ internationally by the International Union for the Conservation of Nature (IUCN) (Munroe *et al* 2015). The species may be found to depths >2,000m in soft-bottomed habitats and is a commercially-valued species with a high market price (Monroe *et al* 2015; Fishbase 2018a).

- Black scabbardfish, *Aphanopus carbo* – The black scabbardfish is a benthopelagic species occurring between approximately 200m and >1,600m depth (FAO 2018a). A recent review of the species stated that spawning occurs around the Madeira and Canary archipelagos in the final quarter of each year with eggs, larvae and possibly juveniles then migrating toward more northern waters and sedimentary slope and seamount habitats (Farias *et al* 2013). The review recommended that further study is required to understand the habitat requirements of the species’ various life stages as few data are presently available. It is both targeted and taken as bycatch in deep-water fisheries and declined steeply in the 1990s before stabilising at a low level (Tyler-Walters *et al* 2016).

- Blue ling, *Molva dipterygia* – Blue ling are mostly found between 350 – 500m depth on muddy sediments feeding on crustaceans and fish but have been recorded to 1,000m (FAO 2018b; Fernandes *et al* 2015). The stock has been assessed by ICES as severely depleted who advise no further exploitation (Tyler-Walters *et al* 2016). The IUCN classifies the species as 'Vulnerable' in the northeast Atlantic.

- Greenland halibut, *Reinhardtius hippoglossoides* – The species is found at depths of 200 – 2,000m and feeds on benthic fish and invertebrates as well as pelagic species. Once an important commercial species, over-exploitation has led to it now being of minor importance (Tyler-Walters *et al* 2016).

- Orange roughy, *Hoplostethus atlanticus* – Orange roughy can occur between 150 – 1,800m with most recorded >1,000m. Dense shoals are associated with large topographical features such as seamounts but they can be found at lower densities over areas of flat seabed (Tyler-Walters *et al* 2016), possibly suggesting these habitats play a connecting role between otherwise isolated populations. Juvenile areas are reported to occur on the continental slope but exact depths and locations are not provided (ICES 2014b). Orange roughy have been exploited commercially but their low growth rate makes them highly susceptible to over exploitation and local / regional extinction.

- Roundnose grenadier, *Coryphaenoides rupestris* – Roundnose grenadier can be found between 180 – 2,000m in all types of deep-sea habitats, but are most commonly encountered between 1,000 – 1,500m along the continental slope (ICES 2014c). Commercial over-exploitation caused it rapid decline in the 1990s to the west of Scotland and it is classified as 'Endangered' in the northeast Atlantic by the IUCN (Cook *et al* 2015; Tyler-Walters *et al* 2016).

- Leafscale gulper shark, *Centrophorus squamosus* – This shark can be found at depths between 230 – 3,300m and often along the continental slope (Tyler-Walters *et al* 2016). It is classified as 'Endangered' in the northeast Atlantic by the IUCN (Guallart *et al* 2015). It is valued commercially as a food fish and for its liver oil. Populations have been depleted by fishing and targeted fishing and landing of bycatch is now prohibited in the EU.

- Portuguese dogfish, *Centroscymnus coelolepis* – Portuguese dogfish are found to depths of ~3,600m on the continental slope and abyssal plains. They feed on cephalopods, fish, molluscs and also cetacean carcasses, thereby playing multiple functions in the marine food web. They are classified as 'Endangered' in the northeast Atlantic by the IUCN (Dureuil & Jung 2015). Populations have been depleted by fishing and targeted fishing and landing of bycatch is now prohibited in the EU.

- Spiny dogfish / spurdog, *Squalus acanthias* – Most frequently this species is recorded from depths between 10 – 200m but they can be found at up to 900m (Tyler-Walters *et al* 2016). The species feeds on small fish and invertebrates and is highly migratory, often travelling in dense 'packs', segregated by size and sex (Ellis *et al* 2015). Spurdog do not associate with any specific habitat and is a bentho-pelagic species, thereby contributing to energy and nutrient cycling between the deep sea and shallower waters. Once an important commercial species, spurdog has been overfished and is seriously depleted; landings are prohibited in EU waters. The species is classified as

'Endangered' in the northeast Atlantic and 'Vulnerable' globally by the IUCN (Ellis *et al* 2015).

2.2.4 Resilience

A number of anthropogenic activities have the potential to influence the presence, structure and function of deep-sea sedimentary habitats and their associated communities throughout the study area. Such impacts have been the subject of various studies and reviews (e.g. Roberts *et al* 2000; Olsgard *et al* 2008; Benn *et al* 2010; Puig *et al* 2012; Lambert *et al* 2014; ICES 2016) and have been included in individual site assessments for existing MPAs within the study area. The Site Information Centres (SIC) for each of the existing offshore MPAs (available through the JNCC SIC portal, http://jncc.defra.gov.uk/page-6895) provide '*Conservation Advice*' for each MPA. This advice links to either 'Advice on Operations' specific to the PMFs within each site or links to Marine Scotland's 'Feature Assessment Sensitivity Tool (FeAST) which provides descriptions of and the evidence base for each potential pressure on PMFs (Marine Scotland 2018). In summary, the main categories of human activity or influence with potential to impact deep-sea sedimentary habitats are:

- Bottom fishing
- Oil and gas (hydrocarbon) industry expansion
- Deep-sea mining activities
- Carbon and gas storage
- Climate change

Commercial interest in the natural resources of both the SEA4 and SEA7 areas, within which the study area is situated, is dominated by fisheries, hydrocarbon exploration, waste disposal and the emerging possibilities of deep-sea mining and carbon dioxide storage (Roberts *et al* 2000; Bett 2003; Davies *et al* 2006). Of those activities, the conservation advice for existing MPAs and the numerous studies of impacts to deep-sea ecosystems often cite fishing activities as the present cause of the highest level of impact (e.g. Bett 2003; Davies *et al* 2006; Benn *et al* 2010). However, even in well-studied deep-sea areas the full and long-term effects of human activities are unknown; whilst physical disturbance can leave lasting evidence of damage, waste disposal and hydrocarbon exploitation might release contaminants over more protracted timescales (Davies *et al* 2006). Davies *et al* (2007) discuss the many impacts faced by deep-sea habitats and communities and the conservation issues they present.

The following sections outline the known and potential impacts from each of the activities listed above on the 'offshore subtidal sands and gravels' and 'offshore deep-sea muds' habitats and their associated communities. Given the known scale of impacts from bottom-fishing, more emphasis has been placed on this activity.

Fishing impacts

The acknowledged benthic impacts of bottom-towed fishing gears include:

- creation of furrows via the scraping or ploughing of doors, shoes, chains or wires on the seabed which can alter bed currents (Hughes *et al* 2003; Davies *et al* 2006);
- larger-scale flattening of the seafloor and reducing environmental heterogeneity which can play important roles in creating biological diversity (Puig 2012);
- sediment resuspension and the subsequent impact on geochemical processes as a result of nutrient and/or contaminant release (Trimmer *et al* 2005; Bradshaw *et al* 2012);

- damage or removal of non-target infaunal and / or epifaunal species thereby affecting community composition, and food web and nutrient cycling processes (Hughes *et al* 2003);
- creation of food subsidies from discards and direct mortality of species on the seabed;
- destruction / reduction of physical or biogenic habitat structure and complexity (Hughes *et al* 2003; Olsgard *et al* 2008); and
- ghost-fishing by lost gears (Bett 2003; Large *et al* 2005).

Many of the deep-sea surveys undertaken to date have recorded impacts from bottom-trawling activities throughout the study area. In 1996 in the Faroe-Shetland Channel during surveys of the potential impact from the oil industry, the '*obvious and extensive*' impact of the fishing industry was encountered in most of the large-scale surveys undertaken (Bett 2003). Specific impacts identified included detection of trawl marks, lost gears and impacts on benthic infauna (Bett 2003). Hughes (2014) stated that none of the Hebridean Slope benthic communities surveyed could be regarded as 'pristine' as they all exhibited evidence of trawl marks and the resulting damage. Benn *et al* (2010) demonstrated that throughout the northeast Atlantic, the extent of bottom-trawling activities on the seabed is "*very significant and, even on the lowest possible estimates, is an order of magnitude greater than the total extent of all the other activities*" and therefore the scale of impact to the wider ecosystem requires careful consideration. Given the extent of the observable effects of bottom-trawling throughout the continental slope off northwest Scotland and beyond (e.g. Roberts *et al* 2000; Hall-Spencer *et al* 2001; Bett 2003; Davies *et al* 2006; Howell *et al* 2016), descriptions of deep-sea sedimentary habitats may already be influenced in part by those activities (Hughes *et al* 2003).

Whilst physical effects of trawling in deep-sea habitats is detectable, the remote nature of these habitats makes detailed investigation of the subsequent community and species-level impacts harder to determine. ICES (2014d) noted that "*little information is available on the effects of trawling on deep-sea soft sediment habitats".* In a summary of bottom-trawling activities on the Irish continental slope sediments, MSFD (2013) stated that "*it is likely that adverse effects are occurring, but the impacts cannot be quantified at this time.*" Studies of the impacts of bottom-trawling within the Greater North Sea Ecoregion however can be provide an indication of the likely knock-on effects following the initial physical disturbance.

Towed fishing gears can create furrows in sediments to ~35cm deep depending on the exact specifications of the gears used; individual otter trawl doors may weigh up to one tonne, whilst large beam trawls can weigh up to seven tonnes. In low-energy mud habitats these furrows can be long-lasting and may have adverse effects on deep-burrowing infaunal species and redox conditions in the sediment (Rosenberg *et al* 2003). Through field and mesocosm experiments, Olsgard *et al* (2008) suggested that a reduction in large-bodied bioturbators caused by bottom-trawling could have a substantial impact on nutrient flux across the sediment:water interface, with knock-on effects on ecosystem function through disruption of nitrogen and silicate concentrations and disruption of food web processes. Changes in sediment relief (rugosity) caused by the furrows could also result in alterations to near-bed currents (acceleration and deceleration) with significant influence on nutrient and chemical fluxes (Rosenberg *et al* 2003). Further disruption of biogeochemical processes from nutrient and/or contaminant release can occur from the resuspension of sediments themselves (Trimmer *et al* 2005; Bradshaw *et al* 2012). A recent study of bottom trawling impacts in the southern North Sea over a clay / mud habitat concluded that in areas trawled three or more times a year the bio-geochemical cycles may remain in a permanent transient state toward recovery (van de Velde *et al* 2016).

Most deep-sea species and communities such as *Lophelia* reefs, coral gardens, sponge aggregations, sea pens and feather stars are long-lived and slow-growing and therefore vulnerable to physical disturbance from bottom-trawling (OSPAR 2009, 2010a-c; sections 3.1 and 4.1). Recovery potential is low and removal of, or damage to species can lead to shifts in benthic communities (OSPAR 2010c). There are few data on the recovery rates for large benthic organisms, but the available studies suggest that organisms such as sponges, corals and sea pens may require decades to centuries to recover from trawling (Buhl-Mortensen *et al* 2013). The proximity to adjacent areas of high diversity / biomass and local / regional tidal streams will also influence recovery rates of impacted habitats and communities (Lambert *et al* 2014).

ICES' WGDEC recently collated evidence from peer-reviewed literature, grey literature and expert judgement on the resistance and resilience of communities at Level 4 of the UK Deep-sea Habitat Classification to the effects of bottom-trawling (ICES 2016). The review covers 19 community types found on hard and soft substrata and considers megafauna and macrofaunal taxa. The fragility of many taxa is noted, particularly xenophyophores, ophiuroids, corals, Hexactinellid sponges and crinoids. Seapens may exhibit some resistance to trawls owing to their flexibility and potential to re-establish themselves if they are uprooted but evidence does not exist for deep-sea species at this time (ICES 2016).

Other impacts

Offshore oil and gas exploration has the potential to lead to relatively localised contamination or smothering of seabed sediments and species, the effects of which can last for several years (Bett 2003; Davies *et al* 2006). In their review of anthropogenic activities and impacts to the deep seafloor, Davies *et al* (2006) describe mining of deep-sea sediments as "[potentially] *devastating*" in both the long and short term for benthic communities (which provide a wide range of key ecosystem services (see section 2.2.2). The authors do not however provide any examples of specific mining threats within the SEA7 area and estimated it to be a threat of low importance at least up until 2025. Within SEA4, none of the geological structures usually associated with deep-sea mining (e.g. manganese nodules, cobalt crusts, or hydrothermal vents containing rare-earth components) are reported (Holmes *et al* 2003).

Davies *et al* (2006) provide a table outlining past, present and future impacts to the deep-sea floor from industries including hydrocarbon exploitation, dumping of waste (including munitions and radioactive waste), bio-prospecting, CO_2 sequestration and climate change amongst others, and outlines the state of knowledge regarding their likely impact and spatial influence. At the time of writing, knowledge on the impacts resulting from activities such as oil and gas exploration, food-falls from fishery bycatch, mining, CO_2 sequestration and climate change was regarded as 'poor' (Davies *et al* 2006).

Marine Scotland's FeAST database provides summary tables for each PMF detailing the pressures to which the PMF might be exposed, its sensitivity, the evidence base for the sensitivity, confidence levels in the assessments and lists of the activities that might exert each pressure on the selected PMF (Marine Scotland 2018). Much of the evidence base for the deep-sea sedimentary habitats draws on information provided in Tillin *et al* (2010), itself a sensitivity matrix for pressures exerted on different MPA receptors. In summary, the FeAST tables state that deep-sea sedimentary habitats are 'sensitive' or 'highly sensitive' to all the pressures listed though they note that the sensitivity may vary between locations depending on the biological communities present. Further work is presently underway within the JNCC to determine the sensitivities of deep-sea habitats and communities to anthropogenic impacts (A. Cornthwaite, pers. comm.).

Climate change

Changes in climate and ocean acidification might result in variable recruitment through changes in mortality rates of early life stages and/or impacts on the physical structure of many deep-sea species, particularly those with carbonate skeletons (OSPAR 2009, 2010a-c). Large-scale changes in community composition throughout the food web could lead to disruption of many of the ecosystem services and functions outlined in section 2.2.2. Relatively rapid changes in ocean conditions could leave many deep-sea species and communities with their slow growth rates and long lifespans unable to adapt quickly enough to survive (Roberts *et al* 2006; Hogg *et al* 2010).

2.3 Data limitations

The spreadsheet accompanying this report provides confidence assessments for the references cited within this report. These are based on the origin of the data and on the methods adopted to reach the conclusions given.

In the northern part of the study area, the Faroe-Shetland Channel has a relatively good distribution of seabed and community data points (compared with the western study area) allowing for a good understanding of the habitats and communities therein. The western study area has a more-patchy distribution of data, much of which remains focused around existing MPAs and / or topographical features. Within the deeper, more topographically ‘featureless’ Rockall Trough, point data are more-scarce. BGS sediment data from the extensive SEA7 surveys are concentrated within the southern part of the western study area. Figure 9 and Figure 11 illustrate the current confidence levels in the UKSeaMap2016 biozone and substrate distribution data. The white and light blue areas on the figures show where confidence is high and medium respectively. Future studies need to target deep-sea areas (presently indicated in dark blue on those figures) to provide a higher certainty in the communities likely to be present, their condition (with respect to human impacts) and the likely ecological functions they provide.

There appear to be no point data for a large majority of the deep-sea biotopes thought likely to be present throughout the study area (Figure 7 and Figure 8, Appendix 1). In theory there should be core records available for each deep-sea habitat listed in the JNCC Marine Habitat Classification Hierarchy since these have been described based on field survey data, however these core data were unavailable at the time of writing. Selection of any one of these habitat types via the JNCC full Marine Habitats Classification Hierarchy provides no information on the location of core records nor the predicted habitat extent. Rectification of this data gap will enable end-users of the classification hierarchy to understand immediately the present extent of knowledge of the distribution of deep-sea sedimentary communities.

Data on species and population distributions remain sparse for many deep-sea species and communities. Better understanding of their distributions through more surveys of sedimentary habitats will enhance our knowledge of these ecosystems, the mechanisms that connect them to one another and the scale of the ecological services / functions they provide. Studies such as that by Hughes (2014) which re-analyse historic survey images using up-to-date taxonomic knowledge can be useful in determining taxa distributions. An audit of available historic photographic data from within the study area along with the date analysed and confidence in taxonomic identification might highlight survey data worth re-visiting to enhance knowledge of likely community distributions whilst limiting further survey effort involved. However, understanding the seabed features and communities in the areas of ‘low confidence’ described above should be given higher priority due to the broadscale areas involved.

In a study undertaken to model connectivity between existing offshore MPAs, Gallego *et al* (2017) stated their study could be improved through the provision of "*better basic ecological information, enhanced oceanographic resolution, more realistic representation of biological processes (e.g. spawning, larval behaviour)… …species presence within and outside MPAs and substrate suitability maps*", thereby suggesting that these are key areas for future work.

Davies *et al* (2006) noted that at the time of writing, knowledge on the impacts on deep-sea communities resulting from activities such as oil and gas exploration, food-falls from fishery bycatch, mining, CO_2 sequestration and climate change was regarded as 'poor'. A detailed review of up-to-date knowledge with respect to these impacts along with likely risk within the study area, could highlight further research priorities.

2.4 Summary

Table 6 below summarises the information provided in section 2 on the present state of knowledge with respect to deep-sea sedimentary habitats throughout the study area.

Table 6: Summary of knowledge on distribution, diversity, ecological function and impact resilience of deep-sea sedimentary communities and data limitations.

Deep-sea muds	**Western Study Area**	**Northern Study Area**
Presence, range and distribution	Present throughout the deeper Rockall Trough and along continental slope habitats.	Mainly present in the deeper northeast section of the Faroe-Shetland Channel, becoming coarser as the channel narrows to the southwest.
Biological diversity	Macrofauna is characterised by polychaete communities whilst nematodes dominate the meiofauna. Significant megafauna includes (but not limited to) xenophyophores, sponges, ophiuroids, crustaceans, bivalves, gastropods acorn worms, octocorals, bamboo coral gardens and anemones. Seapens are known to occur on the continental slope and deep sea floor.	Characterised by polychaete communities but may also support bivalves, seapen and holothurians. Burrowed mud habitats are known to occur. Again, nematodes dominate the meiofauna.
Deep-sea sands and gravels	**Western Study Area**	**Northern Study Area**
Presence, range and distribution	Present in areas with higher energy such as around seamounts, toward and over the Wyville-Thomson Ridge and on the Hatton and George Bligh Banks. Also present along areas of the continental slope.	Present along the continental slope and as the Faroe-Shetland Channel narrows toward the Wyville-Thomson Ridge. Some patches of coarser sediment exist in northern areas.
Biological diversity	Sands and gravels can support varied communities of sponges, urchins, ophiuroids, crustaceans, anemones, holothurians, gastropods, polychaetes and xenophyophores. The coral *Lophelia pertusa* is known from coarse sediments on the Darwin Mounds.	Gravels and cobble pavements support diverse epifaunas including octocorals, sponges, crustaceans, sabellid and serpulid worms, echinoderms and crinoids. Sand dunes and contourites are known to support seapen and anemone communities.

Deep-sea muds / deep-sea sands and gravels	**All areas**
Functional significance	• Biogeochemical cycling and retention e.g. carbon and nitrogen storage • Climate regulation through carbon acquisition • Bioturbation and nutrient exchange • Contaminant and waste processing / storage • Biodiversity promotes secondary production and where three-dimensional structures are formed, can influence near-bed hydrodynamics • Diverse and complex habitats promote more complex food-web dynamics as nursery, feeding and reproductive sites become established, with knock-on benefits for commercial fishing • Bacterial diversity can be novel, with potential biotechnological applications • Sedimentary habitats support numerous commercial fish species • Provide resources for research, education and public engagement • Associated with numerous existing PMF habitats and species
Feature sensitivity / resilience	Susceptible to bottom-trawling impacts which can be long-lasting, widespread and disruptive to ecological function e.g. biogeochemical cycles. Many taxa associated with sedimentary habitats are fragile and slow-growing with long recovery times. Impacts from oil / gas exploration are often more localised but might also be long-lasting due to protracted release of contaminants. Mining activities are potentially devastating although little evidence of these occurring, or the potential for them to occur exists within the present study area. Uncontrolled bioprospecting for novel compounds can damage habitats sampled for long periods. Climate change causing relatively rapid changes in ocean conditions could leave many deep-sea species and communities, with their slow growth rates and long lifespans, unable to adapt quickly enough to survive.

2.5 Conclusions and next steps

In summary, knowledge of the distribution of deep-sea sediments and their associated communities is more complete within the northern part of the study area than within the western part. Within the latter, data are generally scarce within the deeper and / or northern areas of the Rockall Trough away from existing topographical features and MPAs.

Deep-sea muds and deep-sea sands and gravels support diverse biological communities which vary with depth, substrate, topography / current regime and temperature.

Fragile taxa such as sponges, corals, seapens, xenophyophores as well as burrowed-mud communities are likely to occur throughout the study area. These taxa provide structural complexity, and themselves enhance biodiversity, productivity and ecological functions.

The ecological roles and functions provided by deep-sea sedimentary habitats and communities are important on both a regional and global scale and include:

- Biogeochemical cycling and retention
- Climate regulation
- Bioturbation and nutrient exchange
- Contaminant and waste processing / storage
- Biodiversity promotes productivity
- Provision of nursery, feeding and reproductive areas for commercial and other fish species
- Biological diversity can be novel, with potential industrial / pharmaceutical applications
- Provide resources for research, education and public engagement
- Provide potential links between existing PMF habitats and species features

The biological communities and various physical structures that occur within deep-sea sedimentary habitats are in general long-lived, slow-growing, late-maturing and fragile. Numerous assessments of bottom-trawling impacts suggest that almost all deep-sea communities are susceptible to long-lasting damage from such activities; already few pristine examples remain. Other industries such as oil and gas exploitation can cause less widespread deleterious effects but potentially of equal duration. These human impacts have the potential to disrupt and prevent the regionally / globally important ecological functions described above.

Next steps

Further field research should be prioritised in areas currently identified on UKSeaMap2016 with low confidence with respect to the habitats present. Although situated away from present MPAs and major topographical features, data for these areas will enhance our understanding of the deep-sea environment and may continue to reveal novel habitat types and species within the study area.

Core records for each of the deep-sea biotope classifications from the JNCC Marine Habitats Classification Hierarchy along with predicted distribution patterns should be openly available to inform end-users of the available evidence pertaining to those communities.

An audit of available historic survey data may be useful in determining whether any such data sets should be re-analysed based on contemporary taxonomic knowledge, thereby providing further evidence of the potential distributions of species / habitats.

Broad-scale, regional understanding of deep-sea habitats within the study area is relatively good compared with other deep-sea areas. However, knowledge of how communities vary on a small scale is less so given the costs associated with sampling these environments. Whilst data on species or community patchiness would provide a better understanding of the magnitude and importance of the ecological processes known to occur in the deep-sea, priority should first be given to understanding the communities and habitats present in areas of low-confidence, as mentioned above.

3 Species Summaries

The following sections provide general detail on the biology and ecology of feather stars and seapens likely to occur within the study area (Figure 1). Specific information is presented on the range, distribution and conservation importance of two Priority Marine Feature (PMF) feather star and seapen species, the northern feather star (*Leptometra celtica*) and the tall seapen, (*Funiculina quadrangularis*).

3.1 Feather stars, Crinoidea

3.1.1 Biology and ecology

Crinoids or feather stars occur on a wide variety of substrates including rocky reefs and sedimentary habitats. In the latter, they live attached to pebbles, cobbles and other hard surfaces scattered across the habitat using their grasping, curved cirri (e.g. *Leptometra celtica*). Jones *et al* (2007) considered sediment particles >64mm in diameter to be suitable for colonisation by benthic megafauna including crinoids. Where crinoids inhabit soft sediments, the cirri are long and slender (e.g. *Poliometra prolixa*), while stalked species typically live with the basal end of the stalk buried in the sediment, the stalk in the case of *Conocrinus lofotensis* for example, has root-like branching appendages. Gage *et al* (1983) recorded a number of crinoid species from the Rockall Trough and adjacent areas to the south in Irish waters, with one Arctic species (*Heliometra glacialis*) being specifically mentioned as occurring "*usually on gravel with sand and mud and loose stones"* (i.e. coarse or mixed sediments). Additionally, Piechaud and Howell (2013) reported the same species "*on coarse sediment*". Gage *et al* (1984) reviewing the distribution of echinoderms in the Rockall Trough concluded that the crinoids as a group did not occur in sufficient abundance to allow a useful assessment to be made of their changing distribution with depth. Further work by Gage (1986) reported that 69,000 echinoderm specimens collected from the Rockall Trough produced 131 taxa of which only four were crinoids. The collections were heavily dominated by asteroids and ophiuroids. Both free living and stalked crinoids are capable of movement – free living species can swim or crawl across sediment using their arms (Mortensen 1927) while the stalked taxa are able to move slowly across the sediment by a looping process (Messing *et al* 1988).

Crinoids have considerable powers of regeneration with the detachment of various parts being under nervous control (Baumiller 2008; Kondo & Akasaka 2010). Direct evidence of predation on crinoids is rare but crinoid remains have been found in faeces of reef dwelling fish, while in some crinoid populations there is a high frequency of arm loss and subsequent regeneration suggesting predation. There is evidence that arm regeneration may take up to two years with concomitant reduced growth rate (Messing *et al* 2007).

Feather stars are non-selective, passive filter feeders (Southward & Campbell 2006), long arms (usually 10 or multiples thereof) are held up into the water column with the ambulacral groove running along each arm supporting rows of pinnules lined with small tube feet with sensory papillae which transport particles towards the mouth. This whole arrangement forms a very effective feeding net when held up into the water column. The crinoid will orientate this net to ensure the maximum surface area is perpendicular to the prevailing current (Baumiller 2008).

Crinoids have separate sexes (i.e. they are gonochoric) and the larvae hatch directly from the egg and do not feed (lecithotrophic). Some species brood the eggs on the pinnules (e.g. *Antedon bifida*, Nichols (1991)) while others including some of those recorded from UK deep-seas release eggs directly into the water column (Mortensen 1927). The free-swimming larvae have a relatively short life in the plankton perhaps only a few days (Gallego *et al* 2017; Kohtsuka & Nakano 2005), in some species the larva develops an attached pentacrinoid stage which may last for several months or years in the case of some Antarctic species (Duco & Roux 1981). Gage *et al* (1983) found that juvenile stages of echinoderms in the Rockall Trough were more widely distributed than adults of the same species suggesting reasonable opportunities for connectivity between sites given suitable hydrographic conditions.

Little is known of the longevity of crinoids, some may reach maturity within a year and remain reproductive for several years (Haig *et al* 2012), mostly shallow water inshore species. Roux (1976) and Duco and Roux (1981) studying the deep water stalked crinoid *Bathycrinus carpenteri* in the Norwegian Sea estimated a life span from 10 to over 20 years, with individuals reaching maturity in 3-6 years. Parker and Bowden (2010) suggested a life span of over 30 years for an Antarctic crinoid.

3.1.2 Range and distribution

Howell *et al* (2010) reported crinoids (recorded as a general group) occurring regularly on coarse sediments on the Hatton Bank, Rockall Bank and Wyville Thomson Ridge while Narayanaswamy *et al* (2013) reported a crinoid (*Koehlermetra porrecta*) at a single station on the George Bligh Bank between 800 – 900m. Many reports commissioned by the JNCC include photographs of crinoids predominantly from rocky substrates since reefs and other rocky habitats have been specifically targeted in recent surveys conducted within the study area. However, point data necessary to obtain an overview of the distribution of this group in the area were not available for this report. The only point data in the GeMS dataset for habitats including “crinoids” in the description, namely “*Xenophyophore fields, echinoids, anemones, barnacles and crinoids on sand mixed with pebbles/gravel*” and “*Solenosmilia variabilis reef framework with crinoids, encrusting sponges, antipatharians on coral rubble framework and bedrock with patches of sand*” were from the eastern slope of the Hebrides Terrace Seamount on Atlantic mid bathyal mixed sediment at 1,200 – 1,600m depth (Cross *et al* 2014).

Stewart and Davies (2007) reported stalked crinoids on medium to coarse grained sands on Hatton Bank (outside the study area), as well as scattered records for crinoids on Rosemary Bank Seamount. The following species have been reported within the study area, but it should be noted that this is not an exhaustive list:

- *Poliometra prolixa* – Faroe Shetland Channel to 1960m (Mortensen 1927).
- *Leptometra celtica* (no deep-sea point data available in the study area) is a characterising taxon of several deep-sea biotopes.
- *Heliometra glacialis* Rockall Trough (Gage *et al* 1983), Faroe Shetland Channel to 1,350m (Mortensen 1927).
- *Trichometra delicata* (Helga investigations) 700 – 2,075m (Clark 1913).
- *Orthometra hibernica* (Helga investigations) (Clark 1913).
- *Hathrometra tenella* to 1,783m (Mortensen 1927), Rockall Trough (Gage *et al* 1983).
- *Conocrinus lofotensis* Rockall Trough (Gage *et al* 1983), Faroe-Shetland Channel *(*Mortensen 1927).
- *Koehlermetra porrecta* Anton Dohrn seamount, Hatton Bank, George Bligh Bank, East Rockall Bank at depths >1,000m (Henry & Roberts 2014).
- *Pentametrocrinus atlanticus* (Cross *et al* 2014).
- *Thaumatocrinus jungerseni* characterising species of a deep-sea biotope at depths of over 3,500m (Hughes & Gage 2004).
- *Bathycrinus carpenteri* Faroe-Shetland Channel 1,567m (Gates *et al* 2011),

Being passive feeders feather stars depend on water movement to deliver food particles to them, as a consequence, relatively high densities (up to 3-6m^2) are often found where water movement is accelerated around deep-water headlands, gullies and canyons (Howell *et al* 2007). Feather stars occur at much reduced densities on coarse sediments or on drop stones in soft sediment in locations with lower current speeds. Jones *et al* (2007) recorded comatulid crinoids representing just 2.7% of the echinoderm fauna in the cold (<0ºC) waters of the Faroe Shetland Channel at densities of up to 60ha^{-1}, while stalked crinoids (*Conocrinus lofotensis*) were less abundant (17ha^{-1}) in water depths of over 1,000m. Howell *et al* (2007) identified crinoids as being a characterising taxon for a benthic community occurring on coarse sediment with cobbles in the cold waters of the Faroe Shetland Channel, a community distinct from those of the warmer waters of the Rockall Trough to the southwest of the Wyville Thomson Ridge. Where crinoids occur on sandy substrates there is usually physical evidence for strong currents (sediment ripples and dunes for example). Davies *et al* (2015) identified a benthic assemblage characterised by a crinoid together with other taxa on a high energy mixed substrate on the Anton Dohrn Seamount.

A biotope characterised by the crinoid *Thaumatocrinus jungerseni* occurs on Atlantic mid abyssal mud recorded by Hughes and Gage (2004) from a single location in the Rockall Trough at 3,580m on fine silt or pelagic ooze.

3.1.3 Conservation Status

Crinoids as a general group do not have any special conservation status within the study area apart from *Leptometra celtica*. They are however included either as characterising taxa for some deep-sea biotopes (Table 8, Appendix 2) or are specifically listed as occurring within them.

3.2 Northern feather star, *Leptometra celtica*

The Northern Feather Star (*Leptometra celtica*) is a comatulid crinoid occurring on coarse sediments as well as rocky reefs in water depths ranging from <20m to over 1,000m in the study area (Mortensen 1927; Southward & Campbell 2006). Gage *et al* (1984) considered depths >1,200m to be too great for this species but it could be commonly found in shallower offshore waters. Howell *et al* (2014) working in the Hatton-Rockall Basin, north-west Rockall Bank, East Rockall Bank and Darwin mounds did not record *L. celtica* at any sites. During the present review, no georeferenced positional records of *L. celtica* were found within the study area.

Howell *et al* (2010) identified 31 epibenthic assemblages from the upper bathyal regions of the Rockall Trough, Wyville Thomson Ridge and eastern Faroe-Shetland Channel (200-1,000m). Of these assemblages four included *L. celtica* either as a characterising species (one case), or it was present in the typical taxon list for the assemblage (three cases) (Table 7). The record from shallower depths in the South-West Canyons has been included here since there are very few data on the *Leptometra* biotopes. This record gives an indication of the potential for the species to occur at depths >800m on the continental slope. Presently there are few data to support its occurrence as a biotope forming taxon at greater depths.

Table 7: The occurrence of *Leptometra celtica* in upper bathyal sedimentary epibenthic assemblages (from Howell *at al* 2010).

Assemblage name	Characterising species	Substrate	Temp ºC	Depth (m)	Location
Crinoid (*Leptometra celtica*) communities at the shelf edge.	Crinoids including *L celtica*	Mix of sand pebbles-shell	9-12	190-699	South-West Canyons
Munida and Caryophyllids on mixed substrates RBB	*Munida* sp. *L. celtica*	Mix of sand, pebbles and cobbles	8-12	185-825	South-West Canyons, Hatton Bank, Rosemary Bank Seamount
Ophiactis balli and *Munida rugosa* on mixed substrate	Various	Mix of sand, gravel, pebbles, cobbles and boulders	-1 to 12	180-1,054	South-West Canyons, Rosemary Bank Seamount, Faroe-Shetland Channel, Wyville Thomson Ridge
Communities of amphiurid ophiuroids	Various	Fine mud and sand with small percentage of gravel and pebbles	7-12	252-1,008	South-West Canyons
Ophiuroids on rippled sediment	Various	Sand and mud substrates with small percentage of gravel and pebbles	-1 to 12	205-1,021	South-West Canyons Hatton Bank, Rosemary Bank Seamount (5 records from Faroe-Shetland Channel)

Publications which refer to the ecology of *Leptometra celtica* indicate that in the northeast Atlantic it occurs typically in continental slope habitats with mixed sediments of gravel, pebbles and cobbles where there are elevated currents. No ecological studies reporting its occurrence at depths greater than 570m were found in the course of this review. Cranmer *et al* (1984) reported the species from the continental slope of the Norwegian Trench (200m) at densities of 65ha^{-1}, and *L. celtica* was considered to be characteristic of the shelf break on the southwest Irish coast at about 200m (Lavaleye *et al* 2002), Sánchez *et al* (2009) recorded densities of the species of 12ha^{-1} on the Le Danois Bank where it occurred only on rocky habitats at depths of 546 – 570m. Fonseca *et al* (2014) reported a dense population of *L. celtica* at depths of 400 – 450m off the south coast of Portugal, where individuals occurred at densities of >10m^{-2} on a gravelly sand substrate, while Jesus *et al* (1999) recorded the species occurring on sand and sandy mud on the southwest Portuguese continental slope at 125 – 375m. This evidence would suggest that *L. celtica* is most likely to occur on the continental slope on coarse sediments at depths shallower than 800m where there are elevated currents in water temperatures greater than about 8ºC (i.e. in the Atlantic biozone). More detailed survey work is required to understand the full distribution of *L. celtica* in the study area at depths greater than 800m.

Gallego *et al* (2017) reviewing the connectivity of a range of Scottish Priority Marine Features, did not include *L. celtica* in their analysis of offshore MPAs since records for this species were not available from deep sea, offshore sites. This is inconsistent with *L. celtica* being identified as a characterising taxon for biotopes in deep water (Table 8, Appendix 2). Considering the reproductive biology of this species, Gallego *et al* (2017) identified a settlement window for larvae of between 1-10 days based on evidence for other comatulid crinoids. Given this short larval period in the plankton it was concluded that the species has poor dispersal powers. These authors reported no information for spawning season.

3.2.1 Conservation Status

Leptometra celtica is listed as a Scottish Priority Marine Feature and is a characterising taxon for a number of deep-sea biotopes (Table 8, Appendix 2).

3.2.2 Range and distribution

Leptometra celtica is widely distributed in water depths <800m off the Scottish coast but no point data for this species were found within the study area. Parry *et al* (2015) defined a *L. celtica* assemblage occurring at depths of 200 – 700m and the species is listed by Piechaud and Howell (2013) from photographic transects collected at a number of deep-sea survey sites as part of a study to define deep-sea biotopes but with no detail as to precise location or depth. Gallego and co-authors (Gallego *et al* 2013, 2017) found no records from deep water within the present study area.

3.2.3 Confidence in survey data

Georeferenced records for *Leptometra celtica* within the study area were not located. However, the species does occur within the study area and is listed as a characterising taxon for a number of biotopes reported within the study area, so it must be assumed that the species is known to occur widely here. The biotopes in which this species features are listed in Table 8, Appendix 2.

3.3 Seapens, Pennatulacea

3.3.1 Biology and Ecology

Seapens typically occur in sedimentary habitats and are passive, non-selective filter feeders taking particulate organic matter and small invertebrates (Sherwood *et al* 2008). Tyler *et al* (1995) studying *Umbellula lindahli* demonstrated that the tentacles were held in such a way as to maximise the area presented to the current, a behaviour likely in other species. There is a marked seasonality in the flux of organic particles to the deep-sea (Billett *et al* 1983; Duineveld *et al* 2007) with the food quality of the detritus decreasing with increasing depth. This seasonality of food supply to the deep-sea has consequences for the timing of reproductive development in seapens discussed further below. Flach *et al* (1998) working on the Goban Spur south of the Porcupine Seabight demonstrated a correlation between density of suspension feeders and high current velocities (~35cms^{-1}), by contrast deposit feeders predominated at sites with lower current speeds (<10cms^{-1}). This relationship between current velocity and particle supply may be helpful in predicting potentially suitable sedimentary habitats for seapens given information on the hydrography of the study area.

The seapen species occurring in the study area are all gonochoric (i.e. sexes are separate) with a sex ratio of roughly 1:1, for example *Kophobelemnon stelliferum* (Rice *et al* 1992). They are broadcast spawners (Kahng *et al* 2011; Watling *et al* 2011), with the relatively large size of the buoyant oocytes, indicating lecithotrophic (non-feeding) larval development. Sperm is typically ejected in buoyant cysts thus effectively preventing sperm dilution (Eckelbarger *et al* 1998). Breeding cycles in deep-sea seapens have been studied in detail in the northwest Atlantic (Baillon *et al* 2014b; Baillon *et al* 2014c; Eckelbarger *et al* 1998; Neves *et al* 2015; Pires *et al* 2009). Seasonal spawning was demonstrated in these populations with the timing being related to the spring plankton bloom and the chlorophyll *a* maximum (Baillon *et al* 2014b), a situation likely to pertain in the study area, where the seasonal availability of particles to the deep-sea has been studied by Billett *et al* (1983) and Duineveld *et al* (2007). In the study area, it is likely that female seapens typically contain several size classes of oocysts; however, it should be noted that Baillon *et al* (2014b) argued that this might not necessarily imply continuous spawning since oocyte development might take more than one year. It should be noted that a number of other studies have concluded that seapens do not show seasonal spawning based on the presence of a series of oocyte developmental stages in any one specimen (Eckelbarger *et al* 1998; Pires *et al* 2009; Rice *et al* 1992).

Size at first reproduction and longevity have been studied in northwest Atlantic populations of seapens. Eckelbarger *et al* (1998) reported that individuals of *Pennatula aculeata* >7cm in length showed signs of spawning, while Baillon *et al* (2014b) reported colonies of *Anthoptilum grandiflorum* <24cm tall were infertile, suggesting it would take several years for colonies to reach this size. Neves *et al* (2015) determined that *Halipteris finmarchica* took four years to reach sexual maturity at 18cm and lived for over 40 years. Murillo *et al* (2018) working on *A. grandiflorum* estimated a life span of 5-28 years and 2-21 years for *Pennatula aculeata*, with some colonies potentially being as much as 63 years old. These authors noted that the distribution of colony size suggested patchy recruitment possibly on a decadal scale.

3.3.2 Range and Distribution

Pennatulacea or seapens typically occur in soft, unconsolidated, usually muddy, deep-sea sediments (Williams 2011), where in areas with high current velocities, they may reach relatively high densities, up to 8 m^{-2} in *Pennatula aculeata* (Langton *et al* 1990). In the northwest Atlantic a number of seapen species including *Anthoptilum grandiflorum,* *Halipteris finmarchica, Pennatula* spp. and *Funiculina quadrangularis* have been reported to occur at high densities, providing a focal point for colonisation by a range of other taxa including commercially important juvenile fish (Baillon *et al* 2014a; Baillon *et al* 2012). Rice *et al* (1992) reported *Kophobelemnon stelliferum* occurring at up to 2m^{-2} in the Porcupine Seabight at relatively shallow depths (400m), with the largest individuals confined to the deepest sites, the species was found to be rare below 1,000m. In the northeast Atlantic De Clippele *et al* (2015) working on the Norwegian continental margin showed that seapens including *Kophobelemnon stelliferum* and *Funiculina quadrangularis* were frequently associated with shrimps and ophiuroids playing a key role by providing shelter and / or a feeding platform for these taxa. These authors concluded that seapens played an important role as a habitat in this deep-sea environment.

Seapens are widely distributed in sedimentary habitats within the study area, for example Durán Muñoz *et al* (2012) recorded seapens in 90% of trawl samples from the Hatton Bank though density varied. Gage (1986) reported that pennatulids were common in both trawls and seabed photographs from the Feni Ridge, Anton Dohrn Seamount and the Hebridean Slope. There are numerous *ad hoc* references to seapens in many reports commissioned by the JNCC covering the study area but detailed information on location is not generally available. In a report describing Scottish Priority Marine Features, Tyler-Walters *et al* (2016) recorded the Tall Seapen (*Funiculina quadrangularis)* at two localities within the study area, with a maximum reported depth of 2,000m. However, ICES Vulnerable Marine Ecosystems (VME) data show a much wider distribution in deep-water for this species (Figure 13, Appendix 1), although most records were from depths of less than 800m. These authors also report other seapen taxa occurring in deep-water examples of the "Burrowed Mud" biotope, including *Kophobelemnon stelliferum and Umbellula encrinus.* Wienberg *et al* (2008) reported a species of *Pennatula* as "*frequent*" on soft sediment on the western Rockall Bank in water depths of about 650m.

Many of the seapen species recorded in the study area have a very wide global distribution e.g. *F. quadrangularis, A. grandiflorum, Umbellula lindahli* (Williams 2011). Seapen species reported from the area include the following (note this is not an exhaustive list):

- *Anthoptilum grandiflorum*
- *Anthoptilum murrayi*
- *Funiculina quadrangularis*
- *Halipteris finmarchica*
- *Kophobelemnon macrospinosum*
- *Kophobelemnon stelliferum*
- *Pennatula grandis*
- *Pennatula aculeata*
- *Pennatula phosphorea*
- *Scleroptilum*
- *Umbellula huxleyi*
- *Umbellula thomsoni*

Seapens have been used to characterise some deep-sea assemblages and biotopes: Henry and Roberts (2014) include seapens in their definition of Coral Gardens in UK waters, as follows: "*A relatively dense seabed aggregation of at least one coral taxon (Alcyonacea, Pennatulacea, Antipatharia, Stylasteridae, Scleractinia) wherein the density of non-reef forming coral taxa exceeds that of reef-forming Scleractinia…. Coral Gardens taxa should characterise the assemblage and occur in densities that clearly exceed that found in adjacent habitats."* Of the five Coral Garden sub-habitats, Henry and Roberts (2014) identified one which included Pennatulacea as a characterising taxon described thus:

- Deep cup coral (*Caryophyllia* spp.) dominated, occasionally with seapens (*Pennatula phosphorea*, *Halipteris* sp.)
- **Technical description:** *Caryophyllia* spp. (SACFOR abundance category = Occasional; mean density 0.7893 corals m^{-2}) occasionally with seapens including *Pennatula phosphorea* and *Halipteris* sp. (SACFOR abundance category for both = Common; mean density 0.058 and 0.01 corals m^{-2}, respectively).
- **Environmental preferences:** Occurs at depths of 1,069 – 1,769m. Found on substrata such sand, pebbles, cobbles, and boulders.
- **Scottish distribution**: Anton Dohrn Seamount, East Rockall Bank.

Parry *et al* (2015) identified a deep-sea assemblage characterised by the seapens *Kophobelemnon stelliferum* and *Pennatula phosphorea* occurring on Atlantic mid bathyal mud over a depth range of 600 – 1,300m. Cross *et al* (2014) recognised an assemblage on the Hebrides Terrace Seamount, characterised by the seapen *Halipteris* among other taxa, occurring on coarse sand mixed with pebbles and cobbles, often with high mud content at depths of 1,200 – 1,700m. This seapen also occurred at high frequencies in an assemblage occurring on coral rubble in the same area. Deep-sea biotopes which include seapens as characterising taxa are summarised in Table 9, Appendix 2.

Many seapen species span a wide depth range and in the north western Atlantic have been reported at relatively high densities for example: *Funiculina quadrangularis* at up to 17 per 10m transect, *Halipteris finmarchica* 12 per 10m, *Kophobelemnon stelliferum* 13 per 10m, *Pennatula* sp. up to 622 per 10m (Baker *et al* 2012), these are all taxa frequently recorded in the study area. It should be noted that the habit shown by many seapens of withdrawing into the sediment may result in densities being under estimated especially by photographic techniques. Figure 14 - Figure 16 (Appendix 1) show the distribution of records for seapens across the study area.

3.4 Tall seapen, *Funiculina quadrangularis*

The Tall Seapen (*Funiculina quadrangularis*) occurs extensively in shallow water (from <20m) muddy habitats in Scottish seas (Edwards & Moore 2009; Greathead *et al* 2007) and also occurs widely in offshore areas to depths of more than 3,000m (Manuel 1988; Ruiz-Pico *et al* 2017). Its distribution within the study area is shown in Figure 13. It is a characterising species of a sub-biotope of Burrowed Mud which occurs both inshore and in offshore deep-sea areas (Tyler-Walters *et al* 2016). Greathead *et al* (2015) demonstrated the highest Habitat Suitability Index (HSI) value for sediment mud content, for the Tall Seapen, was 100%, while this species was absent from sediments containing more than 30% gravel. It should be noted that this study was restricted to relatively shallow habitats (<120m), but these habitat criteria may be relevant to much deeper situations.

F. quadrangularis grows up to 200cm in length with as much as a quarter of this length buried in sediment (Greathead *et al* 2007). It does not withdraw into the sediment, a behaviour shown by a number of other seapen species. Breeding and fecundity in this species were studied by Edwards and Moore (2009) at an inshore site on the Scottish coast. The species is gonochoric and a broadcast spawner with a sex ratio of 1:1. Females showed asynchronously developing oocytes throughout the year, of which 10% were spawned synchronously in winter, which is unusual for seapens within the study area, as most tend to spawn at the time of the spring phytoplankton bloom. Edwards and Moore (2009) suggest that oocyst development may take as long as 24 months in *F. quadrangularis* and postulated that the large oocyte size could sustain the lecithotrophic larva "*for several months*".

3.4.1 Conservation status

The Tall Seapen is a Scottish Priority Marine Feature as well as being a UK Biodiversity Action Plan (BAP) species (JNCC 2010) and is listed as being present in the OSPAR "Sea-pen and burrowing megafauna community" which occurs in water depths of over 200m and is classified as a "threatened and/or declining habitat" (OSPAR 2010c).

3.4.2 Range and distribution

The Tall Seapen occurs widely in inshore waters around the Scottish coast, typically in sheltered sea lochs often in depths of less than 20m. It is also recorded from deeper water (to 3,000m) with a concentration of records in the study area from the central area of the Rockall Bank (Figure 13) where it generally occurs at depths of less than 800m.

Deep-sea mud habitats occur extensively within the study area (Figure 2 to Figure 5, Appendix 1) which are potentially suitable for seapens, although no records of this species are available for large parts of this area. British Geological Survey data presented in section 2 would suggest that sediments at over half the sites sampled could be suitable for *F. quadrangularis*, i.e. those sediments with a mud content of greater than 75% (Greathead *et al* 2015). Muddy habitats predominate to the northeast of the Wyville Thomson Ridge but there is only a single record for *F. quadrangularis* from this region (Figure 13, Appendix 1). Caution must be exercised when interpreting occurrence records since these records reflect where samples were taken rather than the true distribution of the species. Deep-sea currents will also play a part in determining distributions of sessile fauna by bringing food particles.

Wright *et al* (2015) studied the genetic structure of a population of *F. quadrangularis* in northwest Scottish sea lochs and concluded that these shallow water populations showed high genetic diversity and high gene flow between colonies.

3.4.3 Confidence in survey data

The records presented in Figure 13 were all collected relatively recently (since 2005) with some collections comprising high numbers of individuals, though 43 of the 70 records reported fewer than five specimens in samples. Seapen species are highly susceptible to fishing pressures and much of this region has been targeted by deep-water fisheries in recent years, thus making the inference from older records to present distribution unreliable.

It should be noted much of the recent survey work within the study area has targeted reef habitats. There are large areas of sedimentary habitats, potentially suitable for *F. quadrangularis* and other seapen species, which have been less extensively studied, especially in the Atlantic region to the southwest of the Wyville-Thomson Ridge, comprising very large areas of muddy sediments for which no species data are available (Figure 6 and Figure 8, Appendix 1). Figure 14 (Appendix 1) shows the available distributional data for seapens at the time of writing.

3.5 Ecological connectivity of deep-sea habitats

The ecological connectivity of deep-sea habitats is little understood. To address this, a survey conducted in 2016 visited five locations within the study area, to collect material for analysis of genetic diversity and population connectivity for selected taxa, although no seapen or crinoid species were targeted (Howell *et al* 2016). Outputs from this survey will be highly relevant to understanding population connectivity within the present study area. Gene flow does occur in the deep-sea at the basin level, most likely via stepping stones, but connectivity in the vertical dimension is poor. Hilário *et al* (2015), Ross *et al* (2016) and Ross *et al* (2017) discuss the limitations and gaps in our present knowledge of deep-sea hydrodynamics and biology in terms of predicting larval dispersal; they review available hydrodynamic and particle dispersal models and make recommendations regarding methodology for assessing deep-sea dispersal.

Gallego *et al* (2017) considered the connectivity of a number of Scottish PMFs including *Funiculina quadrangularis* and *Leptometra celtica* across the Scottish MPA network. However, the particle dispersal model used was restricted to a constant depth of 25m, not relevant in a deep-sea context. Their work concluded that at least in nearshore areas, populations of *F. quadrangularis* were relatively well connected, given the longevity of the larvae and the local hydrodynamics. Wright *et al* (2015) concluded that populations of *F. quadrangularis* in Scottish sea lochs were well connected but had no data on deep-sea populations. Gallego *et al* (2017) did not evaluate *Leptometra celtica* because of the lack of records from deep-sea MPAs.

4 References

Baillon, S., Hamel, J.-F., Wareham Vonda, E. & Mercier, A. (2012). Deep cold-water corals as nurseries for fish larvae. *Frontiers in Ecology and the Environment* 10, 351-356. https://doi.org/10.1890/120022

Baillon, S., Hamel, J.-F. & Mercier, A. (2014a). Diversity, Distribution and Nature of Faunal Associations with Deep-Sea Pennatulacean Corals in the Northwest Atlantic. 9(11): e111519. *PLoS ONE* 9, e111519. https://doi.org/10.1371/journal.pone.0111519

Baillon, S., Hamel, J.-F., Wareham, V.E. & Mercier, A. (2014b). Seasonality in reproduction of the deep-water pennatulacean coral *Anthoptilum grandiflorum*. *Marine Biology* 161, 29-43. https://doi.org/10.1007/s00227-013-2311-8

Baillon, S., Hamel, J.F. & Mercier, A. (2014c). Protracted oogenesis and annual reproductive periodicity in the deep-sea pennatulacean *Halipteris finmarchica* (Anthozoa, Octocorallia). *Marine Ecology* 36, 1364-1378. https://doi.org/10.1111/maec.12236

Baker, K.D., Wareham, V.E., Snelgrove, P.V.R., Haedrich, R.L., Fifield, D.A., Edinger, E.N. & Gilkinson, K.D. (2012). Distributional patterns of deep-sea coral assemblages in three submarine canyons off Newfoundland, Canada. *Marine Ecology Progress Series* 445, 235-249. http://www.jstor.org/stable/24875404

Balmford, A., Rodrigues, A.S.L., Walpole, M., ten Brink, P., Kettunen, M., Braat, L. & de Groot, R. (2008). The Economics of Biodiversity and Ecosystems: Scoping the Science. Cambridge, UK: European Commission contract: ENV/070307/2007/486089/ETU/B2)

Baumiller, T.K. (2008). Crinoid Ecological Morphology. *Annual Review of Earth and Planetary Sciences* 36, 221-249. https://doi.org/10.1146/annurev.earth.36.031207.124116

Baxter, J.M., Boyd, I.L., Cox, M., Donald, A.E., Malcolm, S.J., Miles, H., Miller, B. & Moffat, C.F. (Editors) (2011). Scotland's Marine Atlas: Information for the national marine plan. Marine Scotland, Edinburgh. pp. 191. http://www.gov.scot/resource/doc/345830/0115122.pdf

Benn, A.R., Weaver, P.P., Billet, D.S.M., van den Hove, S., Murdock, A.P., Doneghan, G.B. & Le Bas, T. (2010). Human Activities on the Deep Seafloor in the North East Atlantic: An Assessment of Spatial Extent. *PLoS ONE* 5(9): e12730. https://doi:10.1371/journal.pone.0012730

Bett, B.J. (2003). An introduction to the benthic ecology of the Faroe-Shetland Channel (SEA4). 21pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197362/SEA4_TR_Benthos_SOC.pdf

Bett, B.J. (2012). Seafloor biotope analysis of the deep waters of the SEA4 region of Scotland's seas. *JNCC Report No. 472*, JNCC, Peterborough, ISSN 0963-8091. http://jncc.defra.gov.uk/pdf/472_web.pdf

Billett, D.S.M., Lampitt, R.S., Rice, A.L. & Mantoura, R.F.C. (1983). Seasonal sedimentation of phytoplankton to the deep-sea benthos. *Nature* 302, 520. https://doi.org/10.1038/302520a0

Billet, D.S.M., Bett, B.J., Reid, W.D.K., Boorman, B. & Priede, I.G. (2010). Long-term change in the abyssal NE Atlantic: The ‘Amperima Event’ revisited. *Deep-Sea Research II*, 57, 1406-1417. https://doi.org/10.1016/j.dsr2.2009.02.001

Bongiorni, L., Mea, M., Gambi, C., Pusceddu, A., Taviani, M. & Danovaro, R. (2010). Deep-water scleractinian corals promote higher biodiversity in deep-sea meiofaunal assemblages along continental margins. *Biological Conservation*, 143(7), 1687-1700.

Bradshaw, C., Tjensvoll, I., Skold, M., Allan, I.J., Molvaer, J., Magnusson, J., Naes, K. & Nilsson, H.C. (2012). Bottom trawling re-suspends sediment and releases bioavailable contaminants in a polluted fjord. *Environmental Pollution* 170: 232-241.

Brandt, A. (2008). Deep-Sea Ecology: Infectious Impact on Ecosystem Function. *Current Biology* 18(23): R1104-R1106.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl-Mortensen, P., Gheerardyn, H., King, N.J. & Raes, M. (2010). Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. *Marine Ecology* 31, 21–50.

Buhl-Mortensen, L., Buhl-Mortensen, P., Dolan, M.F.J., Dannheim, J., Bellec, V. & Holte, B. (2012). Habitat complexity and bottom fauna composition at different scales on the continental shelf and slope of northern Norway. *Hydrobiologia* 685: 191-219. https://doi.org/10.1007/s10750-011-0988-6

Buhl-Mortensen, L., Aglen, A., Breen, M., Buhl-Mortensen,P., Ervik, A., Husa,V., Løkkeborg, S., Røttingen, I. & Stockhausen, H.H. (2013). Impacts of fisheries and aquaculture on sediments and benthic fauna: suggestions for new management approaches. Havforskningsinstituttet Institute of Marine Research, *Fisken og Havet*, 3, 69pp.

Clark, A.H. (1913). On a collection of recent Crinoids from the waters about Ireland. Department of Agriculture and Technical Instruction for Ireland, Fisheries Branch, Scientific Investigations 4, 1-5.

Cook, R., Fernandes, P., Florin, A., Lorance, P. & Nedreaas, K. (2015). Coryphaenoides rupestris. The IUCN Red List of Threatened Species 2015: e.T15522149A45136880.

Corinaldesi, C. (2015). New perspectives in benthic deep-sea microbial ecology. *Frontiers in Marine Science* 2(17). doi:10.3389/fmars.2015.00017

Cranmer, G.J., Dyer, M.F. & Fry, P.D. (1984). Further results from headline camera surveys in the North Sea. *Journal of the Marine Biological Association of the United Kingdom* 64, 335-342. https://doi.org/10.1017/s0025315400030034

Cross, T., Howell, K.L., Hughes, E. & Seeley, R. (2014). Analysis of seabed imagery from the Hebrides Terrace Seamount (2013). *JNCC Report No. 510*, p. 35, JNCC, Peterborough, ISSN 0963-8091. http://jncc.defra.gov.uk/pdf/Report_510_web.pdf

Danovaro, R., Gambi, C., Dell’Anno, A., Corinaldesi, C., Fraschetti, S., Vanreusel, A., Vincx, M. & Gooday, A.J. (2008). Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. *Current Biology*, 18, 1-8.

Danovaro, R., Canals, M., Gambi, C., Heussner, S., Lampadariou, N. & Vanreusel, A. (2009). Exploring Benthic Biodiversity Patterns and Hotspots on European Margin Slopes. *Oceanography* 22(1), 16-25.

Davies, A.J., Narayanaswamy, B.E., Hughes, D.J. & Roberts, J.M. (2006). An introduction to the benthic ecology of the Rockall – Hatton Area (SEA 7). A Report for the Department of Trade and Industry. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197028/SEA7_Benthos_SRSL.pdf

Davies, A.J., Roberts, J.M. & Hall-Spencer, J. (2007). Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management. *Biological Conservation*, 138(3-4), 299-312. https://doi:10.1016/j.biocon.2007.05.011

Davies, A.J. & Guinotte, J.M. (2011). Global Habitat Suitability for Framework-Forming Cold-Water Corals. PLoS ONE 6(4): e18483. https://doi.org/10.1371/journal.pone.0018483

Davies, J.S., Stewart, H.A., Narayanaswamy, B.E., Jacobs, C., Spicer, J., Golding, N. & Howell, K.L. (2015). Benthic assemblages of the Anton Dohrn Seamount (NE Atlantic): defining deep-sea biotopes to support habitat mapping and management efforts with a focus on vulnerable marine ecosystems. *PLoS ONE* 10, e0124815. https://doi.org/10.1371/journal.pone.0124815

De Clippele, L.H., Buhl-Mortensen, P. & Buhl-Mortensen, L. (2015). Fauna associated with cold water gorgonians and sea pens. *Continental Shelf Research* 105, 67-78. https://doi.org/10.1016/j.csr.2015.06.007

Dinter, W.P. (2001). Biogeography of the OSPAR Maritime Area. Bundesamt fur Naturschutz Federal Agency for Nature Conservation, Bonn, Germany, 167 pp.

Duco, A. & Roux, M. (1981). Modalités particulières de croissance liées au milieu abyssal chez les Bathycrinidae (Echinodermes, Crinoïdes pédonculés). *Oceanologica Acta* 4, 389-393. http://archimer.ifremer.fr/doc/00000/5367/

Duineveld, G.C.A., Lavaleye, M.S.S., Bergman, M.J.N., de Stigter, H. & Mienis, F. (2007). Trophic structure of a cold-water coral mound community (Rockall Bank, NE Atlantic) in relation to the near-bottom particle supply and current regime. *Bulletin of Marine Science* 81, 449-467. https://www.ingentaconnect.com/content/umrsmas/bullmar/2007/00000081/00000003/art00012

Durán Muñoz, P., Sayago-Gil, M., Patrocinio, T., González-Porto, M., Murillo, F.J., Sacau, M., González, E., Fernández, G. & Gago, A. (2012). Distribution patterns of deep-sea fish and benthic invertebrates from trawlable grounds of the Hatton Bank, north-east Atlantic: effects of deep-sea bottom trawling. Journal of the Marine Biological Association of the United Kingdom 92, 1509-1524. https://doi.org/10.1017/s002531541200015x

Dureuil, M. & Jung, A. (2015). *Centroscymnus coelolepis*. The IUCN Red List of Threatened Species 2015: e.T41747A48923952.

Eckelbarger, K.J., Tyler, P.A. & Langton, R.W. (1998). Gonadal morphology and gametogenesis in the sea pen *Pennatula aculeata* (Anthozoa: Pennatulacea) from the Gulf of Maine. *Marine Biology* 132, 677-690. https://doi.org/10.1007/s002270050432

Edwards, D.C.B. & Moore, C.G. (2009). Reproduction in the sea pen *Funiculina quadrangularis* (Anthozoa: Pennatulacea) from the west coast of Scotland. *Estuarine, Coastal and Shelf Science* 82, 161-168. https://doi.org/10.1016/j.ecss.2009.01.006

Ellis, J., Soldo, A., Dureuil, M. & Fordham, S. (2015). *Squalus acanthias*. The IUCN Red List of Threatened Species 2015: e.T91209505A48910866

EMODnet (2018). Available online at: http://www.emodnet.eu/ [Accessed April 2018].
FAO (2018a). Species Fact Sheet: *Aphanopus carbo*. Food and Agriculture Organisation of the United Nations. Available online at: http://www.fao.org/fishery/species/2469/en

FAO (2018b). Species Fact Sheet: *Molva dipterygia*. Food and Agriculture Organisation of the United Nations. Available online at: http://www.fao.org/fishery/species/2221/en

FAO (2018c). Species Fact Sheet: *Coryphaenoides rupestris*. Food and Agriculture Organisation of the United Nations. Available online at: http://www.fao.org/fishery/species/3035/en

Farias, I., Morales-Nin, B., Lorance, P. & Figueiredo, I. (2013). Black scabbardfish, *Aphanopus carbo*, in the northeast Atlantic: distribution and hypothetical migratory cycle. *Aquatic Living Resources* 26, 333-342. https://doi:10.1051/alr/2013061

Fernandes, P., Cook, R., Florin, A., Lorance, P. & Nedreaas, K. (2015). *Molva dypterygia*. The IUCN Red List of Threatened Species 2015: e.T198591A45131980.

Fishbase (2018a). Species Summary: Atlantic halibut. Available online at: http://www.fishbase.org/Summary/SpeciesSummary.php?ID=1371andAT=atlantic+halibut [Accessed May 2018].

Flach, E., Lavaleye, M., de Stigter, H. & Thomsen, L. (1998). Feeding types of the benthic community and particle transport across the slope of the N.W. European continental margin (Goban Spur). *Progress in Oceanography* 42, 209-231. https://doi.org/10.1016/S0079-6611(98)00035-4

Fletcher, S., Saunders, J., Herbert, R. & Roberts, C. (2011). Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area. Report to Natural England.

Fonseca, P., Abrantes, F., Aguilar, R., Campos, A., Cunha, M., Ferreira, D., Fonseca, T.P., García, S., Henriques, V., Machado, M., Mechó, A., Relvas, P., Rodrigues, C.F., Salgueiro, E., Vieira, R., Weetman, A. & Castro, M. (2014). A deep-water crinoid *Leptometra celtica* bed off the Portuguese south coast. *Marine Biodiversity* 44, 223-228. https://doi.org/10.1007/s12526-013-0191-2

Freiwald, A., Fosså, J.H., Grehan, A., Koslow, T. & Roberts, J.M. (2004). Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK. Available at: http://www.lophelia.org/images/stories/pdfs/CWC_HR.pdf

Gage, J.D., Pearson, M., Clark, A.M., Paterson, G.L.J. & Tyler, P.A. (1983). Echinoderms of the Rockall Trough and adjacent areas I. Crinoidea, Asteroidea and Ophiuroidea. *Bulletin of the British Museum* (Natural History) Zoology 45, 263-308.

Gage, J., Pearson, M., Billett, D.S.M., Clark, A.M., Jensen, M., Paterson, G.L.J. & Tyler, P.A. (1984). Echinoderm zonation in the Rockall Trough (NE Atlantic). In: Keegan, B.F. & O'Connor, D.S. (eds) Echinodermata - proceedings of the fifth international Echinoderm conference, Galway, 24-29 September 1984, pp. 31-36, A A Balkema, Galway.

Gage, J.D. (1986). The benthic fauna of the Rockall Trough: regional distribution and bathymetric zonation. *Proceedings of the Royal Society of Edinburgh*. Section B. Biological Sciences 88, 159-174. https://doi.org/10.1017/s026972700000453x

Gage, J.D., Lamont, P.A., Kroeger, K., Paterson, G.L.J. & Gonzalez Vecino, J.L. (2000). Patterns in deep-sea macrobenthos at the continental margin: standing crop, diversity and faunal change on the continental slope off Scotland. *Hydrobiologia*, 440. 261–271.

Gage, J.D. (2002). Benthic biodiversity across and along the continental margin: patterns, ecological and historical determinants, and anthropogenic threats. In: Wefer, G., Billett, D., Hebbeln, D., Jørgensen, B.B., Schlüter, M. & Van Weering, T. (eds.), Ocean Margin Systems. Springer-Verlag, Berlin, Heidelberg, pp. 307-321.

Gallego, A., Gibb, F.M., Tullet, D. & Wright, P.J. (2013). Connectivity of benthic priority marine species within the Scottish MPA network, p. 55, Marine Scotland Science.

Gallego, A., Gibb, F.M., Tullet, D. & Wright, P.J. (2017). Bio-physical connectivity patterns of benthic marine species used in the designation of Scottish nature conservation marine protected areas. *ICES Journal of Marine Science* 74, 1797-1811. https://doi.org/10.1093/icesjms/fsw174

Greathead, C.F., Donnan, D.W., Mair, J.M. & Saunders, G.R. (2007). The sea pens *Virgularia mirabilis*, Pennatula phosphorea and *Funiculina quadrangularis*: distribution and conservation issues in Scottish waters. Journal of the Marine Biological Association of the United Kingdom 87, 1095-1103. https://doi.org/10.1017/s0025315407056238

Greathead, C., González-Irusta, J.M., Clarke, J., Boulcott, P., Blackadder, L., Weetman, A. & Wright, P.J. (2015). Environmental requirements for three sea pen species: relevance to distribution and conservation. *ICES Journal of Marine Science* 72, 576-586. https://doi.org/10.1093/icesjms/fsu129

Guallart, J., Walls, R.H.L. & White, W.T. (2015). *Centrophorus squamosus*. The IUCN Red List of Threatened Species 2015: e.T41871A48954989.

Haig, J.A., Gillanders, B.M. & Rouse, G.W. (2012). Live fast, die young: the life cycle of the brooding feather star *Aporometra wilsoni* (Echinodermata: Crinoidea). Invertebrate Biology 131, 235-243. https://doi.org/10.1111/j.1744-7410.2012.00270.x

Hall-Spencer, J., Allain, V. & Fosså, J.H. (2001). Trawling damage to northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society of London B*, 269. 507–511.

Henry, L.-A. & Roberts, J.M. (2014). Developing an interim technical definition for Coral Gardens specific for UK waters and its subsequent application to verify suspected records. *JNCC Report No. 507*, p. 42, JNCC, Peterborough, ISSN 0963-8091.

HERMES (2016). Hotspot Ecosystem Research on the Margins of European Seas. http://www.eu-hermes.net/

Hilário, A., Metaxas, A., Gaudron, S.M., Howell, K.L., Mercier, A., Mestre, N.C., Ross, R.E., Thurnherr, A.M. & Young, C. (2015). Estimating dispersal distance in the deep sea: challenges and applications to marine reserves. *Frontiers in Marine Science 2*. https://doi.org/10.3389/fmars.2015.00006

Hogg, M.M., Tendal, O.S., Conway, K.W., Pomponi, S.A., van Soest, R.W.M., Gutt, J., Krautter, M. & Roberts, J.M. (2010). Deep-sea sponge grounds: reservoirs of biodiversity. UNEP-WCMC Biodiversity Series, 32.

Holmes, R., Fraser, J., Gunn, V., Henni, P., Jacobs, C., Shannon, P. & Unnithan, V. (2002). DTI Strategic Environmental Assessment Area 7 (SEA7) Geological Metadata. British Geological Survey, Commissioned Report CR/02/275, 123pp.

Holmes, R., Cooper, R. & Jones, S. (2003). DTI Strategic Environmental Assessment Area 4 (SEA4): Continental shelf seabed geology and processes. British Geological Survey Commercial Report CR/03/081.

Howell, K., Davies, J.S., Hughes, D.J. & Narayanaswamy, B.E. (2007). Strategic Environmental Assessment/Special Area for Conservation Photographic Analysis Report, p. 82, University of Plymouth and Scottish Association for Marine Science.

Howell, K.L., Davies J.S., Jacobs, C. & Narayanaswamy, B.E. (2009). Broadscale Survey of the Habitats of Rockall Bank, and mapping of Annex I Reef Habitat. *JNCC Report No. 422*, JNCC, Peterborough, ISSN 0963-8091. http://jncc.defra.gov.uk/PDF/jncc422_web.pdf

Howell, K.L., Davies, J.S. & Narayanaswamy, B.E. (2010). Identifying deep-sea megafaunal epibenthic assemblages for use in habitat mapping and marine protected area network design. Journal of the Marine Biological Association of the United Kingdom 90, 33-68. https://doi.org/10.1017/s0025315409991299

Howell, K.L., Huvenne, V., Piechaud, N., Robert, K. & Ross, R.E. (2014). Analysis of biological data from the JC060 survey of areas of conservation interest in deep waters off north and west Scotland. *JNCC Report No. 528*, p. 109, JNCC, Peterborough, ISSN 0963-8091. http://jncc.defra.gov.uk/page-6842

Howell, K.L., Taylor, M., Crombie, K., Faithfull, S., Golding, N., Nimmo-Smith, W.A., Perrett, J., Piechaud, N., Ross, R.E., Stashchuk, N., Turner, D., Vlasenko, V. & Foster, N.L. (2016). RRS James Cook, Cruise No JC136, 14th May - 23rd June, DEEPLINKS: influence of population connectivity on depth-dependent diversity of deep-sea marine biota., p. 150, Plymouth University Marine Institute, Plymouth. https://www.bodc.ac.uk/resources/inventories/cruise_inventory/reports/jc136.pdf

Hughes, A.J., Narayanaswamy, B.E. & Bett, B.J. (2003). SEA 4: An overview of the benthic ecology of the Faroe-Shetland Channel. 63pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197362/SEA4_TR_Benthos_SOC.pdf

Hughes, D.J. & Gage, J.D. (2004). Benthic metazoan biomass, community structure and bioturbation at three contrasting deep-water sites on the northwest European continental margin. *Progress in Oceanography* 63, 29-55. https://doi.org/10.1016/j.pocean.2004.09.002

Hughes, D.J. (2014). Benthic habitat and megafaunal zonation across the Hebridean Slope, western Scotland, analysed from archived seabed photographs. *Journal of the Marine Biological Association of the United Kingdom*, 94(4): 643-658. https://doi:10.1017/S0025315413001896

Hughes, D., Nickell, T. & Gontarek, S. (2014). Biotope analysis of archived stills from the SEA7 region of Scotland's seas (2011). *JNCC Report No. 502*, JNCC, Peterborough, ISSN 0963-8091. http://jncc.defra.gov.uk/pdf/502_web.pdf

ICES (2011). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 28 February–4 March, Copenhagen, Denmark. ICES CM 2011/ACOM:27. 104 pp.

ICES (2012). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 26–30 March 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:29. 120pp.

ICES (2013). Report of the ICES\NAFO Joint Working Group on Deep-water Ecology (WGDEC), 11-15TH March 2013, Floedevigen, Norway, ICES CM 2013\ACOM:28. 95pp.

ICES (2014). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 24–28 February 2014, Copenhagen, Denmark. ICES CM 2014/ACOM:29. 70 pp.

ICES (2014b). Orange roughy (*Hoplostethus atlanticus*) in the Northeast Atlantic. In Stock Summaries, ICES Advice 2014, Book 9, Section 9.3.18.

ICES (2014c). Roundnose grenadier (*Coryphaenoides rupestris*) in the Northeast Atlantic. In ICES Advice 2014, Book 9, Section 9.3.23.

ICES (2014d). Report of the Working Group on Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP), 4–11 April 2014, Copenhagen, Denmark. ICES CM 2014/ACOM:17. 862 pp.

ICES (2015). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 16–20 February 2015, Horta, Azores, Portugal. ICES CM 2015/ACOM:27. 113 pp.

ICES (2016). Report of the Joint ICES/NAFO Working Group on Deep-water Ecology (WGDEC), 15–19 February 2016, Copenhagen, Denmark. ICES CM 2016/ACOM:28. 82 pp.

ICES (2017a). Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 20–24 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:25. 121 pp.

ICES (2017b). Report of the Working Group on the Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP), 24 April–1 May 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:14. 702 pp.

Inall, M.E. & Sherwin, T.J. (2006). SEA7 Technical Report - Hydrography. SAMS Report No. 251, 76pp.

JNCC (2010). UK priority species data collation: Funiculina quadrangularis v.2. JNCC, Peterborough. http://jncc.defra.gov.uk/_speciespages/317.pdf

JNCC (2018a). Rosemary Bank Seamount Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6486 [Accessed April 2018]

JNCC (2018b). The Barra Fan and Hebrides Terrace Seamount Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6489 [Accessed April 2018]

JNCC (2018c). Anton Dohrn Seamount MPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6527 [Accessed April 2018]

JNCC (2018d). Geikie Slide and Hebridean Slope NCMPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6481 [Accessed April 2018]

JNCC (2018e). Faroe Shetland Sponge Belt MPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6479 [Accessed April 2018]

JNCC (2018f). Wyville-Thomson Ridge MPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6545 [Accessed April 2018]

JNCC (2018g). North West Rockall Bank MPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6538 [Accessed April 2018]

JNCC (2018h). Darwin Mounds SAC Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6531 [Accessed April 2018]

JNCC (2018i). East Rockall Bank SAC Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6532 [Accessed April 2018]

JNCC (2018j). North-East Faroe-Shetland Channel NCMPA Site Summary. JNCC, Peterborough. http://jncc.defra.gov.uk/page-6483 [Accessed April 2018]

JNCC (2018k). UKSeaMap 2016. JNCC, Peterborough. Available online at: http://jncc.defra.gov.uk/page-7354 [Accessed April 2018].

JNCC (2018l). Access to MPA Site Information Centres. JNCC, Peterborough. Available online at:
http://jncc.defra.gov.uk/page-6895 [Accessed April 2018].

Jones, D.O.B., Bett, B.J. & Tyler, P.A. (2007). Megabenthic ecology of the deep Faroe–Shetland channel: A photographic study. *Deep Sea Research Part I: Oceanographic Research Papers* 54, 1111-1128. https://doi.org/10.1016/j.dsr.2007.04.001

Kahng, S.E., Benayahu, Y. & Lasker, H.R. (2011). Sexual reproduction in octocorals. *Marine Ecology Progress Series* 443, 265-283. http://www.jstor.org/stable/24875291

Kohtsuka, H. & Nakano, H. (2005). Development and growth of the feather star *Decametra tigrina* (Crinoidea), with emphasis on the morphological differences between adults and juveniles. *Journal of the Marine Biological Association of the United Kingdom* 85, 1503-1510. https://doi.org/10.1017/s0025315405012701

Kondo, M. & Akasaka, K. (2010). Regeneration in crinoids. Development, Growth and Differentiation 52, 57-68. https://doi.org/10.1111/j.1440-169X.2009.01159.x

Lambert, G.I., Jennings, S., Kaiser, M.J., Davies, T.W. & Hiddink, J.G. (2014). Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. *Journal of Applied Ecology* 51: 1326-1336.

Lamont, P. & Gage, J.D. (2002). DTI Strategic Environmental Assessment 2002. SEA 7 area: BENTHOS. Scottish Association for Marine Science, October 2002. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197027/SEA7_Benthos.pdf

Langton, R.W., Langton, E.W., Theroux, R.B. & Uzmann, J.R. (1990). Distribution, behavior and abundance of sea pens, *Pennatula aculeata*, in the Gulf of Maine. *Marine Biology* 107, 463-469. https://doi.org/10.1007/bf01313430

Large, P., Revill, A., Randall, P., Armstrong, M., Houghton, C. & Hareide, N-R. (2005). Programme 5: Western Edge Ghost Nets (gill net retrieval). Fisheries Science Partnership:

2005/06. Available online at: http://www.rundecentre.no/wp-content/uploads/2014/03/FSP200506-Prog-5-Gill-net-rerieval-survey-final-report.pdf

Lavaleye, M.S.S., Duineveld, G.C.A., Berghuis, E.M., Kok, A. & Witbaard, R. (2002). A comparison between the megafauna communities on the N.W. Iberian and Celtic continental margins—effects of coastal upwelling? *Progress in Oceanography* 52, 459-476. https://doi.org/10.1016/S0079-6611(02)00019-8

Long, D. (2006). BGS detailed explanation of seabed sediment modified Folk classification. Available from: http://www.emodnet-seabedhabitats.eu/PDF/GMHM3_Detailed_explanation_of_seabed_sediment_classification.pdf [Accessed May 2018].

Manuel, R.L. (1988). Synopses of the British Fauna: British Anthozoa, 2nd Ed, p. 241, Academic Press, London.

MAREMAP (2018). Available online at: http://www.maremap.ac.uk/index.html [Accessed April 2018].

Marine Scotland (2018). Feature Assessment Sensitivity Tool. Available online at: http://www.marine.scotland.gov.uk/feast/GlossaryFeatureView.aspx [Accessed April 2018].

Masson, D.G. (2003). Seafloor sediments and sedimentary processes on the outer continental shelf, continental slope and basin floor. DTI SEA4 Report, 49pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197371/SEA4_TR_Sediments_SOC.pdf

Masson, D.G., Wynn, R.B. & Bett, B.J. (2004). Sedimentary environment of the Faroe-Shetland and Faroe Bank Channels, north-east Atlantic, and the use of bedforms as indicators of bottom current velocity in the deep ocean. *Sedimentology* 51, 1207-1241. https://doi.org/10.1111/j.1365-3091.2004.00668.x

McBreen, F. & Askew, N. (2011). UKSeaMap 2010, Technical Report 3: Substrate data. JNCC, Peterborough.

Messing, C.G., RoseSmyth, C.M., Mailer, S.R. & Miller, J.E. (1988). Relocation Movement in a Stalked Crinoid (Echinodermata). *Bulletin of Marine Science* 42, 480-487. https://www.ingentaconnect.com/content/umrsmas/bullmar/1988/00000042/00000003/art00011

Messing, C.G., David, J., Roux, M., Améziane, N. & Baumiller, T.K. (2007). *In situ* stalk growth rates in tropical western Atlantic sea lilies (Echinodermata: Crinoidea). *Journal of Experimental Marine Biology and Ecology* 353, 211-220. https://doi.org/10.1016/j.jembe.2007.08.021

Mortensen, T. (1927). Handbook of the Echinoderms of the British Isles. Oxford University Press, London.

MSFD (2013). Ireland's Marine Strategy Framework Directive Article 19 Report: Initial Assessment, GES and Targets and Indicators. October 2013. Available online at: http://www.environ.ie/en/Publications/Environment/Water/FileDownLoad,34365,en.pdf

Munroe, T., Costa, M., Nielsen, J., Herrera, J., de Sola, L., Rijnsdorp, A.D. & Keskin, Ç. (2015). *Hippoglossus hippoglossus*. The IUCN Red List of Threatened Species 2015: e.T10097A45790126.

Murillo, F.J., MacDonald, B.W., Kenchington, E., Campana, S.E., Sainte-Marie, B. & Sacau, M. (2018). Morphometry and growth of sea pen species from dense habitats in the Gulf of St. Lawrence, eastern Canada. *Marine Biology Research*, 1-17. https://doi.org/10.1080/17451000.2017.1417604

Narayanaswamy, B.E., Hughes, D.J., Howell, K.L., Davies, J. & Jacobs, C. (2013). First observations of megafaunal communities inhabiting George Bligh Bank, Northeast Atlantic. *Deep Sea Research Part II: Topical Studies in Oceanography* 92, 79-86. https://doi.org/10.1016/j.dsr2.2013.03.004

Neves, B.d.M., Edinger, E., Layne, G.D. & Wareham, V.E. (2015). Decadal longevity and slow growth rates in the deep-water sea pen *Halipteris finmarchica* (Sars 1851) (Octocorallia: Pennatulacea): implications for vulnerability and recovery from anthropogenic disturbance. *Hydrobiologia* 759, 147-170. https://doi.org/10.1007/s10750-015-2229-x

Nichols, D. (1991). Seasonal reporoductive periodicity in the European comatulid crinoid *Antedon bifida* (Pennant). Yanagisawa, T., Yasumasu, I., Oguro, C., Suzuki, N. and Motokawa, T. (eds), pp. 241-248, Balkema.

Olsgard, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A. & Austen, M.C. (2008). Effects of bottom trawling on ecosystem functioning. *Journal of Experimental Marine Biology and Ecology* 366(1-2): 123-133.

OSPAR (2009). Background Document for Lophelia pertusa reefs. OSPAR Biodiversity Series, 32pp. http://www.ospar.org/documents?v=7182

OSPAR (2010a). Background Document for Deep-sea sponge aggregations. OSPAR Biodiversity Series, 47pp. http://www.ospar.org/documents?v=7234

OSPAR (2010b). Background Document for Coral gardens. OSPAR Biodiversity Series, 41pp. http://www.ospar.org/documents?v=7217

OSPAR (2010c). Background document for seapen and burrowing megafuna communities, p. 27, OSPAR Convention. https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-species-habitats

Parker, S.J. & Bowden, D.A. (2010). Identifying taxonomic groups vulnerable to bottom longline fishing gear in the Ross Sea region. CCAMLR Science 17, 105-127. http://203.13.22.3/en/system/files/science_journal_papers/05parker-bowden.pdf

Parry, M.E.V., Howell, K.L., Narayanaswamy, B.E., Bett, B.J., Jones, D.O.B., Hughes, D.A., Piechaud, N., Nickell, T.D., Ellwood, H., Askew, N., Jenkins, C. & Manca, E. (2015). A Deep-sea Section for the Marine Habitat Classification of Britain and Ireland v15.03, p. 29 JNCC, Peterborough. http://jncc.defra.gov.uk/page-6997

Paterson G.L.J. & Lambshead P.J.D. (1995). Bathymetric patterns of polychaete diversity in the Rockall Trough, northeast Atlantic. *Deep-Sea Research Part I - Oceanographic Research Papers*, 42, 1199-1214 https://doi.org/10.1016/0967-0637(95)00041-4

Piechaud, N. & Howell, K. (2013). Definition of faunal assemblages for inclusion in a deep sea seaction of the Marine Habitat Classification of Britain and Ireland., p. 75, JNCC, Peterborough.

Pires, D.O., Castro, C.B. & Silva, J.C. (2009). Reproductive biology of the deep-sea pennatulacean *Anthoptilum murrayi* (Cnidaria, Octocorallia). M*arine Ecology Progress Series* 397, 103-112. http://www.jstor.org/stable/24874292

Populus, J., Vasquez, M., Albrecht, J., Manca, E., Agnesi, S., Al Hamdani, Z., Andersen, J., Annunziatellis, A., Bekkby, T., Bruschi, A., Doncheva, V., Drakopoulou, V., Duncan, G., Inghilesi, R., Kyriakidou, C., Lalli, F., Lillis, H., Mo, G., Muresan, M., Salomidi, M., Sakellariou, D., Simboura, M., Teaca, A., Tezcan, D., Todorova, V. & Tunesi, L. (2017). EUSeaMap, a European broad-scale seabed habitat map. 174p. http://doi.org/10.13155/49975

Puig, P., Canals, M., Company, J.B., Martın, J., Amblas, D., Lastras, G., Palanques, A. & Calafat, A.M. (2012). Ploughing the deep sea floor. *Nature* 489: 286-290.

Ribeiro Santos, A. (2013). The life history and ecology of black scabbardfish (*Aphanopus carbo* Lowe 1839) in the north-east Atlantic. PhD Thesis, University College Cork.

Rice, A.L., Tyler, P.A. & Paterson, G.J.L. (1992). The pennatulid *Kophobelemnon stelliferum* (Cnidaria: Octocorallia) in the Porcupine Seabight (north-east Atlantic Ocean). *Journal of the Marine Biological Association of the United Kingdom* 72, 417-434. https://doi.org/10.1017/s0025315400037796

Roberts, J.M., Harvey, S.M., Lamont, P.A., Gage, J.D. & Humphery, J.D. (2000). Seabed photography, environmental assessment and evidence for deep-water trawling on the continental margin west of the Hebrides. *Hydrobiologia*, 441. 173–183.

Roberts, C. (2002). Deep impact: the rising toll of fishing in the deep sea. *TRENDS in Ecology and Evolution* 17(5), p242-245.

Roberts, J.M., Wheeler, A.J. & Freiwald. A. (2006). Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science*, 312. 543–547.

Rosenberg, R., Nilsson, H.C., Gremare, A. & Amouroux, J.M. (2003). Effects of demersal trawling on marine sedimentary habitats analysed by sediment profile imagery. Journal of Experimental Marine Biology and Ecology 285-286: 465-477.

Ross, R.E., Nimmo-Smith, W.A.M. & Howell, K.L. (2016). Increasing the depth of current understanding: sensitivity testing of deep-sea larval dispersal models for ecologists. *PLoS ONE* 11, e0161220. https://doi.org/10.1371/journal.pone.0161220

Ross, R.E., Nimmo-Smith, W.A.M. & Howell, K.L. (2017). Towards ‘ecological coherence’: assessing larval dispersal within a network of existing Marine Protected Areas. *Deep Sea Research Part I: Oceanographic Research Papers* 126, 128-138. https://doi.org/10.1016/j.dsr.2017.06.004

Roux, M. (1976). Aspects de la variabilité et de la croissance au sein d’une population de la pentacrine actuelle: *Annacrinus wyvillethomsoni* Jeffreys (Crinoidea) Bisacy. Thalassia Yogoslavica 12, 307-320.

Ruiz-Pico, S., Serrano, A., Punzón, A., Altuna, Á., Fernández-Zapico, O. & Velasco, F. (2017). Sea pen (Pennatulacea) aggregations on the northern Spanish shelf: distribution and faunal assemblages. 2017 81, 11. https://doi.org/10.3989/scimar.04359.06A

Sánchez, F., Serrano, A. & Ballesteros, M.G. (2009). Photogrammetric quantitative study of habitat and benthic communities of deep Cantabrian Sea hard grounds. *Continental Shelf Research 29*, 1174-1188. https://doi.org/10.1016/j.csr.2009.01.004

Sherwood, O.A., Jamieson, R.E., Edinger, E.N. & Wareham, V.E. (2008). Stable C and N isotopic composition of cold-water corals from the Newfoundland and Labrador continental slope: Examination of trophic, depth and spatial effects. *Deep Sea Research Part I: Oceanographic Research Papers* 55, 1392-1402. https://doi.org/10.1016/j.dsr.2008.05.013

Southward, E.C. & Campbell, A.C. (2006). Echinoderms. Keys and notes for the identification of British species, p. vii+272, Field Studies Council, Shrewsbury.

Stewart, H.A. & Davies, J.S. (2007). Habitat investigations within the SEA7 and SEA4 areas of the UK continental shelf (Hatton Bank, Rosemary Bank, Wyville Thomson Ridge and Faroe–Shetland Channel). British Geological Survey Commissioned Report, CR/07/051, p. 85, British Geological Survey. http://nora.nerc.ac.uk/id/eprint/507375/1/CR07051N.pdf

Thurber, A.R., Sweetman, A.K., Narayanaswamy, B.E., Jones, D.O.B., Ingels, J. & Hansman, R.L. (2014). Ecosystem function and services provided by the deep sea. *Biogeosciences*, 11, 3941–3963, 2014 www.biogeosciences.net/11/3941/2014/.

Tillin, H.M., Hull, S.C. & Tyler-Walters, H. (2010). Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK. Defra Contract No. MB0102 Task 3A, Report No. 22. http://randd.defra.gov.uk/Document.aspx?Document=MB0102_9721_TRP.pdf

Trimmer, M., Petersen, J., Sivyer, D.B., Mills, C., Young, E. & Parker, E.R. (2005). Impact of long-term benthic trawl disturbance on sediment sorting and biogeochemistry in the southern North Sea. *Marine Ecology Progress Series* 298: 79-94.

Tyler, P.A., Bronsdon, S.K., Young, C.M. & Rice, A.L. (1995). Ecology and gametogenic biology of the genus Umbellula (Pennatulacea) in the North Atlantic Ocean. Internationale Revue der gesamten Hydrobiologie und Hydrographie 80, 187-199. https://doi.org/10.1002/iroh.19950800207

Tyler-Walters, H., James, B., Carruthers, M., Wilding, C., Durkin, O., Lacey, C., Phillpott, E., Adams, L., Chaniotis, P.D., Wilkes, P.T.V., Seeley, R., Dargie, J. & Crawford-Avis, O.T. (2016). Descriptions of Scottish Priority Marine Features (PMFs). Scottish Natural Heritage Commissioned Report No. 406, p. 149, Scottish Natural Heritage. https://www.nature.scot/snh-commissioned-report-406-descriptions-scottish-priority-marine-features-pmfs

UKSeaMap (2016). A broad-scale seabed habitat map for the UK. http://jncc.defra.gov.uk/page-7354.

Van de Velde, S., Gao, Y. & Meysman, F. (2016). Bottom trawling keeps the geochemistry of the seafloor permanently out of steady state. Poster: Department of Analytical, Environmental and Geochemistry, Vrije Universiteit Brussel / Department of Ecosystem Studies, Royal Netherlands Institute for Sea Research.

Watling, L., France, S.C., Pante, E. & Simpson, A. (2011). Biology of Deep-Water Octocorals. *Advances in Marine Biology*. Lesser, M. (ed), pp. 41-122, Academic Press.

Wienberg, C., Beuck, L., Heidkamp, S., Hebbeln, D., Freiwald, A., Pfannkuche, O. & Monteys, X. (2008). Franken Mound: facies and biocoenoses on a newly-discovered “carbonate mound” on the western Rockall Bank, NE Atlantic. *Facies* 54, 1-24. https://doi.org/10.1007/s10347-007-0118-0

Williams, G.C. (2011). The Global Diversity of Sea Pens (Cnidaria: Octocorallia: Pennatulacea). *PLoS ONE* 6, e22747. https://doi.org/10.1371/journal.pone.0022747

Wright, E.P., Kemp, K., Rogers, A.D. & Yesson, C. (2015). Genetic structure of the tall sea pen *Funiculina quadrangularis* in NW Scottish sea lochs. *Marine Ecology* 36, 659-667. https://doi.org/10.1111/maec.12174

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Data available under the Open Government Licence: Contains British Geological Survey materials ©NERC (1980, 1984, 1986, 1987, 1992, 1994, 1995) and Department of Energy and Climate Change materials ©DECC (2000). (http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/)

ICES VME datasets
ICES VME Dataset 2015, ICES, Copenhagen http://www.ices.dk/marine-data/data-portals/Pages/vulnerable-marine-ecosystems.aspx

Appendix 1 - Figures

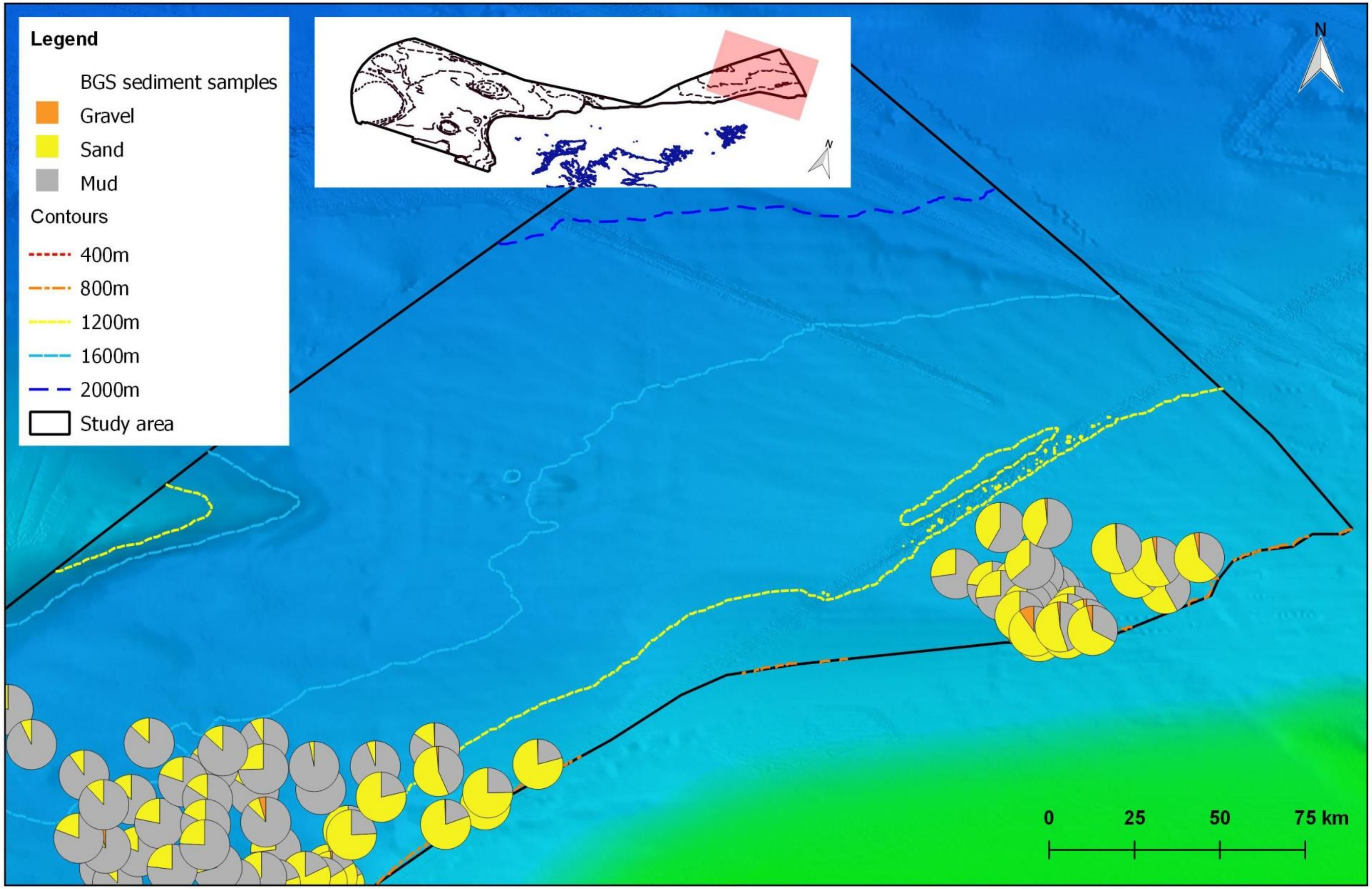

Figure 2: Distribution of broad sediment categories (gravel, sand and mud) in part of the northern study area. (Data sources: British Geological Survey\GeoIndex Offshore. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

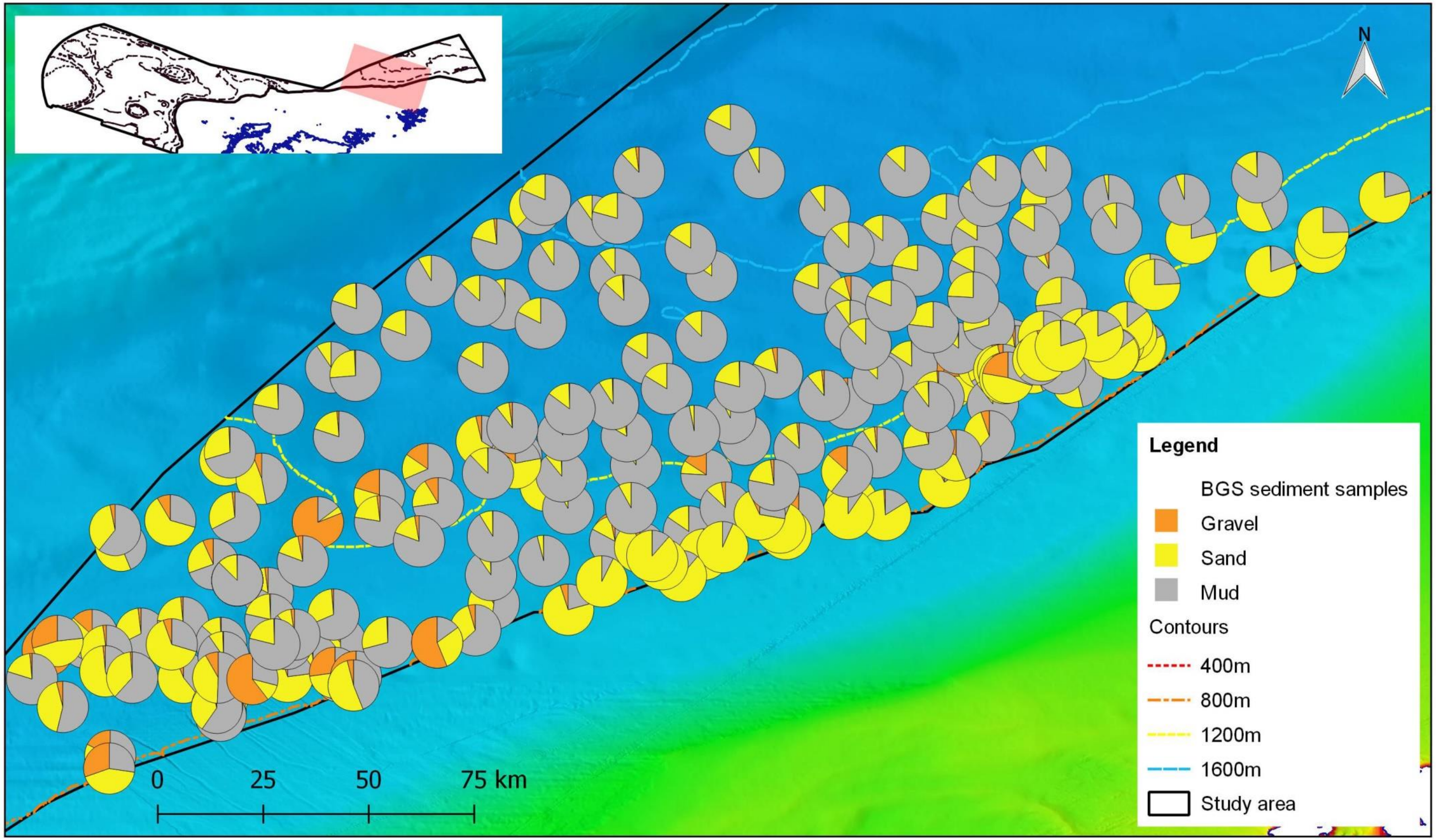

Figure 3: Distribution of broad sediment categories (gravel, sand and mud) in part of the northern study area. (Data sources: British Geological Survey\GeoIndex Offshore. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

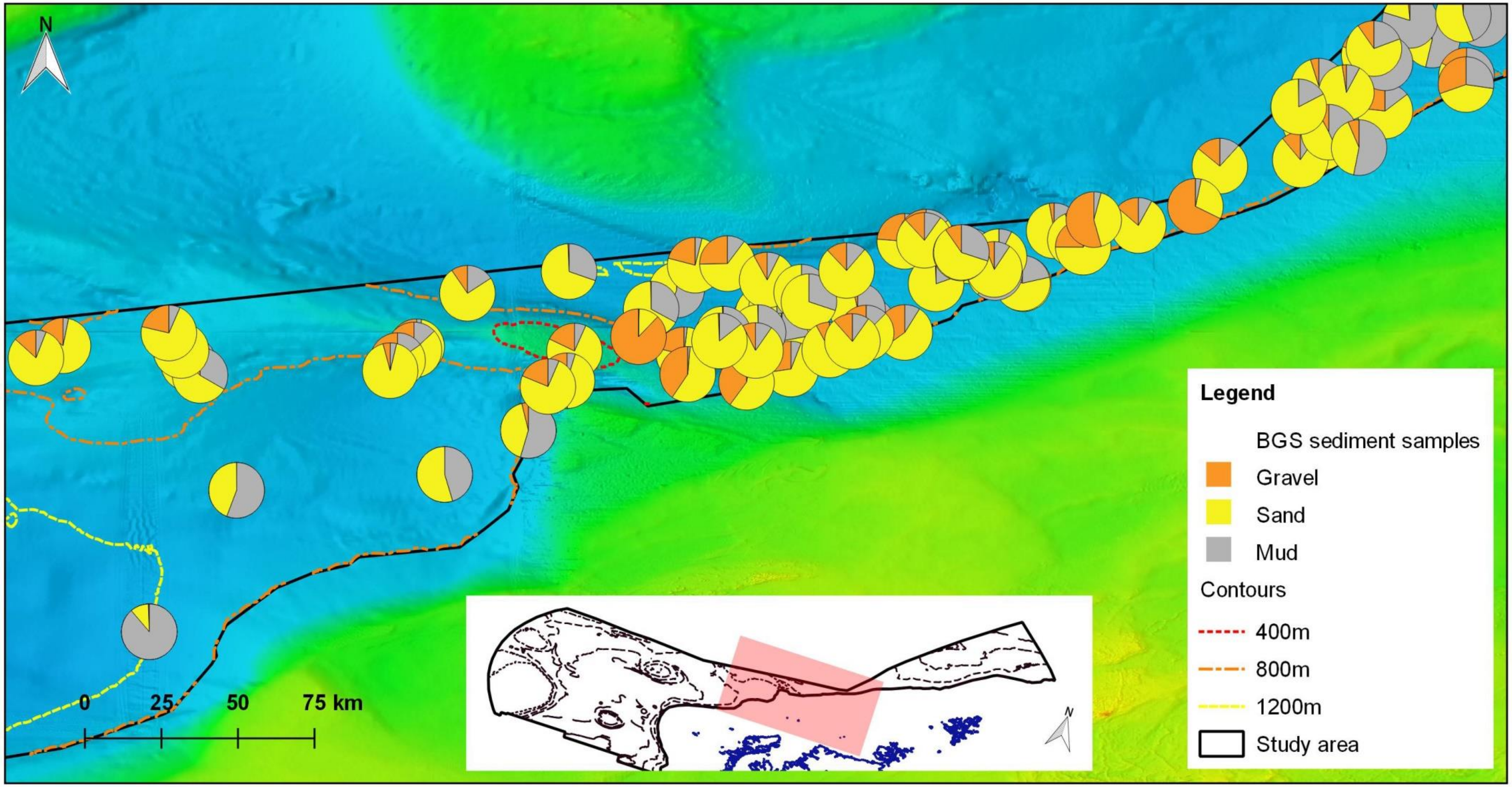

Figure 4: Distribution of broad sediment categories (gravel, sand and mud) in the central part of the study area. (Data sources: British Geological Survey\GeoIndex Offshore. Bathymetry: EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

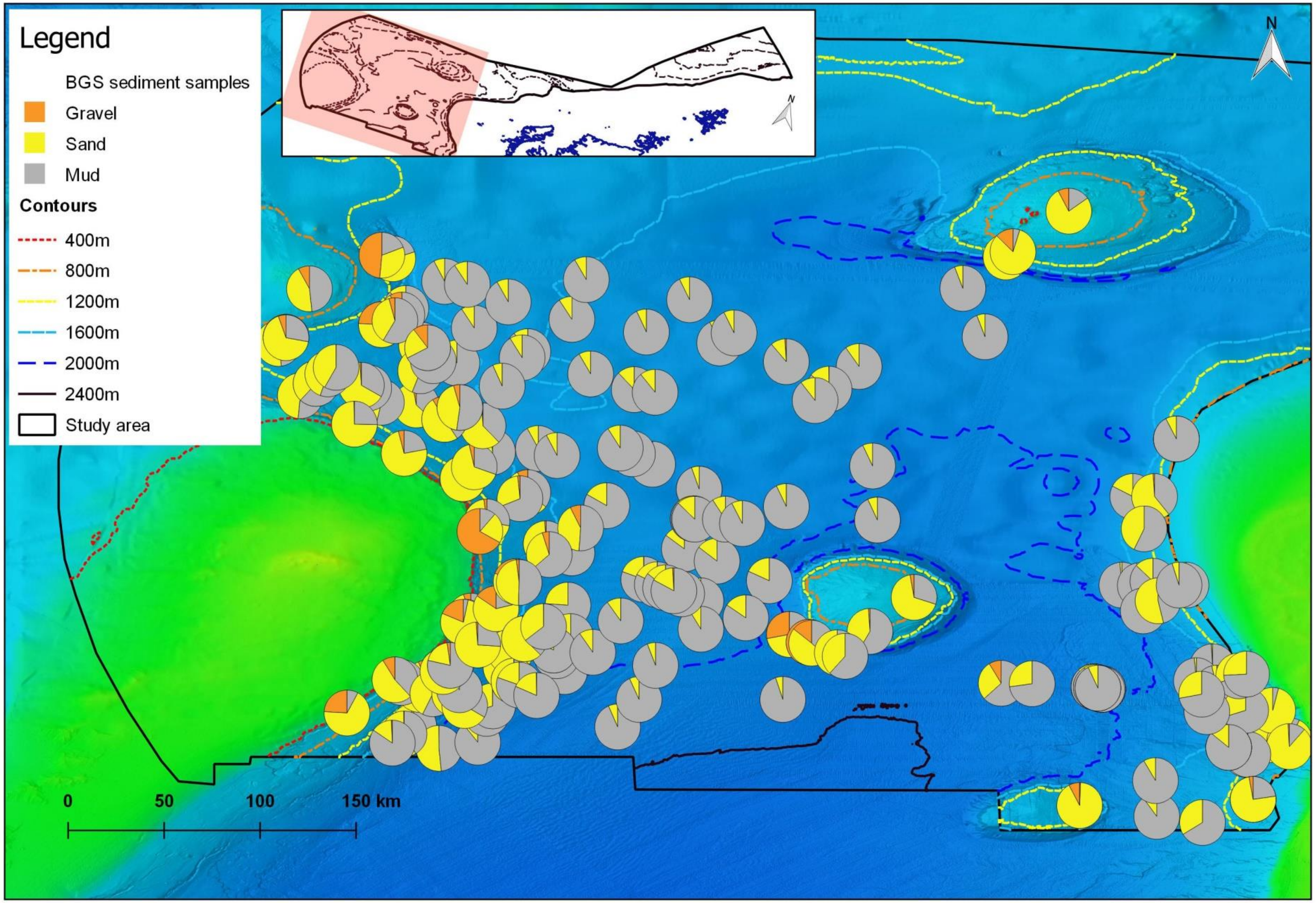

Figure 5: Distribution of broad sediment categories (gravel, sand and mud) in the western study area. (Data sources: British Geological Survey\GeoIndex Offshore. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

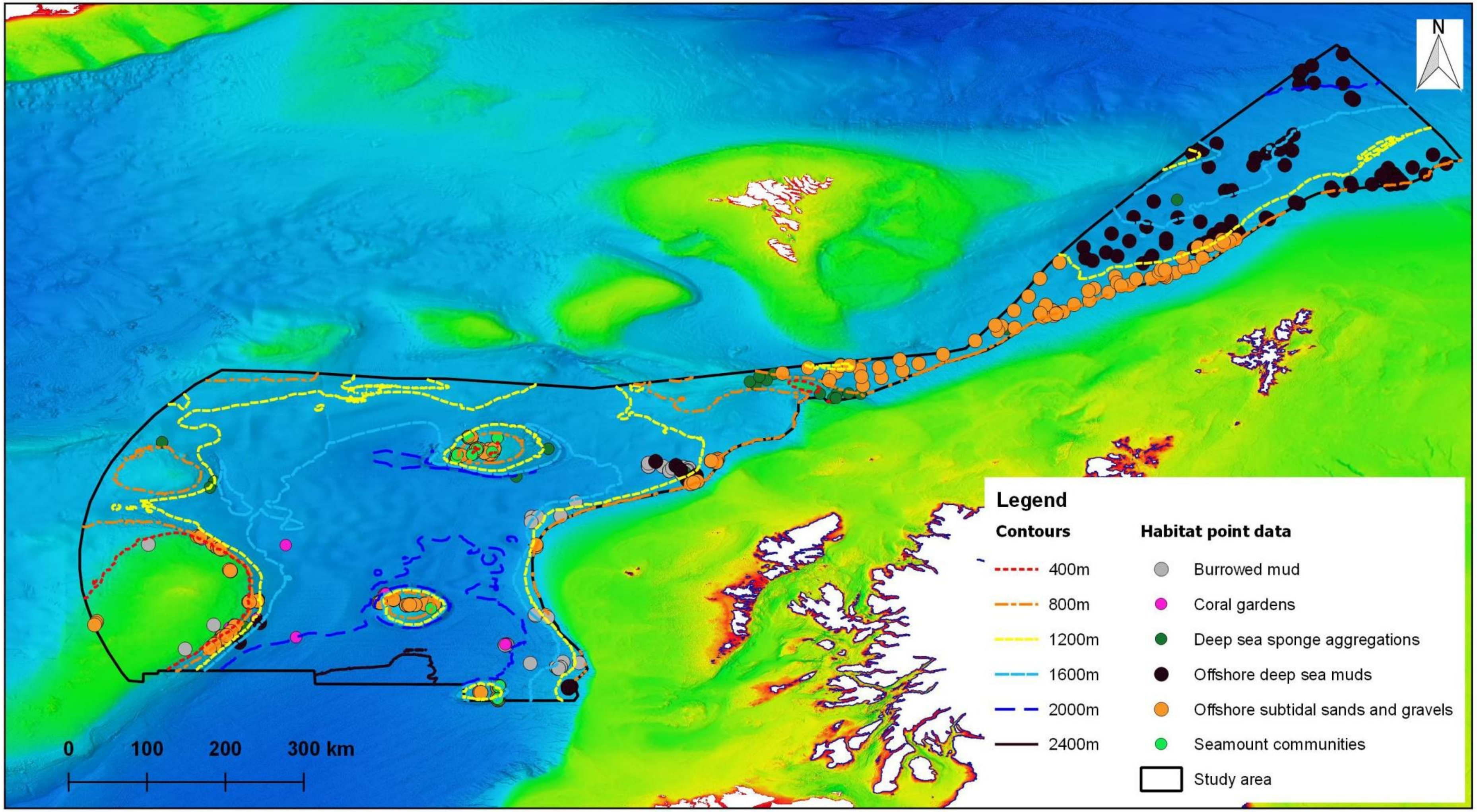

Figure 6: Location of point habitat data across the study area. (Data sources: GeMS. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

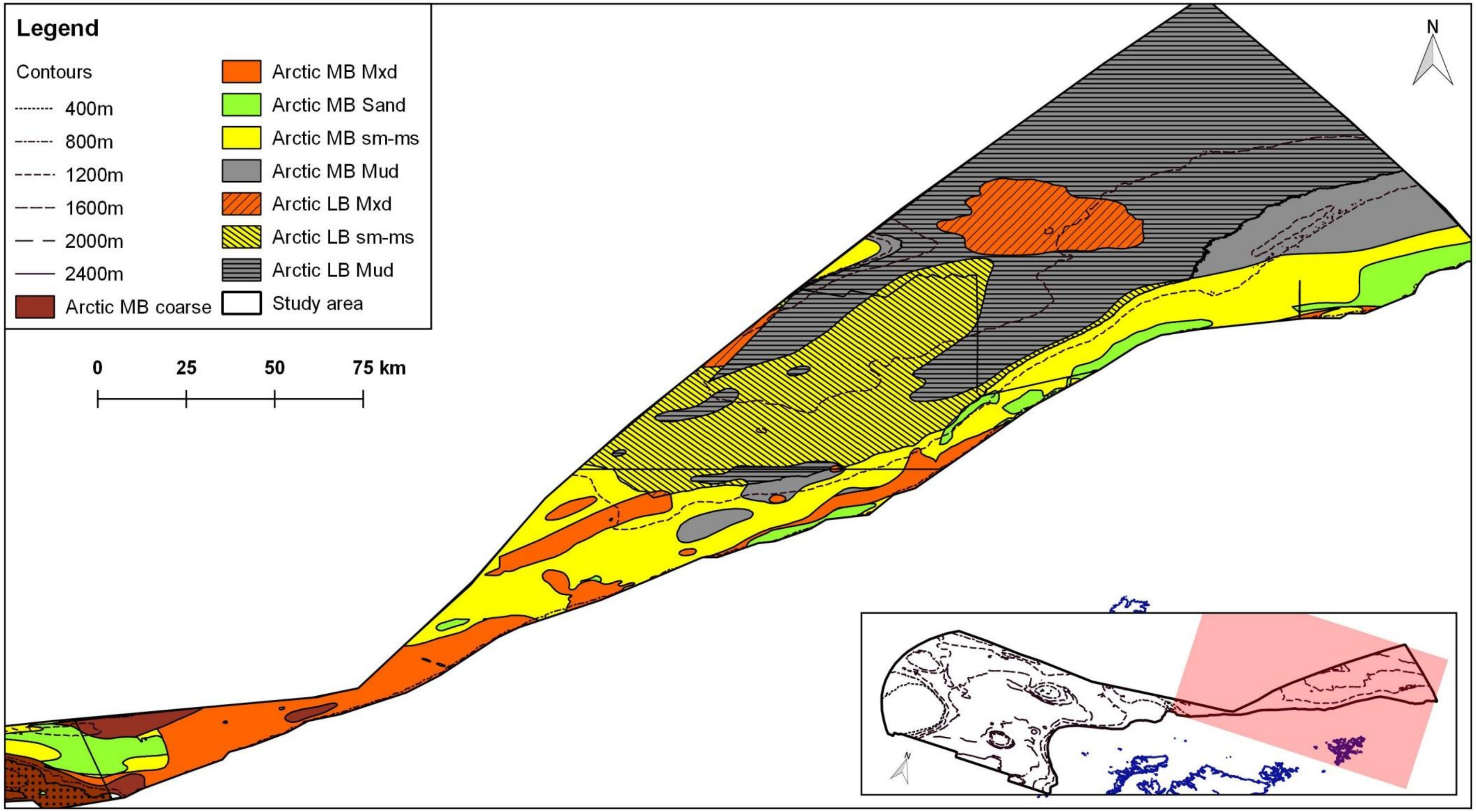

Figure 7: Distribution of Arctic bathyal sedimentary habitats across the northern study area (MB = mid bathyal; LB = lower bathyal; Mxd = mixed sediment; sm-ms = sandy mud-muddy sand). (Data source: UKSeaMap2016).

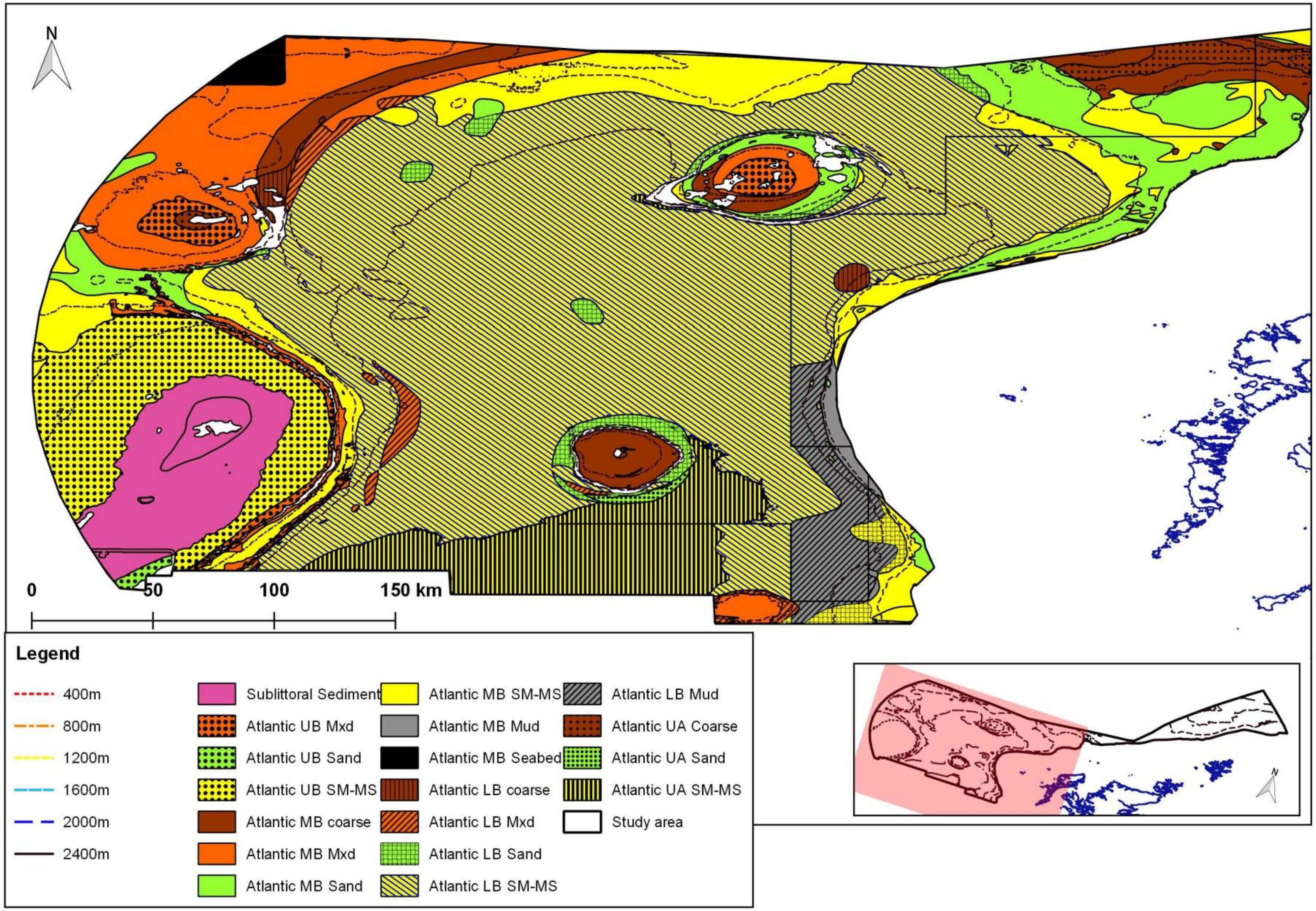

Figure 8: Distribution of Atlantic bathyal and abyssal sedimentary habitats across the western study area. (UB = upper bathyal; MB = mid bathyal; LB = lower bathyal; UA = upper abyssal; Mxd = mixed sediment; SM-MS = sandy mud-muddy sand). (Data source: UKSeaMap2016).

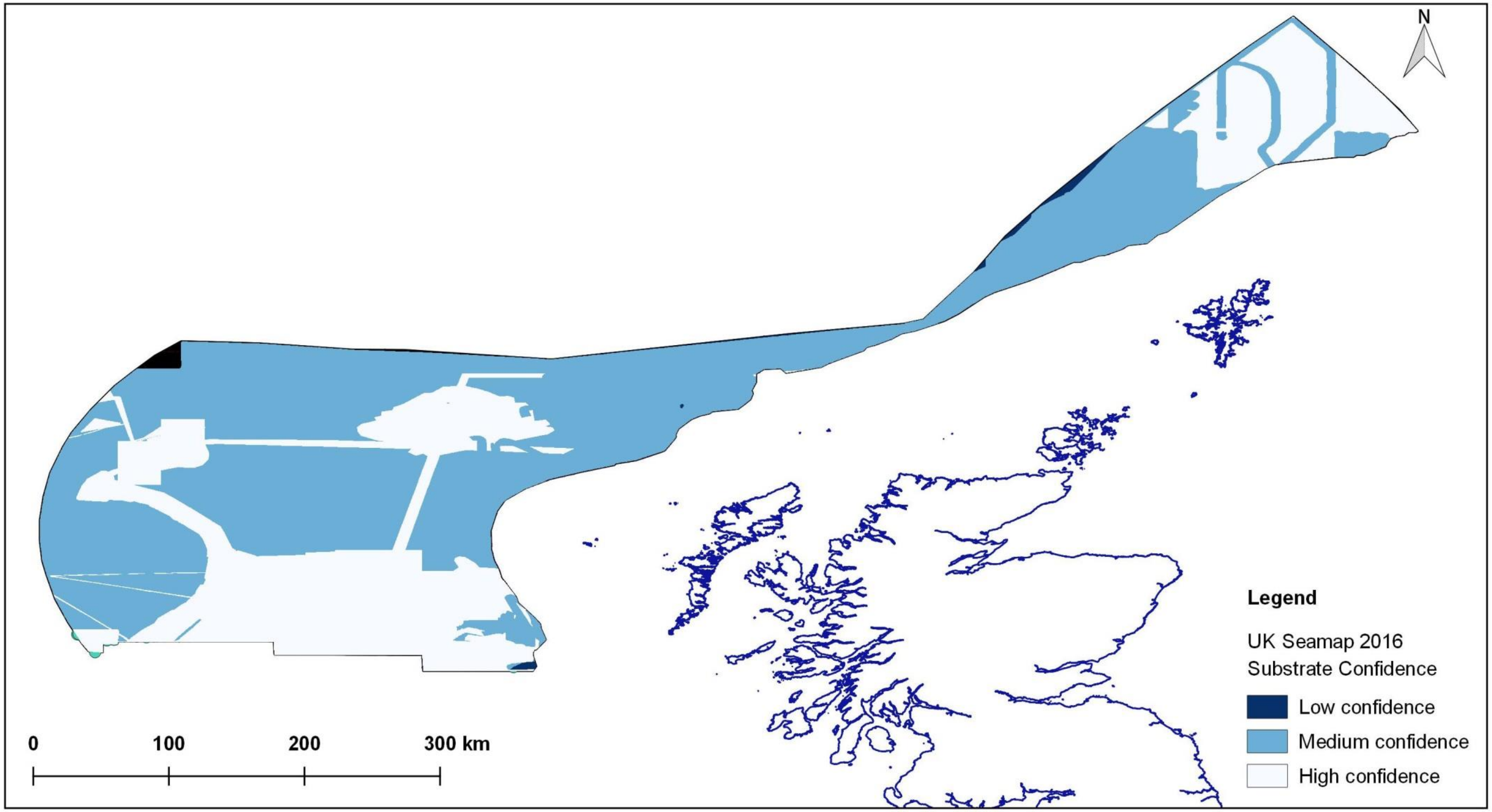

Figure 9: Confidence in the assignment of substrate type across the study area. (Data source: UKSeaMap2016).

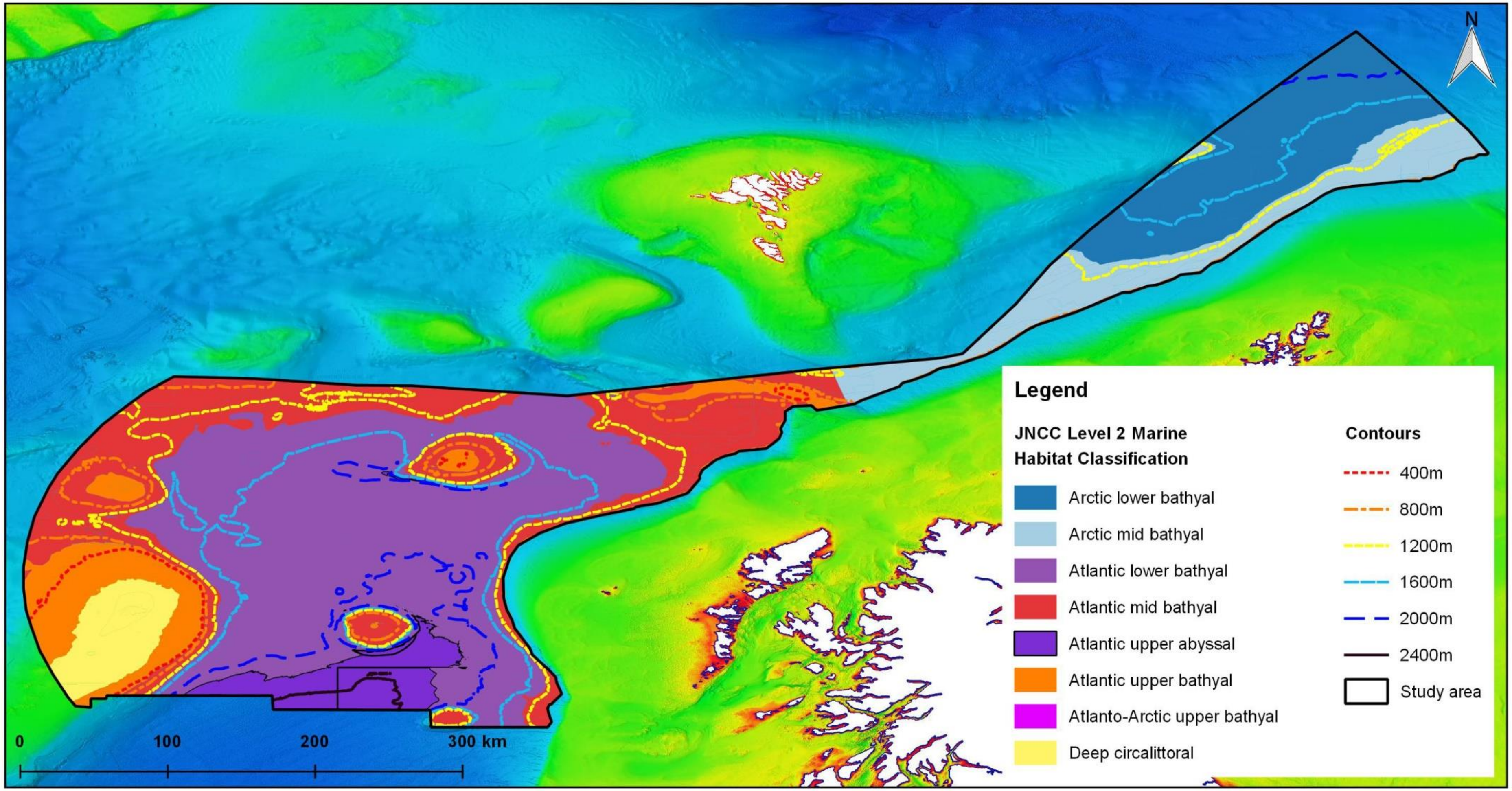

Figure 10: Distribution of level 2 habitats from the JNCC Marine Classification Hierarchy which form the Arctic and Atlantic biozones across the study area. (Data source: UKSeaMap2016).

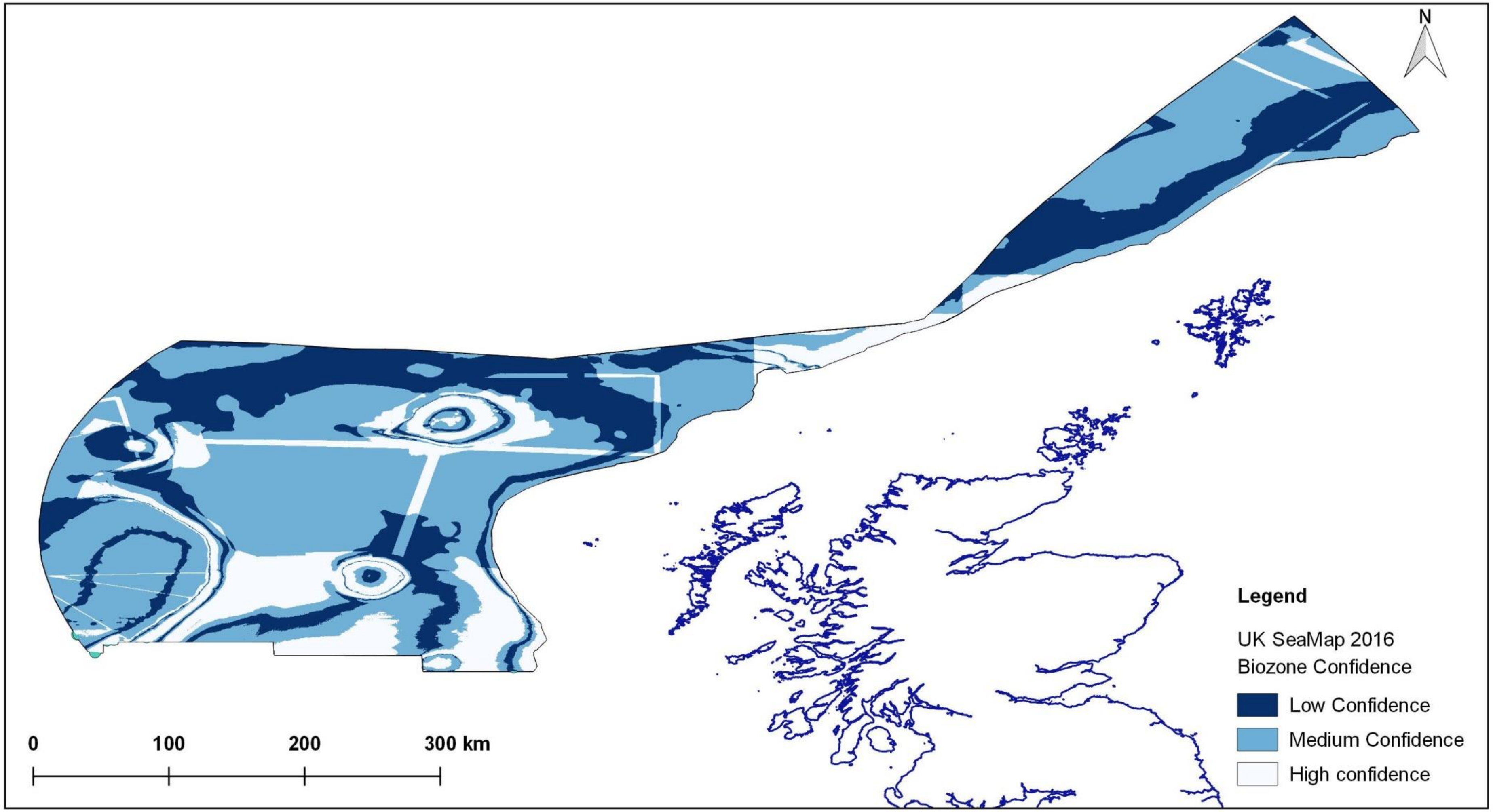

Figure 11: Confidence in the assignment of biozones across the study area. (Data source: UKSeaMap2016).

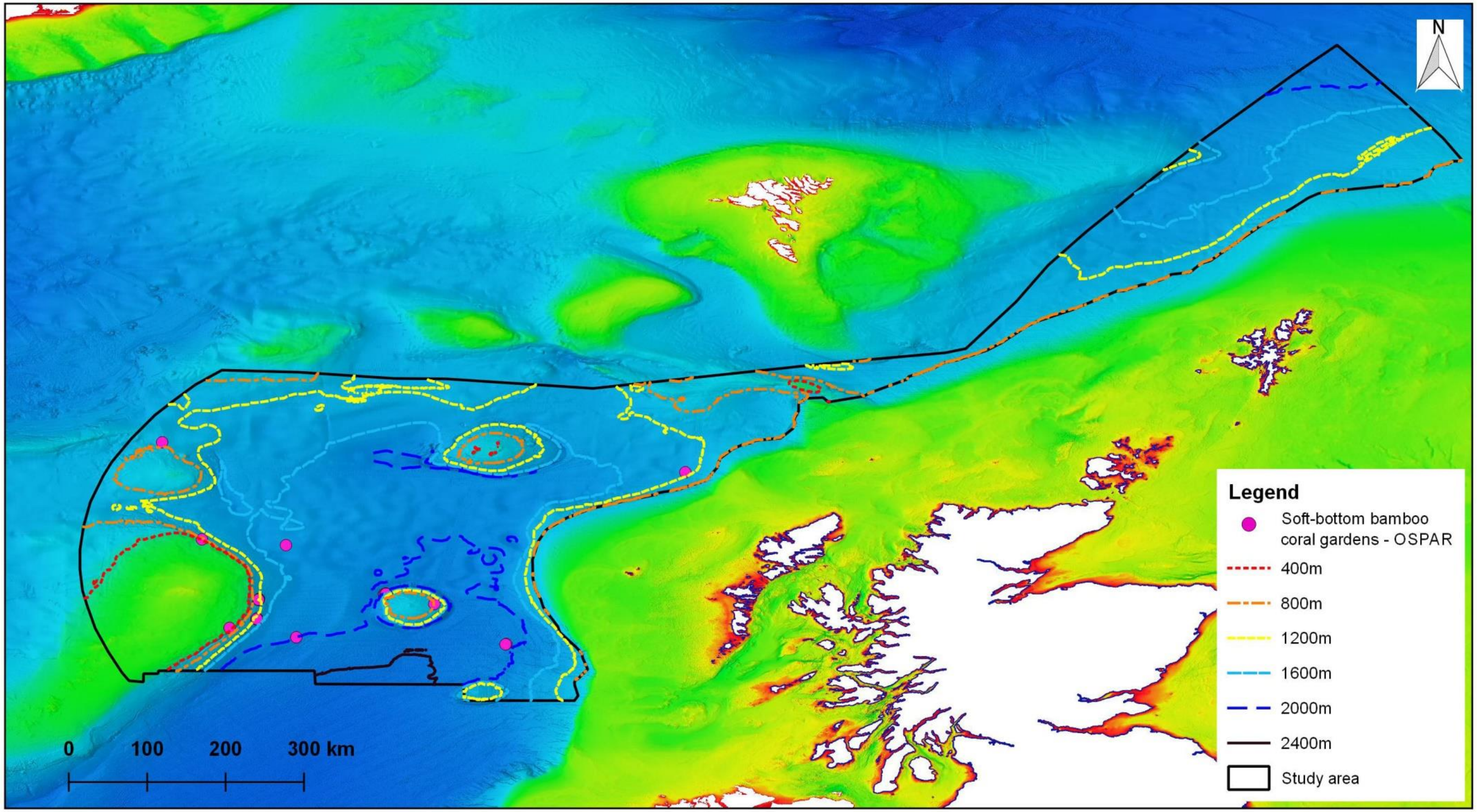

Figure 12: Distribution of soft bottom bamboo coral gardens across the study area. (Data sources: GeMS. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

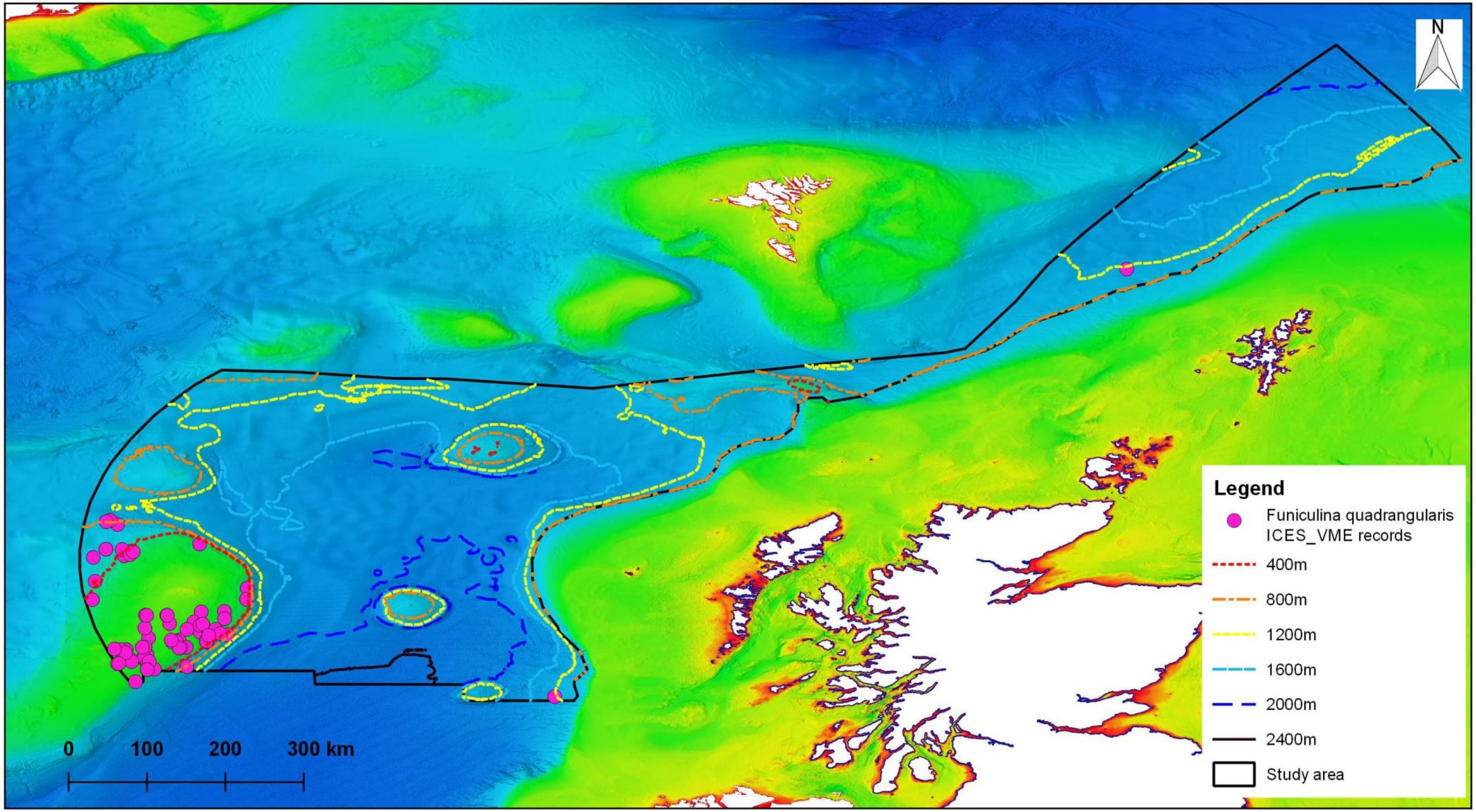

Figure 13: Occurrence of *Funiculina quadrangularis* across the study area (Data sources: ICES VME data. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

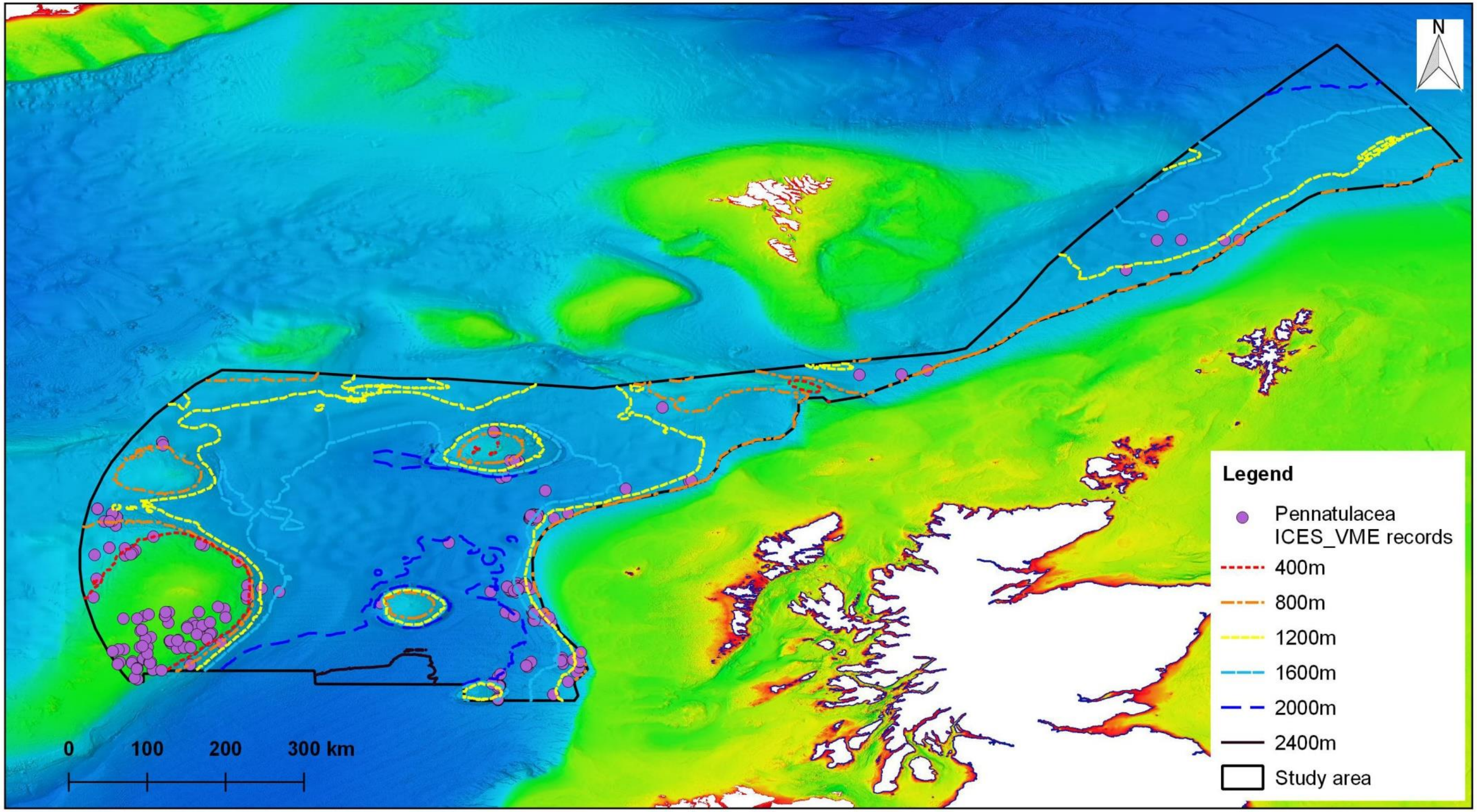

Figure 14: Occurrence of Seapens *(*Pennatulacea*)* across the study area (Data sources: ICES VME data. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

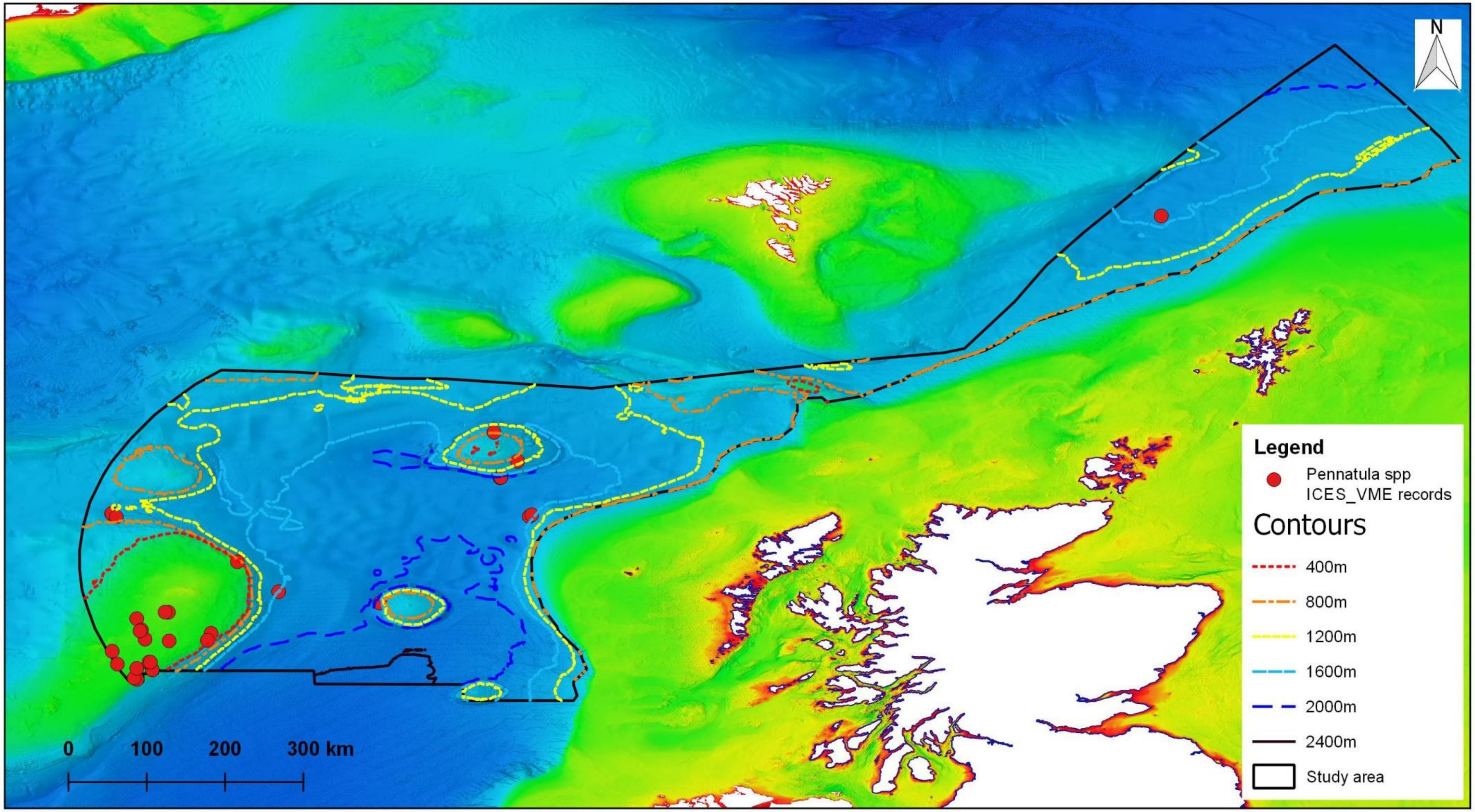

Figure 15: Occurrence of *Pennatula* spp. across the study area (Data sources: ICES VME data. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

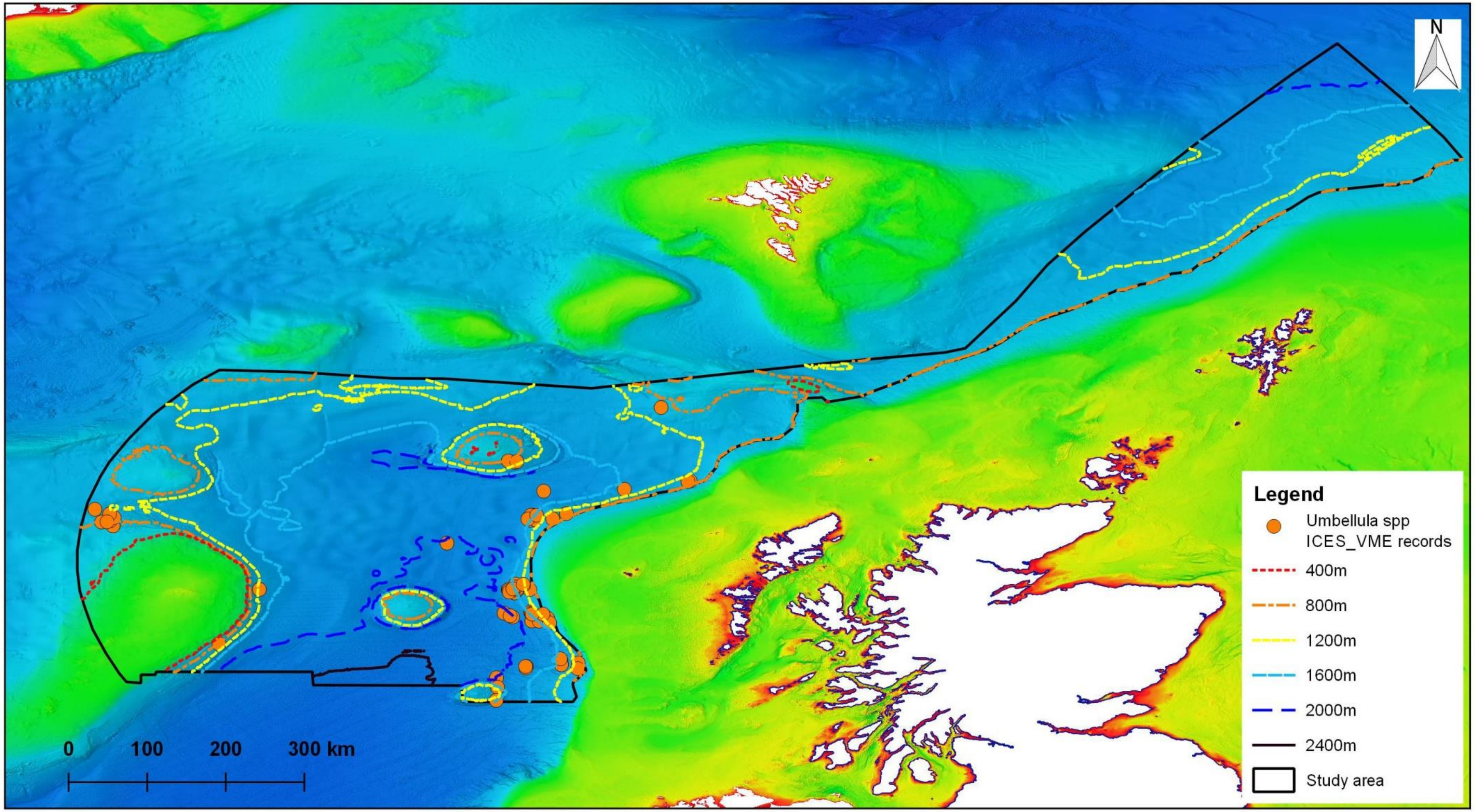

Figure 16: Occurrence of *Umbellula* spp. across the study area (Data sources: ICES VME data. EMODnet Bathymetry Consortium (2016): EMODnet Digital Bathymetry (DTM)).

Appendix 2 - Tables

Table 8: Biotopes listed in the Marine Habitat Classification for Britain & Ireland which include crinoids either as characterising taxa or are mentioned in the description (JNCC 2018).

Biotope Code	Biotope Name	Depth (m)	Description	Characterising spp.
M.AtMB.Co.CriCom	Crinoid dominated community on Atlantic mid bathyal coarse sediment	600-1300	This broad community contains assemblages where crinoids dominate the fauna. Crinoid assemblages are found typically in areas with higher current speeds that facilitate filter feeding, such as the shelf edge. The crinoid species *Leptometra celtica* is recorded in the Atlantic upper and mid bathyal. Associated species are likely to differ with depth and substrate type.	None listed
M.AtMB.Co.CriCom.LepCel	*Leptometra celtica* assemblage on Atlantic mid bathyal coarse sediment	Recorded from 180-792m Zone: 600-1300	This biotope consists of dense aggregations of the crinoid L*eptometra celtica* on coarse sediment in the mid bathyal. It occurs at the shelf edge and in the heads of canyons. It is likely that the fast currents associated with the heads of canyon systems provide a favourable habitat for suspension feeding organisms such as **crinoids.** The same assemblage has been recorded in the upper bathyal on various substrate types but any associated species are likely to differ. Characterising species listed refer to all *Leptometra celtica* assemblages not just those found associated with the zone and substrate specified in this biotope.	*Leptometra celtica* and other crinoids
M.AtMB.Sa.CriCom	Crinoid dominated community on Atlantic mid bathyal sand	600-1300	This broad community contains assemblages where **crinoids** dominate the fauna. **Crinoid** assemblages are found typically in areas with higher current speeds that facilitate filter feeding, such as the shelf edge. The crinoid species *Leptometra celtica* is recorded in the Atlantic upper and mid bathyal. Associated species are likely to differ with depth and substrate type.	None listed
M.AtMB.Sa.CriCom.LepCel	*Leptometra celtica* assemblage on Atlantic mid bathyal sand	Recorded from 180-792m Zone: 600-1300	This biotope consists of dense aggregations of the crinoid *Leptometra celtica* on sand in the mid bathyal. It occurs at the shelf edge and in the heads of canyons. It is likely that the fast currents associated with the heads of canyon systems provide a favourable habitat for suspension feeding organisms such as **crinoids.** The same assemblage has been recorded in the upper bathyal on various substrate types but any associated species are likely to differ. Characterising species listed refer to all *Leptometra celtica* assemblages not just those found associated with the zone and substrate specified in this biotope.	*Leptometra celtica* and other crinoids
M.AtMB.Mu.CriCom	Crinoid dominated community on Atlantic mid bathyal mud	600-1300	This broad community contains assemblages where **crinoids** dominate the fauna. **Crinoid** assemblages are found typically in areas with higher current speeds that facilitate filter feeding, such as the shelf edge. The crinoid species *Leptometra celtica* is recorded in the Atlantic upper and mid bathyal. Associated species are likely to differ with depth and substrate type	None listed
M.AtLB.Co.MixCor.DisSol	Discrete *Solenosmilia variabilis* colonies on Atlantic lower bathyal coarse sediment	Recorded 1270-1763m Zone: 1300-2100	This biotope is a deeper variant of discrete *Lophelia pertusa* colonies where *L. pertusa* is replaced by *Solenosmilia variabilis* occurring on coral rubble. The same assemblage was recorded on rock but associated species are likely to differ. Characterising species listed refer to all discrete *Solenosmilia variabilis* assemblages not just those found associated with the zone and substrate specified in this biotope.	Crinoidea sp. 1

Biotope Code	Biotope Name	Depth (m)	Description	Characterising spp.
M.AtMA.Mu.CriCom	Crinoid dominated community on Atlantic mid abyssal mud	3100-4100	This broad community contains assemblages where crinoids dominate the fauna. **Crinoid** assemblages are found typically in areas with higher current speeds that facilitate filter feeding, such as the shelf edge. The crinoid species *Thaumatocrinus jungerseni* has been recorded on Atlantic mid abyssal mud.	None listed
M.AtMA.Mu.CriCom.ThaJun	*Thaumatocrinus jungerseni* assemblage on Atlantic mid abyssal mud	Recorded from 3,580m Zone: 3100-4100	Recorded from the mouth of Rockall Trough at 3580m dominated by the comatulid crinoid *Thaumatocrinus jungerseni* on fine silt or pelagic ooze. It is possible that this site experiences increased current speeds as a result of the constriction of the topography in this area, making it favourable to suspension feeding organisms such as crinoids. This assemblage may therefore be a variation on the *Psychropotes longicauda* and *Oneirophanta mutabilis* assemblage. This assemblage was described based on literature only.	*Thaumatocrinus jungerseni*
M.ArMB.Co.BurAne	Burrowing anemone field in Arctic mid bathyal coarse sediment	600-1100	This broad community includes sediment biotopes where burrowing anemones are the dominant fauna. In Arctic mid bathyal coarse sediment, the burrowing anemones have been tentatively identified as Halcampids. They are found associated gravel/ pebble coarse sediment which is interspersed with rock. This community can occur in association with ophiuroid dominated communities, and **crinoid** dominated communities may attach to any rock present. Due to difficulties in taxonomic identification using only video footage, no species level assemblages could be described for this type of burrowing anemone field. Species are likely to differ from those occurring in Atlantic waters.	None listed

Table 9: Biotopes listed in the Marine Habitat Classification for Britain & Ireland which include seapens either as characterising taxa or they are mentioned in the description (JNCC 2018).

Biotope Code	Biotope Name	Depth (m)	Description	Characterising taxa
M.AtMB.Mu.SpnMeg	Sea pens and burrowing megafauna on Atlantic mid bathyal mud	600-1300	Dense aggregations of sea pens on fine sediments. The species composition will vary with depth and location. *Kophobelemnon* has been recorded in Atlantic upper and mid bathyal mud and sand, but associated species are likely to differ with zone and substrate type.	None listed
M.AtMB.Mu.SpnMeg.KopFie	*Kophobelemnon* fields on Atlantic mid bathyal mud	600-1300	This biotope is composed of dense aggregations of seapens of the genus *Kophobelemnon* (in the UK likely to be Kophobelemnon stelliferum) on mud. *Kophobelemnon* fields are also found in the upper bathyal zone but the associated infauna are likely to differ. Characterising species listed refer to all *Kophobelemnon stelliferum* assemblages not just those found associated with the zone and substrate specified in this biotope. Includes these taxa.	*Kophobelemnon, Prototilum, Kophobelemnon stelliferum, Pennatula phosphorea*
M.ArMB.Mu	Arctic mid bathyal mud	600-1300	Deep-sea mud sediments have a diverse infaunal community dominated by polychaetes. Epifauna tend to be sparse, mobile species, but aggregations of erect fauna such as glass sponges, **sea pens** and soft corals can occur. In the absence of ecological data, mud habitat can be defined according to Long (2006), which describes the classification's broad sediment types according to the relative proportion of mud, sand and gravel. Note that Folk muddy sand sediments are classed as mud habitat if the mud content is great enough to support species usually associated with mud. In the absence of particle size data it can be difficult to reliably distinguish between mud and sand.	None listed
M.AtMA.Mu	Atlantic mid abyssal mud	3100-4100	Deep-sea mud sediments have a diverse infaunal community dominated by polychaetes. Epifauna tend to be sparse, mobile species, but aggregations of erect fauna such as glass sponges, **sea pens** and soft corals can occur. In the absence of ecological data, mud habitat can be defined according to Long (2006), which describes the classification's broad sediment types according to the relative proportion of mud, sand and gravel It can be difficult to reliably distinguish between mud and sand using video data only. Note that muddy sand sediments are classed as mud if the mud content is great enough.	None listed

Biotope Code	Biotope Name	Depth (m)	Description	Characterising taxa
M.AtMA.Mu.CriCom.ThaJun	*Thaumatocrinus jungerseni* assemblage on Atlantic mid abyssal mud	Recorded from 3,580m Zone: 3100-4100	Recorded from the mouth of Rockall Trough at 3580m dominated by the comatulid crinoid *Thaumatocrinus jungerseni* on fine silt or pelagic ooze. It is possible that this site experiences increased current speeds as a result of the constriction of the topography in this area, making it favourable to suspension feeding organisms such as crinoids. This assemblage may therefore be a variation on the *Psychropotes longicauda* and *Oneirophanta mutabilis* assemblage. This assemblage was described based on literature only.	Pennatulidae
M.ArUA.Mu	Arctic upper abyssal mud	2000-3100	Deep-sea mud sediments have a diverse infaunal community dominated by polychaetes. Epifauna tend to be sparse, mobile species, but aggregations of erect fauna such as glass sponges, **sea pens** and soft corals can occur. In the absence of ecological data, mud habitat can be defined according to Long (2006), which describes the classification's broad sediment types according to the relative proportion of mud, sand and gravel. It can be difficult to reliably distinguish between mud and sand using video data only. Note that muddy sand sediments are classed as mud if the mud content is great enough.	None listed
M.AtLA.Mu	Atlantic lower abyssal mud	>4100	Deep-sea mud sediments have a diverse infaunal community dominated by polychaetes. Epifauna tend to be sparse, mobile species, but aggregations of erect fauna such as glass sponges, **sea pens** and soft corals can occur. In the absence of ecological data, mud habitat can be defined according to Long (2006), which describes the classification's broad sediment types according to the relative proportion of mud, sand and gravel. It can be difficult to reliably distinguish between mud and sand using video data only. Note that muddy sand sediments are classed as mud if the mud content is great enough.	None listed