Supplementary Advice on Conservation Objectives for Dogger Bank Special Area of Conservation

December 2022

JNCC

jncc.gov.uk

The information provided in this document sets out JNCC's current view of the site's condition, the conservation benefits which the site can provide and the measures required to support achievement of the site's conservation objectives. This forms part of JNCC's formal conservation advice package for the site and must be read in conjunction with all parts of the package as listed below:

- Background document explaining where to find the advice package, JNCC's role in the provision of conservation advice, how the advice has been prepared, when to refer to it and how to apply it;
- Conservation Objectives setting out the broad ecological aims for the site;
- Statements on:
  - the site's qualifying features condition;
  - conservation benefits that the site can provide; and
  - conservation measures needed to support achievement of the conservation objectives set for the site (this document);
- Supplementary Advice on Conservation Objectives (SACO) providing more detailed and site-specific information on the conservation objectives (this document); and
- Advice on Operations providing information on those human activities that, if taking place within or near the site, can affect it and present a risk to the achievement of the conservation objectives.

The most up-to-date conservation advice for this site can be downloaded from the conservation advice tab in the Site Information Centre (SIC) on JNCC's website.

The advice presented here describes the ecological characteristics or 'attributes' of the site's qualifying feature: Annex I Sandbanks which are slightly covered by seawater all the time, specified in the site's conservation objectives. These attributes include extent and distribution, structure and function and supporting processes.

Figure 1 below illustrates the concept of how a feature's attributes are interlinked: with impacts on one potentially having knock-on effects on another e.g. the impairment of any of the supporting processes on which a feature relies can result in changes to its extent and distribution and/or structure and function.

Collectively, the attributes set out in Table 1 below, along with the objectives set for each of them, describe the desired ecological condition (favourable) for the site's feature. The condition of a feature contributes to its favourable conservation status more widely, as well as the site's integrity. All attributes listed in Table 1 must be taken into consideration when assessing impacts from an activity.

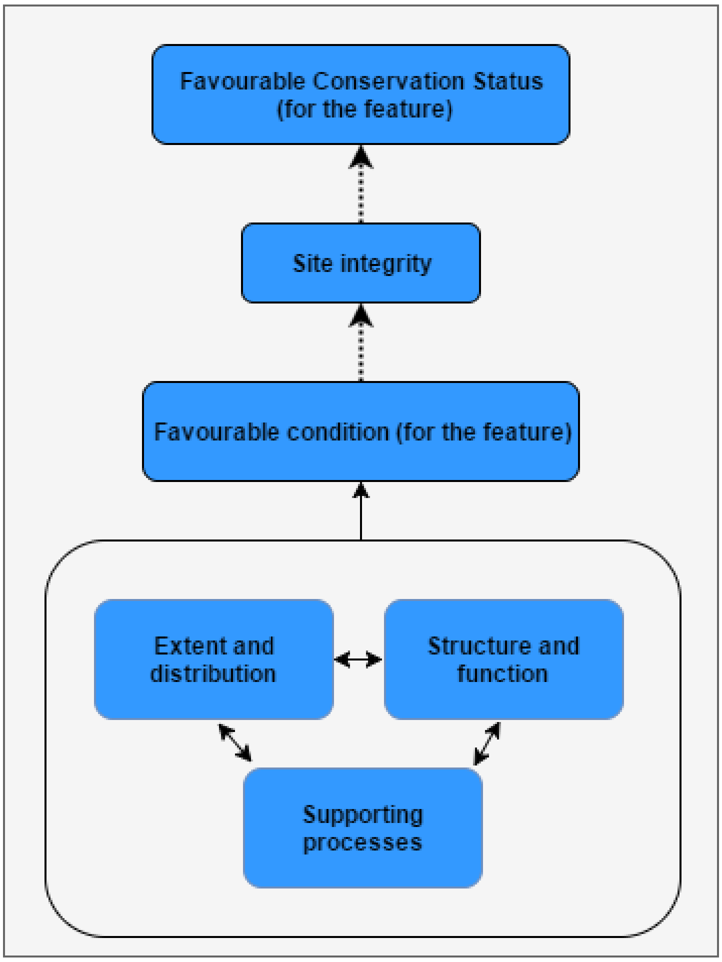

Figure 1. Conceptual diagram showing how feature attributes are interlinked, describe favourable condition and contribute to site integrity and wider favourable conservation status.

In Table 1 below, the attributes for the Annex I Sandbanks which are slightly covered by seawater all the time, are listed and a description provided in explanatory notes. An objective of restore or maintain is set for each feature attribute. The objective reflects our current understanding of a feature's condition e.g. where evidence indicates some of a feature's extent is lost and needs to be restored or that extent is not lost and needs to be maintained in order to ensure the feature is in overall favourable condition. The rationale for setting an objective is also provided in the explanatory notes, along with reference to supporting evidence from the site. Note that where it is not practical through human intervention to restore a feature's attribute, a maintain objective is set, accompanied by a statement to reflect the impracticality of restoration.

Note also that when a maintain objective is set, this does not preclude the need for management, now or in the future. Please see the conservation measures for further detail regarding managing activities.

Table 1. Supplementary advice on conservation objectives (SACO): Annex I Sandbanks slightly covered by seawater all the time

Attribute: Extent and distribution

Objective: Restore

JNCC understands that the site continues to be subjected to activities that have resulted in a change to the extent and distribution of the feature within the site, noting bottom trawling no longer occurs within the site. Installation and/or removal of infrastructure will have a continuing effect on extent and distribution. As such, ***JNCC continues to advise a restore objective*** *which is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. offshore wind farms, cabling and oil and gas industry activities. Our confidence in setting this objective will continue to improve with longer-term monitoring and access to better information on the activities taking place within the site. Activities must look to minimise, as far as is practicable, changes in substratum within the site to minimise further impact on feature extent and distribution.*

Explanatory notes

Extent refers to the total area in the site occupied by the qualifying feature and must include consideration of its distribution, i.e. how it is spread out within the site. A reduction in extent has the potential to alter the biological and physical functioning of sedimentary habitat types (Elliott *et al.,*1998). The distribution of a habitat influences the component communities present, and can contribute to the health and resilience of the feature (JNCC, 2004b). The extent within the site must be conserved to the full known distribution.

Annex I sandbanks are defined and delineated (Pinder, 2020) by:

- ***large-scale topography*** which is elevated, elongated, rounded or irregular, permanently submerged and predominantly surrounded by deeper water (EC, 2013);
- ***sediment composition*** that is mainly sandy sediments (sand is defined as sediment particles between 2 mm and 0.0625 mm in diameter and sandy sediment must be composed of less than 30% gravel and have more sand than mud). Other sediment types including boulders, cobbles or mud may also be present on a sandbank; and
- ***biological assemblages***. See JNCC's Marine Habitat Correlation Table for more detail about the range of biological communities (biotopes) that can occur on Annex 1 sandbanks.

Loss of large-scale topography would constitute loss of the sandbank feature extent. Loss of the characterising sandbank biological assemblages or sandbank sediments from an area of the feature would constitute some of sandbank habitat and a reduction in overall feature extent.

In the UK offshore area, there are two different types of sandbank:

1. Sandy mound sandbanks: created by glacial processes which have long since stopped acting on the feature. While surface sediments may be mobilised, the extent and distribution of the sandbanks as a whole remain broadly unaffected by ongoing hydrodynamic processes. It is important to note that we would not expect large scale topography or the underlying immobile substrates to recover, should they be physically impacted. The sandbank communities, however, are capable of recovering from impacts but this will be dependent on prevailing environmental conditions, the influence of human activities i.e. the scale of any current impacts, species life history traits, environmental connectivity between populations and habitat suitability (Mazik *et al.,* 2015);
2. Open shelf ridge sandbanks: can be relatively mobile with their extent and distribution being actively influenced by ongoing hydrodynamic processes and subsequently changing naturally over time. Recovery from physical impacts for these types of sandbanks is possible but again dependent on the range of factors mentioned in 1 above.

Extent and distribution within the site
The site map for Dogger Bank SAC is available on JNCC's Interactive MPA Mapper. Dogger Bank is a sandy mound type sandbank, shaped by the Dogger Bank Formation; a geological formation deposited during the last glacial period and overlain by reworked glacial sediments (Cameron *et al.,* 1992; Diesing *et al*., 2009). Dogger Bank SAC contains the largest single continuous expanse of shallow sandbank in UK waters (JNCC, 2011). The site boundary delineates the sandbank feature in UK waters and is calculated to be 12,331km^2. The crest of the Dogger Bank lies in water less than 20m deep and the bank gradually extends into deeper water with the greatest slope change around the 45-50m depth contour (Diesing *et al*., 2009; JNCC, 2011).

The physical delineation and extent of the sandbank in deeper waters was determined using information on the biological communities as well as physical information and is supported by the original Site Assessment Document (JNCC, 2011). Further information on the distribution of biological communities within the feature is available in the **characteristic communities section.**

Some of the sandbank's extent is currently considered to be lost due to the presence of large-scale and widespread infrastructure associated with offshore oil and gas and cabling activities, which have resulted in changes to the substratum of the site. Four large-scale offshore wind farms and associated cables have also been approved across the site, with construction activities having begun in early 2021 (Dogger Bank Wind Farm, 2021). A further two offshore wind farms have been proposed through The Crown Estate's Offshore Leasing Round Four process (The Crown Estate, 2022).

These industries have placed infrastructure i.e. gas platforms, pipelines, wind turbines, cables and protective materials (e.g. rock dump and mattresses), in or on the seabed throughout the site; although it is not possible to quantify the amount of material introduced. While several reviews have contributed to quantifying the presence of hard substrate placed into the marine environment (Genesis, 2021; MBIEG, 2020;

Peritus International Ltd, 2022), this is not site specific and therefore certainty in the quantity of hard substrate deposited in Dogger Bank SAC remains low. The introduction of infrastructure and some protective materials e.g., concrete mattresses, results in changes to substratum, such as from sedimentary to hard substrate, and consequently changes to sandbank communities such that these areas no longer represent the sandbank feature as defined. Please see the physical structure: **sediment composition and distribution** within the site for more information on the substrate types that compose the sandbank feature within the site.

There has been significant decommissioning of oil and gas infrastructure in the site since 2018, primarily involving the placement of protective materials to support the removal of infrastructure (platforms and subsea structures). The removal of infrastructure will have a temporary impact on the site and may result in some local restoration of the sandbank due to recolonisation of sandbank communities where the original substrate is exposed. This will increase the extent of the sandbank feature, as more of the original sandbank substrate becomes available for colonisation by sandbank communities. However, oil and gas decommissioning operations may also result in further permanent impacts, due to deposition of material (e.g. rock dump) which can differ in size from sandbank substrate, which may cause localised changes to the sediment type.

A significant amount of offshore wind farm turbines and associated cabling is proposed within the site which will continue to change the substratum across the site due to the introduction of hard substrata placed for offshore wind farm cabling and scour protection. This is a long-term impact for the lifetime of the wind farm, which may range from 20-65 years (as stated in the Crown Estate Round 4 Habitats Regulations Assessment). While this hard substratum is present this reduces the area of natural sandbank available to biological communities and further reduces the Annex I sandbank extent. The impacts of future planned activities on the conservation objectives of the site will need to be taken into consideration during licence applications and reassessed in this conservation advice once activities begin and new evidence becomes available.

Whilst JNCC does not consider it likely that the human activities taking place within the site have the potential to permanently impact on the **large-scale topography** of the sandbank feature, JNCC continues to advise that the extent of the sandbank feature in terms of its **sedimentary composition** and **biological assemblages** has been reduced and it continues to be reduced by ongoing activities; albeit by an unquantifiable amount.

JNCC continues to advise a restore objective which is based on expert judgement; specifically, our **understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities** i.e. offshore wind farms, cabling, and oil and gas industry activities on the extent and distribution of the sandbank feature due to impacts on its sediment composition and consequently associated biological communities. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring, available evidence from wider sources and access to better information on the activities taking place within the site. Activities must look to minimise, as far as is practicable, changes in substratum (beyond expected substratum types in the site) and the biological assemblages within the site as to minimise further impact on feature extent and distribution. Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time can be found in the **Advice on Operations workbook** for the site.

Attribute: Structure and function

Objective: Restore

JNCC understands that the site continues to be subjected to some activities that have resulted in a change to the finer topography, sediment composition and distribution, and characteristic communities of the feature within the site, noting bottom trawling no longer occurs within the site due to the introduction of a byelaw in June 2022.

Installation and/or removal of infrastructure may have a continuing effect on structure and function, specifically the characteristic communities and sediment composition and distribution. Historical demersal fishing may have an ongoing effect on the characteristic communities until such times as they fully recover from associated pressures.

*As such, **JNCC continues to advise a restore objective**, which is based on expert judgement; specifically, our **understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities** i.e. offshore wind farms, cabling and oil and gas industry activities.*

Our confidence in setting this objective will continue to improve with longer-term monitoring, available evidence from wider sources and access to better information on the activities taking place within the site. Activities must look to minimise, as far as is practicable, disturbance and changes to the finer scale topography, sediment composition and biological communities within the site.

Explanatory notes

Structure

Structure encompasses both the physical structure of a habitat type together with the biological structure. **Physical structure** refers to **finer scale topography** and **sediment composition and distribution** Physical structure can have a strong influence on the hydrodynamic regime at varying spatial scales in the marine environment, as well as the presence and distribution of biological communities (Elliot *et al.*, 1998). This is particularly true of features like sandbanks which are large-scale topographic features. The biological structure refers to the **key and influential species** and **characteristic communities** present. Biological communities are important in not only characterising the sandbank feature but supporting the health of the feature i.e. its conservation status and the provision of ecosystem services by performing functional roles.

Physical structure: finer scale topography

Sandbank topography can be characterised by finer scale bedforms such as sand waves, mega-ripples and mounds which are driven by hydrodynamic processes. These bedforms can support different sediment types and associated communities (Elliott *et al.,* 1998; Barros *et al.,* 2004; Limpenny *et al.,* 2011). Where finer bedforms are known to be naturally present on a sandbank feature they should be conserved.

Physical structure: finer scale topography of the feature within the site
Bed forms around Dogger Bank are limited (EMU Ltd, 2010), however, sand waves (wavelengths greater than 25m) and megaripples (wavelengths between 0.5 and 25m) sculpted into both gravel and sand substrates are present in patches across the southern-western and the east-central area of the site (GEMS, 2011). Sand waves are symmetrical with wavelengths of 50-150m (average approximately 100m) and amplitudes up to 2m (average approximately 0.5m). Their crests are orientated in an east-northeast to west-southwest direction, but their symmetrical nature suggests that they are not actively migrating in any one direction (Forewind, 2013c).

Overall, JNCC consider finer-scale topography of the feature may be impacted by the activities occurring within the site and therefore **continues to need to be restored**. This objective is based on expert judgement; specifically, our **understanding of the feature's sensitivity to pressures which can be exerted by historical and ongoing activities** i.e. historic aggregates, cabling, oil and gas industry and offshore wind farm activities which can modify bed forms in the site. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring and access to better information on the activities taking place within the site and their impacts.

Recovery from historic aggregate dredging is expected to be slow given the relatively static nature of the sand waves. Recovery from aggregate extraction can require much greater periods than from benthic fishing (Foden *et al*., 2010). JNCC cannot provide advice on the timeframe for full recovery from aggregate pressures for Dogger Bank at this time. Activities must look to minimise, as far as is practicable, disturbance and changes to the finer scale topography within the site.

Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time, can be found in the **Advice on Operations workbook** for the site.

Physical structure: sediment composition and distribution
Sediment composition of sandbanks is highly dependent on the level of energy experienced by the environment. It can be varied but in the offshore tends to be limited to primarily circalittoral sand and circalittoral coarse sediments and to a lesser extent, circalittoral mixed sediments where finer sediment fractions (mud, silt/clay) are present. We expect finer sands to continue dominating the site, with mixed and coarse sediment remaining present within the site in patchy distributions along with muddy sediment to a lesser extent. Coarser sediments tend to be located in higher energy environments that are subject to strong prevailing currents. Conversely, finer sediment types are typically associated with lower energy environments. Storm conditions, however, can mobilise all sediment types including some coarser fractions. Furthermore, it is important to note that the composition and spatial distribution of sediments can change naturally over time.

Many functional ecological groups have specific niche sedimentary requirements; some species occur on all types of sediment, but most are restricted to a type and therefore limited in their distribution. Particle composition (including grain size and type) is a key driver influencing the biological community composition (Cooper *et al.,* 2011; Coates *et al.,* 2015; 2016; Coblentz *et al.,* 2015) and the distribution and extent of these communities. The natural range of sedimentary habitats known to be present within a sandbank along with their composition and distribution, should be conserved.

Physical structure: sediment composition and distribution of the feature within the site
Sediment composition and distribution of sediments within the site can be seen in the site map available on JNCC's Interactive MPA Mapper. A number of sedimentary habitat types are present, however finer subtidal sands dominate. The underlying substrate of Dogger Bank is composed mainly of clay material, with areas of peat across the bank deposited when Dogger Bank was a terrestrial environment (Emery *et al*., 2019). Sands of variable thickness overlie the geological Dogger Bank Formation, reaching 20m thickness in the southeast, while thinner layers (typically 0.1 – 0.2m) cover the west and north of the site (British Geological Survey and Rijks Geologische Dienst, 1988; British Geological Survey, 1990a,1990b). Note it is not possible to map substrate which has been introduced in the site.

The majority of sediments present across the Dogger Bank consist of fine sands with mud content below 5% (JNCC, 2011), with sandy gravel in patches mainly concentrated on the western edge of Dogger Bank. There is evidence of small mixed sediment patches located centrally in the site. Coarse sediment patches are widespread, most of which are relatively small but a few larger patches are notable towards the western and southern edges of the site. There are also a few muddy sediments in the central north area (Eggleton *et al*., 2017).

The sediment types within the site are characterised by the following Particle Sediment Analysis (PSA): Subtidal sand within the site are on average 1.31 ± 1.33%, 94.94. ± 3.16%, and 3.75 ± 2.90% (gravel, sand and silt/clay respectively). PSA reported for Subtidal mixed sediment within the site are on average 24.46 ± 19.13%, 58.90 ± 23.17%, and 16.64 ± 6.75% (gravel, sand and silt/clay, respectively) and for Subtidal coarse sediment are on average 18.47 ± 18.98%, 79.30 ± 18.78%, and 2.23 ± 1.16% (gravel, sand and silt/clay respectively). PSA reported for Subtidal mud within the site are on average 2.00 ± 1.46%, 56.88 ± 27.47%, and 41.14 ± 27.47% (gravel, sand and silt/clay respectively). The relatively dynamic nature of the currents around the site may mobilise finer surface sediments within the site and it is expected that the spatial distribution of the surface sediments could change naturally over time. Nevertheless, evidence indicates that the hydrodynamic regime on Dogger Bank operates in such a way as to generally retain mobile sediments on the bank and tidal current velocities are considered insufficient for initiating sediment transport (Wieking and Kröncke, 2005).

As mentioned previously under the **extent and distribution** attribute, infrastructure, mainly from oil and gas platforms, pipelines and concrete mattressing, is present on the seabed throughout the site. Where introduced, these result in changes to substratum from sedimentary to hard substrate, such that these areas no longer represent the sandbank feature as previously defined. Introduced substrates, such as rock dump normally consisting of gravel/ pebbles/ cobbles, and historic cuttings piles have also been deposited onto the seabed.

There has been significant decommissioning of oil and gas infrastructure in the site since 2018, primarily involving the removal of infrastructure (platforms, subsea structures) and the placement of protective materials to support this removal. Oil and gas decommissioning operations may remove infrastructure allowing local substrate composition to return to its original distribution. However, it may also result in further permanent impacts, due to deposition of material (e.g. rock dump) which considerably changes the sediment type.

It is unclear how much rock dump is within the site or its composition. Consequently, it is not possible to quantify how much of the sandbank's substratum is impacted or where (Genesis, 2021; MBIEG, 2020; Peritus International Ltd, 2022). The significant number of offshore wind farm turbines and associated cabling that is currently being placed within the site, and is planned within the site, will continue to change the substratum across the site, hindering recovery of the sandbank's sediment composition and distribution.

A restore objective continues to be advised for sediment composition and distribution of the feature within the site based on expert judgement; specifically, our **understanding of the feature's sensitivity to pressures which can be exerted by historical and ongoing activities** i.e. offshore wind farms, cabling and oil and gas industry activities. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring and access to better information on the activities taking place within the site and their impacts. Activities must look to minimise, as far as is practicable, changes in substratum (grain size distribution) within the site. Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time can be found in the **Advice on Operations workbook** for the site.

Biological structure: key and influential species

Key species form a part of the habitat structure or help to define a biotope. Influential species are those that have a core role in the structure and function of the habitat. For example, species that are bioturbators which are benthic organisms that forage and burrow bottom tunnels, holes and pits in the seabed, help to cycle nutrients and oxygen between seawater and the seabed, supporting organisms that live within and above the sediment. Grazers, surface borers, predators or other species with a significant functional role linked to the habitat, can also be influential species. Changes to the spatial distribution of communities across the feature could indicate changes to the overall feature (JNCC, 2004b). It is therefore important to conserve the key natural structural and influential species of the sandbank within the site to avoid diminishing biodiversity and ecosystem functioning within the habitat and to support its health (JNCC, 2004a; Hughes *et al.,* 2005).

Biological structure: key and influential species of the feature within the site

A variety of bioturbators, predators and grazers have been recorded from surveys within the Dogger Bank site, such as polychaete worms (*Spiophanes bombyx),* brittle stars *(Amphiura filiformis)*, as well as sea urchins, gastropods (Family Buccinidae), hermit crabs and other unidentified crustaceans. The bivalve *Arctica islandica*, commonly known as Ocean quahog and a notable species listed as an OSPAR threatened or declining species, is also present in the site (Eggleton *et al.,* 2017). A few individuals have been found associated mainly with subtidal sand although some were found in subtidal coarse sediment. *A. islandica's* abundance, population structure and distribution within the site is not well understood and is therefore not considered further in our advice. Bioturbators are important for benthic-pelagic coupling. Since studies began in 1986, there has been significant changes in the dominance of bioturbator functional groups across the south-eastern North Sea. Evidence suggests that the changes in species dominance found in the bioturbator communities can be attributed to anthropogenic pressures such as fisheries and seabed degradation, as well as increases in sea surface temperature, food limitation, and de-eutrophication (Meyer *et al.,* 2019).

It is possible that the species listed above play a critical role in maintaining the structure and functioning of the protected subtidal sedimentary habitats. For example, bioturbator species, such as *A. filiformis*, can be key indicators of ecosystem health in Dogger Bank (Birchenough *et al*., 2012). However, there is insufficient information available to support an understanding of the significance of the role which these species play in maintaining the structure and function of the qualifying feature. Therefore, **it is not possible to set an objective for this sub-attribute and it is not considered further at this current time.**

--

Biological structure: characteristic communities
The variety of communities present make up the habitat and reflect the habitat's overall character and conservation interest. Characteristic communities include, but are not limited to, representative communities, for example, those covering large areas, and notable communities, for example, those that are nationally or locally rare or scarce such as those listed as OSPAR threatened or declining, or known to be particularly sensitive. Characteristic communities are ones associated with established biological communities (biotopes) that form the feature. The objective for this attribute is made in relation to known characterising communities.

The biological communities typical of sandbanks will vary greatly depending on location, sediment type and depth, as well as fine-scale physical, chemical and biological processes. Communities found on sandbank crests are predominantly those typical of mobile sediment environments and tend to have relatively low diversity. Fauna such as polychaetes (worms) and amphipods (shrimp-like crustaceans) thrive in this environment as they are able to rapidly bury themselves. Animals like hermit crabs, flatfish and starfish also live on the surface of the sandbanks. Deeper areas more sheltered from prevailing currents or wave action can have reduced sediment movement. Such areas tend to have a higher diversity of burrowing species and often can support an abundance of attached bryozoans, hydroids and sea anemones, particularly on stones and dead shells.

Changes to the spatial distribution of characteristic communities across the feature could indicate changes to the overall feature (JNCC, 2004b). It is therefore important to conserve the natural spatial distribution, composition, diversity and abundance of the main characterising biological communities of the sandbank within the site, to avoid diminishing biodiversity and ecosystem functioning within the habitat and to support its health (Hughes *et al.,* 2005).

Biological structure: characteristic communities of the feature within the site
Macrofaunal communities on the Dogger Bank show distinct spatial variability across the site and a high overall abundance of individuals, numbers of species and total biomass (Eggleton *et al.,* 2017). Despite this variability, evidence supports the existence of four main biological communities at this site (Wieking and Kröncke, 2003; Eggleton *et al*., 2017):

- The Bank community is the predominant one and straddles across the bank from north to southeast. It is mainly present in the shallowest part of the Dogger Bank, and it is characterised by a *Bathyporeia-Tellina* (amphipod and bivalve) community;
- The North-Eastern community bordering the northern North Sea is inhabited by a community with lower densities but with the highest number of species. The tube-inhabiting Velvet anemone (*Cerianthus lloydii*) and the small echinoid *Echinocyamus pusillus* occur at high densities in the shallower part. The ophiuroid *Amphiura filiformis*, the bivalve *Abra prismatica* and the polychaete *Scoloplos armiger* are more common in the deeper part. The community has a high number of rare northern species, such as the bioturbator worms *Aricidea cerrutii* and *A. simonae*, and the brittle star *Ophiura affinis* and the diversity is highest of all four communities;
- The South-West Patch community; a sub-group of the Bank community in the shallow western side (18-23m depth) with the lowest species number and abundance. Here, the amphipod *Bathyporeia elegans* is the most abundant species. The bivalve *Donax vittatus* and the polychaete *Nephtys cirrosa* show their highest abundances in this sub-area of the Bank community; and
- The Southern *Amphiura* community; in the deeper southern part of the Bank and harbours an *Amphiura* (brittlestar) community. The polychaete *S. bombyx* is abundant, but here the ophiuroid *Amphiura filiformis* and its commensal bivalve *Kurtiella bidentata* dominate in numbers.

Large areas of heterogeneous sediments are characterised by species typical of sandy sediments, such as *Spiophanes bombyx*, *Tellina fibula*, *Magelona filiformis* and *Bathyporeia* spp. (Eggleton *et al.,* 2017). Epifauna samples include many endobenthic bivalves such as *Mactra stultorum*, *Donax vittatus*, *Arctica islandica* and *Ensis species*, and also the Masked crab (*Corystes cassivelaunus*) and Sea potato (*Echinocardium cordatum*); species hardly encountered at the seabed surface (Van Moorsel, 2011). The most frequently observed taxonomic groups were Asteroidea (*Asterias rubens, Astropecten irregularis)*, the Cnidarian, *Alcyonium digitatum,* the bryozoan *Flustra* sp. and Paguridae (*Cancer pagurus*) although these varied widely with sediment composition (Eggleton *et al.,* 2017).

Sandeels have been recorded on the western side of the bank (Forewind, 2013a). Declines in prey availability, such as the abundance of small copepods, have been correlated with declines in sandeel size. The decline in sandeel size is thought to be attributed to the declines in available energy, median prey size and abundance of *Calanus* copepods (Olin *et al*., 2022). The reduction on mean sandeel size could have a knock-on effect for their predator species such as Black-legged kittiwakes (*Rissa tridactyla*) (Thaxter *et al*., 2012) and Harbour porpoise (*Phocoena phocoena*) (IAMMWG *et al*., 2015). The presence of sandeels, and consequently characteristic predator species, show that Dogger Bank supports species of wider importance across the North Sea and is an important area for connectively across the MPA network.

While there are limited studies focussing specifically on the impacts of ongoing human activities on the Dogger Bank, there is an indication that over time (data spanning from 1920, 1950, 1980 to 2000) that longer-lived species including bivalves such *Spisula subtruncata* and *Mactra stultorum* (rayed trough-shells) have now been substituted by short-living and opportunistic bivalve feeders e.g. *Spiophanes bombyx* (bristleworm, polychaeta), *Amphiura filiformis* (brittle star belonging to the family Amphiuridae) and *Phoronids* (horseshoe worms, a separate phylum) (Kröncke, 2011). More recently, there have been two basic shifts in the community structure found in the wider Dogger Bank area, which were paralleled with changes in the hydroclimatic regime of the south-eastern North Sea, namely sea surface temperature and North Atlantic Oscillation Index (NAOI) (pressure) changes (Meyer and Kroncke, 2019). Other long-term data studies show a decline in the mean abundance and biomass of macrofaunal communities since 1986; this is thought to be due to de-eutrophication effects related to decreased phytoplankton biomass over time. Other causes include increased sea surface temperatures and seabed degradation (Meyer *et al*. 2018). Meyer *et al.* (2018) identified these changes were driven by pressures from changes in climate and anthropogenic interactions. More evidence will be needed to determine how this may impact and influence the designated feature, characteristic communities, and site functions now and into the future.

A byelaw is now in place and bottom trawling has been banned in Dogger Bank. The sandbank communities are not expected to be fully recovered yet from the impacts from historic bottom trawling, but are expected to start recovering following removal of this pressure. Full recovery is based on the resilience of the feature (medium for subtidal sand) and would not be expected for two to ten years, and only where it is not hindered by other pressures. This site primarily consists of subtidal sand, however; it does include a small proportion of mud, which is expected to recover from impacts at a different rate to sand.

As mentioned under the **extent and distribution** attribute, the continued loss of sandbank habitat brought about by historic and ongoing activities associated with cabling, the oil and gas industry and offshore wind farms, may result in the continued loss of the sandbank communities they support. The creation of artificial reefs from industry infrastructure may also change the characteristic communities found in sandbanks (Degraer *et al*., 2020).

A restore objective continues to be advised for characteristic communities of the feature within the site based on expert judgement; specifically, our **understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities** i.e., cabling and oil and gas industry activities and historical demersal fishing. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring, available evidence from wider sources and access to better information on the activities taking place within the site and their impacts.

Activities must look to minimise, as far as is practicable, changes in the biological communities within the site. Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time, can be found in the **Advice on Operations workbook** for the site.

Function
Functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition. These functions rely on the supporting natural processes and the growth and reproduction of those biological communities which characterise the habitat and provide a variety of functional roles within it (Norling *et al.,* 2007) i.e. key and influential species and characteristic communities

These functions can occur at a number of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (European Topic Centre, 2011). Ecosystem services typically provided by Annex 1 sandbanks include:

- Nutrition: due to the level of primary and secondary productivity on or around sandbanks, a range of fish species use these areas as feeding and nursery grounds. Some will migrate to certain parts of the habitat for feeding and breeding e.g. cod, plaice, dab, sole (Ellis 2012), whilst others are more resident e.g. sandeels (Scottish Natural Heritage and JNCC, 2012) making the conservation of sandbanks important as a source of food for important commercial species and other species such as seabirds and marine mammals.
- Bird and whale watching: foraging seals, cetaceans and seabirds may also be found in greater numbers in the vicinity of sandbanks due to their shallower nature that enhances the availability of their typical prey items (Daunt *et al.,* 2008; Scott *et al,* 2010; Camphuysen *et al.,* 2011; McConnell *et al.,* 1999, Jones *et al.,* 2013);
- Climate regulation: by providing a long-term sink for carbon within sedimentary habitats.

Epifaunal assemblages are functionally important in fine sediment (mud) habitats as they are bioturbators that alter the oxygen levels and nutrients cycles of the sediment (Mermollid-Blondin and Rosenberg, 2006). In coarser sediments (typically where mud content < 8%), the sediment oxygen processes are more governed by physical forces, such as wave and tidal processes, rather than biological (van Oevelen *et al*., 2009). Thus, the predominant functional role of the infauna within the coarse sediments of sandbanks is for the provision of food/prey for the next trophic level (bottom-feeding predatory or scavenging fish). Secondary production is the estimate of incorporation of organic matter or energy per unit of time and area (Cusson and Bourget, 2005), which has assumed a fundamental role in the quantification of ecosystem dynamics, as they quantify one of the major pathways of energy flow (Tumbiolo and Downing, 1994).

The prevailing hydrodynamic regime and sedimentary composition have a strong influencing effect on the recovery potential of the functional components of subtidal sedimentary habitats – higher-energy, coarser sedimentary habitats (with the exception of cobbles/boulders) showing greater recovery potential following impact than lower-energy, finer sedimentary habitats (Dernie *et al.,* 2003). Recovery of populations of individual species or communities also depends on life history traits of species (e.g. their growth rate, longevity), and interactions with other species including predators. Furthermore, the environmental connectivity between populations or species patches and the suitability of the habitat (e.g. substrate type), depth, water and sediment quality (Mazik *et al.,* 2015), will also influence the recovery potential of features.

The natural range of sandbank communities within the site should be conserved to ensure the functions they provide support the health of the feature and the provision of ecosystem services to the wider marine environment.

Function of the feature within the site

The ecosystem services that may be provided by the sandbank feature within Dogger Bank include:

- **Nutrition** – the site provides a feeding ground where prey is made available for a variety of species of commercial importance. The site hosts spawning areas for plaice (*Pleuronectes platessa*) and spawning and nursery grounds for young commercial fish species, such as sandeels (*Ammodytes* spp.), the common dab (*Limanda limanda*), sole (*Solea solea),* lemon sole *(Microstomus kitt)* and sprat (*Sprattus sprattus)* (JNCC, 2011; Coull *et al*.,1998; Ellis *et al*., 2012). A study by Katara *et al.* (2021) has shown that Dogger Bank is a spawning hot spot area within the North Sea for commercial pelagic fish, including cod (*Gadus morhua*) and mackerel (*Scomber scombrus*). The byelaw implemented in 2022 prohibits the use of bottom towed fishing in Dogger Bank. This will reduce the impact of fishing pressures on species of commercial importance within the site.

- **Bird and whale watching** – the site provides some supporting function for wider marine bird and mammal populations. Evidence shows, for example, that in the breeding season, Black-legged kittiwakes from colonies on the York coast forage (for sandeels mainly) as far as the Dogger Bank (Thaxter *et al*., 2012). Furthermore, data acquired over 2010-2015 by the RSPB from GPS tracking of kittiwakes from colonies at Filey Brigg and Flamborough Head, corroborate the previous findings (unpublished data, RSPB). Other marine bird species have maximum foraging ranges which overlap the site limits, and therefore might use the site as well (Thaxter *et al.,* 2012). The site falls within the Southern North Sea SAC, which suggests that this site may contribute to the conservation of Harbour porpoise (*Phocoena phocoena*) (JNCC, 2017). A study by Todd *et al*. (2022) has shown that *P. phocoena* populations significantly decreased during oil and gas platform construction and initial drilling operations; however it was deemed that there were no long-term effects of the presence of the platforms in the Dogger Bank on the porpoise population sizes during the operational period. The Southern North Sea SAC site designation includes a conservation objective on the condition of supporting habitats and processes and sets out that the availability of prey is to be maintained. Pinnipeds, such as Grey seals *(Halichoerus grypus)* and Harbour seals (*Phoca vitulina)* have been recorded travelling out to the site from haul out sites on the east coast of England (Jones *et al.,* 2013 and Carter *et al*., 2022), suggesting Dogger Bank could help support local wildlife tourism around the east coast haul out areas. However, the purpose of their travelling out to this site is not understood as yet.

- **Climate regulation** – the range of sedimentary habitats and associated communities in the site perform ecological processes common to sandbanks such as deposition and burial of carbon in seabed sediments through bioturbation, living biomass and calcification of benthic organisms (Hattam *et al*., 2015). The English North Sea is estimated to store 100.4 Mt carbon (37.4 Mt of organic carbon and 63.0 Mt of inorganic carbon), which equates to 880 tC per km². Annually, an estimated 1.27 Mt of organic carbon is added to sediment stores across the area, predominantly within mud and sand/mud seabed sediments. This makes the Dogger Bank an area of interest due to its sediment composition and shallowness (as there is sufficient light for photosynthesis within the surface sediment) (Burrows *et al*., 2021). Across the North Sea, it is estimated that 0.411 Tg CH_4 (methane) is trapped within oceanic basal peats (Lippmann *et al*., 2021). The peatlands developed due to postglacial sea level rise and were covered by marine clay and sand deposits. It is unknown how much microbial activity, and in turn carbon capture, occurs within Dogger Bank specifically, but its carbon storage capacity is relatively high due to the thickness of its peat layers (up to 30cm deep); some of which may be relatively close to the surface of the sandbank. The level of abrasion from human activity, and in turn level of carbon release from the peat deposits underneath the surface sediment of the Dogger Bank is uncertain. The exact location and areas of peat within Dogger Bank is unclear according to previous surveys in the site (Diesing *et al,* 2009 and Ware and McIlwaine, 2015).

As previously set out under **extent and distribution** and **characterising communities**, there is evidence to indicate that the biological communities within the site would continue to be impacted by activities associated with the oil and gas industry, cabling and historic bottom trawling and historic aggregate dredging. Effects from historic activities, including aggregates and bottom-trawling, may continue to impact the carbon storage function of Dogger Bank through their disturbances to subsurface peat (Diesing *et al.,* 2009). The significance of any impact on the health of the sandbank feature and/or its provision of ecosystem services to the wider marine environment is unclear, but it is likely impacted. Some evidence (e.g. Wieking and Kröncke, 2005) also supports the view that the ecological function of the Dogger Bank is being impacted by wider environmental drivers i.e. enrichment of southern water masses due to riverine inputs and climatic variability. However, it is not feasible to manage these drivers at a site level.

A **restore objective continues to be advised** for function within the site **based on impacts to the characterising communities and peat deposits from ongoing and historical activities** i.e., wind farm, demersal fishing, aggregates, cabling and oil and gas industry activities. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring, access to better information about the activities occurring within the site and a clearer understanding of the role which biological communities and the Dogger Bank's abiotic components play in the health of the feature and its provision of ecosystem services.

Activities must look to minimise, as far as is practicable, disturbance and changes to the biological communities and the abiotic components of the Dogger Bank to conserve the functions that it provides to the wider marine environment.

Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time can be found in the **Advice on Operations workbook** for the site.

Attribute: Supporting processes

Objective: Maintain

*A **maintain objective** continues to be advised for supporting processes based on expert judgement; specifically, our understanding of the impacts of ongoing activities on the feature attributes. Our confidence in setting this objective will continue to improve with longer-term monitoring; specifically of contaminant levels within the site and a better understanding of the hydrodynamic regime acting upon the site. Activities must look to avoid, as far as is practicable, impairing the hydrodynamic regime acting upon the site and exceeding Environmental Quality Standards set out in the relevant section below.*

Explanatory notes

The sandbank feature relies on a range of supporting natural processes to support the functions (ecological processes) and help any recovery from adverse impacts. For the site to fully deliver the conservation benefits set out in the statement on conservation benefits, the following natural supporting processes must remain largely unimpeded:

Hydrodynamic regime

Water and sediment quality.

Hydrodynamic regime

Hydrodynamic regime refers to the speed and direction of currents, seabed shear stress and wave exposure. These mechanisms circulate food resource and propagules, influence water properties by distributing dissolved oxygen, and facilitating gas exchange from the surface to the seabed (Chamberlain *et al.,* 2001; Biles *et al.,* 2003; Hiscock *et al.,* 2004; Dutertre *et al.,* 2012). Hydrodynamic regime also effects the movement, size structure and sorting of sediment particles. Shape and surface complexity within sandbank features can be influenced by coarse as well as finer-scale oceanographic processes, supporting the formation of topographic bedforms. The hydrodynamic regime plays a critical role in the natural formation and movement of mobile sandbanks.

Hydrodynamic regime within the site

The predominant wave direction for the Dogger Bank is from the north and the majority of waves are less than 2m in height, but have been recorded to reach 6m (Posford Duvivier, 2001). The annual mean significant wave height ranges between 1.75-2.0m across the Dogger Bank (BERR, 2008).

Whilst evidence indicates that the hydrodynamic regime of the Dogger Bank operates in such a way as to generally retain mobile sediments, there is also evidence to suggest that parts of the site experience very strong tidal currents. Tidal current velocities across the Dogger Bank are generally considered insufficient for initiating sediment transport (Wieking and Kröncke, 2005). BERR (2008) modelled mid-depth peak flows for mean spring tides, which show to be about 0.4m/s for the offshore. However, there are estimates of extreme tidal current velocities at eight locations across Dogger Bank (Mathiesen and Nygaard, 2010) with maximum extreme velocities for return periods of one, ten and 100 years of 0.88m/s, 0.98m/s and 1.11m/s, respectively (Forewind, 2013c).

Large parts of the Dogger Bank are situated above the storm-wave base (Connor *et al.,* 2006) and it is estimated that during a storm event, sediment up to the particle size of medium sand can be mobilised as deep as 60m at the northern slope of the Dogger Bank (Klein *et al.,* 1999). Models of natural disturbance have estimated that the seabed in Dogger Bank is disturbed to 4cm depth at least once every year by tides and waves (Diesing *et al.,* 2013).

The wind wake effect is the aggregated influence of energy production of a wind farm and can either cause reductions or increases in wind speed. This in turn can also affect the hydrodynamic regime operating in the marine environment in both pelagic and benthic ecosystems. Modelled data by Daewel *et al*. (2022) suggests that large-scale changes in annual primary production in the marine environment can occur both within offshore windfarms, and across wider regions. The speed of currents can reduce by up to 43% within the wakes of a windfarm and it is thought that the cumulative impacts of increasing the concentration of offshore installations in the Dogger Bank SAC might impact the environment on a much larger scale than previously thought. Reductions in the current velocities in deeper waters around wind farms may also cause increases in sediment biomass, changing the benthic composition and possibly altering characteristic communities.

While it is likely that the presence of hard substrate supporting infrastructure on the site is impacting the hydrodynamic regime locally, it is unclear what impact this would have on the movement of sediment over the wider sandbank feature and the consequences for sandbank sediment composition and biological communities. There is the potential that the wind wake effect may influence the ability of Dogger Bank to retain mobile sediments for example. Further research on the wind wake effect is essential.

There is no other evidence to suggest that the hydrodynamic regime within the site is impacted by ongoing activities taking place at or near the site such that the conservation status of the feature may be impacted. However, this will need to be reviewed subject to further research on the wind wake effect associated with the installation of windfarm structures moving forward as this poses a potential risk to this attribute associated with the feature’s conservation objective.

A maintain objective continues to be advised at the current time for the hydrodynamic regime within the site based on expert judgement; specifically, our understanding of the impacts of ongoing activities on the hydrodynamic regime within the site. Our confidence in advising on suitable objectives will continue to improve with longer-term monitoring and specifically a better understanding of the effects that human activities have on the hydrodynamic regime within the site and its influence on the formation and movement of the feature; **in particular**

windfarms and the wind wake effect. Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time can be found in the **Advice on Operations workbook** for the site.

Water and sediment quality
Contaminants may also impact the ecology of a sandbank feature through a range of effects on different species within the habitat, depending on the nature of the contaminant (JNCC, 2004c; UKTAG, 2008; EA, 2014). It is important therefore to avoid changing the natural water quality and sediment quality properties of a site and as a minimum ensure compliance with existing Environmental Quality Standards (EQS) as set out below.

Environmental Quality Standards (EQS)

The targets listed below for water and sediment contaminants in the marine environment are based on existing targets within OSPAR and require concentrations and effects to be kept within levels agreed in the existing legislation and international commitments. These targets are set out in The UK Marine Strategy Part 1: The UK Initial Assessment, 2012).

Aqueous contaminants must comply with water column annual average (AAEQSs according to the amended Environmental Quality Standards Directive (EQSD) (2013/39/EU), or levels equating High/Good Status (according to Annex V of the Water Framework Directive (WFD) (2000/60/EC), avoiding deterioration from existing levels.

Surface sediment contaminants (<1cm from the surface) must fall below the OSPAR Environment Assessment Criteria (EAC) or Effects Range Low (ERL) threshold. For example, mean cadmium levels must be maintained below the ERL of 1.2mg per kg. For further information, see Chapter 5 of the OSPAR Quality Status Report (OSPAR 2010) and associated QSR Assessments.

The following sources provide information regarding historic or existing contaminant levels in the marine environment:

- Marine Environmental and Assessment National Database (MERMAN);
- The UK Benthos database available to download from the Offshore Energies UK (OEUK) website.
- Cefas Green Book;
- Strategic Environmental Assessment Contaminant Technical reports available to download from the British Geological Survey website;
- Charting Progress 1: The State of the UK Seas (2005) and Charting Progress 2: The State of the UK Seas (2014).

Water quality

The water quality properties that influence habitats include salinity, pH, temperature, suspended particulate concentration, nutrient concentrations and dissolved oxygen. They can act alone or in combination to affect habitats and their communities in different ways, depending on species-specific tolerances. In fully offshore habitats these parameters tend to be relatively more stable, particularly so for deeper waters, although there may be some natural seasonal variation. Water quality properties can influence the abundance, distribution and composition of communities at relatively local scales. Changes in any of the water quality properties can impact habitats and the communities they support (Elliot *et al.,*1998; Little, 2000; Gray and Elliot, 2009). Changes in suspended sediment in the water column may have a range of biological effects on different species within the habitat; affecting the ability to feed or breathe. A prolonged increase in suspended particulates for instance can have a number of implications, such as affecting fish health, clogging filtering organs of suspension feeding animals and affecting seabed sedimentation rates (Elliot *et al.,*1998). Low dissolved oxygen can have sub-lethal and lethal impacts on fish and infaunal and epifaunal communities (Best *et al.,* 2007). Concentrations of contaminants in the water column must not exceed the EQS listed above.

Water quality within the site

The Dogger Bank is a highly productive area due to its shallowness, topography, hydrography and sediment types (Wieking and Kröncke, 2001). The warmer waters from the Channel, located on the top of the bank and in more southerly regions, are enriched by riverine input and remain mixed throughout the year (Kröncke, 1992). The cool Atlantic waters to the north of the bank exhibit seasonal stratification during spring and summer (Wieking and Kröncke, 2005; Weston *et al.,* 2005). Available evidence indicates relatively low suspended sediment concentrations of the order of 2mg/l with a maximum of 10mg/l (Doerffer and Fisher, 1994; Eleveld *et al.,* 2004). Phytoplankton production on the bank occurs throughout the year with chlorophyll a (Chl a) levels up to 5.8µg l-1 (Brockmann and Wegner, 1985; Brockmann *et al.,*1990), supporting a higher biomass of species at higher trophic levels year-round and creating a region that is biologically unique in the North Sea (Kröncke and Knust, 1995). The maximum levels of chlorophyll found during spring algal blooms across Dogger Bank are shown to have the largest variability in the southern part of the bank, this is due to the shallow depths and urbanised coastline. The beginning of the spring blooms have also begun earlier each year since studies began in 1998 (Alvera-Azcárate *et al*., 2021).

As mentioned previously, riverine inputs and climatic variability are thought to be affecting ecological function at the Dogger Bank (Wieking and Kröncke, 2005) and these impacts are not feasible to manage at the site level. Atmospheric deposition in the North Sea has also been highlighted as a major source of contamination of trace metals (cadmium, lead, copper and zinc) (Injuk *et al.,* 1992) including in Dogger Bank (Norberg, 1990; Preston and Merrett, 1991).

While this information identifies possible sources of contamination, there is no information available at this time which indicates that water quality within the site is falling below EQS. **JNCC therefore advise a maintain objective** for water quality within the site and that **aqueous contaminants must be restricted to comply with water column annual average (AA_EQS) according to the amended EQSD (2013/39/EU) or levels equating to High/Good Status (according to Annex V of the Water Environment Regulations 2017),** avoiding deterioration from existing levels.

Sediment quality

Various contaminants are known to affect the species that live in or on the surface of sediments. These include heavy metals like Mercury, Arsenic, Zinc, Nickel, Chrome and Cadmium, polyaromatic hydrocarbons (PAHs), poly-chlorinated biphenyls (PCBs), organotins (TBT) and pesticides such as hexachlorobenzene. These metals and compounds can impact species sensitive to particular contaminants, (e.g. heavy metals) and bioaccumulate within organisms thus entering the marine food chain (e.g. PCBs) (OSPAR Commission 2009; 2010; 2012). This contamination can alter the structure of communities within a site e.g. lowering species diversity or abundance. It is important therefore to avoid changing the natural sediment quality of a site and as a minimum ensure compliance with existing EQS as set out above. Sediment contaminants must not exceed the EQS listed above.

Sediment quality within the site

The available evidence is inconclusive regarding sediment quality within the site. Some studies support a view that sediments within the site are contaminated with heavy metals (Kröncke and Knust, 1995, Scholten *et al.,* 1998, Langston *et al*.,1999), whilst others do not (Chapman, 1992; Chapman *et al.,* 1992 and Forewind, 2013b). It is unclear why studies differ in their conclusions; however it is worth noting that there is a lack of consistency in the way the data were collected over the years, including what has been measured. This makes the comparison of results challenging.

Charting Progress 2 reports that open seas are little affected by pollution and levels of monitored contaminants continue to fall, albeit slowly in many cases. Dogger Bank was, however, subject to a considerable number of oil and gas exploration developments where produced water and drill cuttings could have acted as potential sources of contaminants. As such, it is possible that sediment quality within the site in some places may fall below EQS. Trends in the concentration and distribution of contaminants in sediments in the wider southern North Sea, including hydrocarbons (HCs), are similar as those described for surface water contamination i.e. higher concentrations in the immediate vicinity of installations with concentrations generally falling to background levels within a very short distance from discharge (Hartley Anderson Ltd., 2001). Gross contamination of sediments by metals extends no further than 500m downstream from production platforms, with the exception of Barium, which shows evidence of elevated levels in the area within 500 to 1,000m of platforms (Hartley Anderson Ltd., 2001). There are, however, some notable exceptions for Lead, Vanadium, Copper and Iron.

A maintain objective continues to be advised. Whilst evidence indicates there may be elevated levels of contaminants in the site, exceeding EQS, a maintain objective is advised as **restoration of contaminants in the offshore is not currently feasible**. Our confidence in this objective would be improved with longer-term monitoring and available evidence from wider sources; specifically of contaminants within the site. Further information on the impacts associated with human activities on Annex I Sandbanks slightly covered by seawater all the time can be found in the **Advice on Operations workbook** for the site.

References

Alvera-Azcárate A., Van der Zande D., Barth A., Troupin C, Martin S, and Beckers, JM. (2021). Analysis of 23 Years of Daily Cloud-Free Chlorophyll and Suspended Particulate Matter in the Greater North Sea. *Frontiers in Marine Science*, 8:707632.

Barros, F., Underwood, A.J. and Archambault, P. (2004). The influence of troughs and crests of ripple marks on the structure of subtidal benthic assemblages around rocky reefs. *Estuarine, Coastal and Shelf Science*, 60: 781-790.

Best, M.A., Wither, A.W. and Coates, S. (2007). Dissolved oxygen as a physico-chemical supporting elements in the Water Framework Directive. *Marine Pollution Bulletin*, 55: 53-64.

Biles, C.L., Solan, M., Isaksson, I., Paterson, D.M., Emes, C. and Raffaelli, G. (2003). Flow modifies the effect of biodiversity on ecosystem functioning: an *in-situ* study of estuarine sediments. *Journal of Experimental Marine Biology and Ecology*, 285-286: 165-177.

Birchenough, S., Parker, R., McManus, E., Barry, J. (2012). Combining bioturbation and redox metrics: Potential tools for assessing seabed function. *Ecological Indicators*, 12: 8-16.

British Geological Survey, Rijks Geologische Dienst. (1988). Silver Well.1:250000, Sea bed sediments and Holocene. British Geological Survey, Edinburgh, Scotland.

British Geological Survey. (1990a). Swallow Hole.1:250000, Sea bed sediments. British Geological Survey, Edinburgh, Scotland.

British Geological Survey. (1990b). Dogger.1:250000, Sea bed sediments and Holocene. British Geological Survey, Edinburgh, Scotland.

Brockmann, U. and Wegner, G. (1985). Hydrography, nutrient and chlorophyll distribution in the North Sea in February 1984. *Archive FischWiss*, 36:27–45.

Brockmann, U., Laane, R. W. P. M. and Postma, H. (1990). Cycling of nutrient elements in the North Sea. *Netherlands Journal Sea Research*, 26:239–264.

Burrows, M.T., Moore, P., Sugden, H., Fitzsimmons, C., Smeaton, C., Austin, W., Parker, R., Kröger, S., Powell, C., Gregory, L., Procter, W., Brook, T. (2021). Assessment of Carbon Capture and Storage in Natural Systems within the English North Sea (Including within Marine Protected Areas). A North Sea Wildlife Trusts, Blue Marine Foundation, WWF and RSPB commissioned report.

Cameron, T., Crosby, A., Balson, P., Jeffery, D., Lott, G., Bulat, J. and Harrison, D. (1992). The Geology of the Southern North Sea. HMSO for the British Geological Survey, 152 pp.
Camphuysen, K., Scott, B. and Wanless, S. (2011). Distribution and foraging interactions of seabirds and marine mammals in the North Sea: A metapopulation analysis [online]. Available at: http://www.abdn.ac.uk/staffpages/uploads/nhi635/ZSLpaper-kees.pdf [Accessed 06 August 2020].

Carter, M. I., Boehme, L., Cronin, m., Duck C., Grecian W., Hastie, G., Jessopp M., Matthiopoulos, J., McConnell, B., Miller, D., Morris, C., Moss, S., Thompson, D., Thompson, P., Russell, D. 2022. Sympatric seals, satellite tracking and protected areas: habitat-based distribution estimates for conservation and management. *Frontiers in Marine Science,* vol. 9, 875869.

Chamberlain, J., Fernandes, T.F., Read, P., Nickell, D. and Davies, I.M. (2001). Impacts of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments. *ICES Journal of Marine Science*, 58: 411-416.

Chapman, P. M. (1992). Pollution status of North Sea sediments - an international integrative study. *Marine Ecology Progress Series*, 91:313 – 322.

Chapman, P. M., Power, E. A., and Burton, G A. Jr. (1992). Integrate assessments in aquatic ecosystems. In: Burton. G. A Jr. (ed.) Contaminated sediment toxicity assessment. Lewis Publishers. Chelsea, Michigan. 313-340.

Coates, D.A., Alexander, D., Herbert, R.J.H. and Crowley, S.J. (2016). Conceptual ecological modelling of shallow sublittoral sand habitats to inform indicator selection. JNCC Report No. 585 [online]. Available at: https://hub.jncc.gov.uk/assets/f3d0abfa-c117-4afc-aab8-13abe31e77b1 [Accessed 06 August 2020].

Coates, D.A., Alexander, D., Stafford, R. and Herbert, R.J.H. (2015). Conceptual ecological modelling of shallow sublittoral mud habitats to inform indicator selection. JNCC Report No. 557 [online]. Available at: https://hub.jncc.gov.uk/assets/7151a86b-ddcc-4756-aa3d-0c5446859398 [Accessed 06 August 2020].

Coblentz, K. E., Henkel, J. R., Sigel, B.J., and Taylor, C.M. (2015). Influence of sediment characteristics on the composition of soft-sediment intertidal communities in the northern Gulf of Mexico. *PeerJ* 3: e1014 [online] https://dx.doi.org/10.7717/peerj.1014 [Accessed 06 August 2020]

Connor, D. W, Gilliland, P.M., Golding, N., Robinson, P., Todd, D. and Verling, E. (2006). UKSeaMap: the mapping of seabed and water column features of UK seas. Joint Nature Conservation Committee, Peterborough, 104 pp.

Cooper, K.M., Curtis, M., Wan Hussin, W.M.R., Barrio F.C.R.S., Defew, E.C., Nye, V. and Paterson, D.M. (2011). Implications of dredging induced changes in sediment particle size composition for the structure and function of marine benthic macrofaunal communities. *Marine Pollution Bulletin*, 62: 2087-2094.

Cusson, M. and Bourget, E. (2005). Global patterns of macroinvertebrate production. *Marine Ecology Progress Series* 297: 1–14.

Daewel, U., Akhtar, N., Christiansen, N., Schrum, C. (2022) Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea. *Communications Earth & Environment*, 3: 292.

Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K.C. and Harris, M,P. (2008). The impact of the sandeel fishery on seabird food consumption, distribution and productivity in the northwestern North Sea. *Canadian Journal of Fisheries and Aquatic Science*, 65: 362-81.

Degraer, S., Carey, D. A., Coolen, J. W. P., Hutchison, Z. L., Kerckhof, F., Rumes, B., & Vanaverbeke, J. (2020). Offshore wind farm artificial reefs affect ecosystem strucutre and functioning: A Synthesis. *Oceanography*, 33: 48–57.

Dernie, K.M., Kaiser, M.J. and Warwick, R.M. (2003). Recovery rates of benthic communities following physical disturbance. *Journal of Animal Ecology*, 72: 1043–1056.

Diesing, M., Stephens D., and Aldridge J. (2013). A proposed method for assessing the extent of the seabed significantly affected by demersal fishing in the Greater North Sea. *ICES Journal of Marine Science*, 70:1085-1096.

Diesing, M., Ware, S., Foster-Smith, R., Stewart, H., Long, D., Vanstaen, K., Forster, R. and Morando, A. (2009). Understanding the marine environment - seabed habitat investigations of the Dogger Bank offshore draft SAC. JNCC Report No. 429. Peterborough.

Dutertre, M., Hamon, D., Chevalier, C. and Ehrhold, A. (2012). The use of the relationships between environmental factors and benthic macrofaunal distribution in the establishment of a baseline for coastal management. *ICES Journal of Marine Science*, 70:294-308.

Eggleton, J., Murray, J., Mcilwaine, P., Mason, C., Noble-James, T., Hinchen, H., Nelson, M., Mcbreen, F., Ware, S., and Whomersley, P. (2017). Dogger Bank SCI 2014 Monitoring Survey Report, *JNCC/Cefas Partnership Report No. 11*, JNCC, Peterborough, UK. Available at: http://jncc.defra.gov.uk/page-7368.

Eleveld, M. A., Pasterkamp, R. and Van Der Woerd, H. J. (2004). A survey of total suspended matter in the southern North Sea based on the 2001 SeaWiFS data. *EARSeL eProceeding*, 3:166-178.

Elliott, M., Nedwell, S., Jones, N.V., Read, S.J., Cutts, N.D. and Hemingway, K.L. (1998). Intertidal sand and mudflats and subtidal mobile sandbanks volume II. An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. UK Marine SACs Project. Oban, Scotland, English Nature.

Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. and Brown, M.J. (2012). Spawning and nursery grounds of selected fish species in UK waters. Cefas Report No. 147.

Emery, A., Hodgson, D., Barlow, N., Carrivick, J., Cotterill, C., Mellett, C. and Booth, A. (2019). Topographic and hydrodynamic controls on barrier retreat and preservation: An example from Dogger Bank, North Sea. *Marine Geology*, 416: 105981.

Emu Ltd. (2010). Dogger Bank Zonal Characterisation Interim Report. Report to Forewind Ltd, October 2010.

European Commission (EC) (2013). DG MARE Interpretation manual of European Union habitats [online]. Available at: http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf [Accessed 30 July 2021].

European Topic Centre (ETC) (2011). Assessment and reporting under Article 17 of the Habitats Directive. Explanatory notes and guidelines for the period 2007-2012. Available at: https://circabc.europa.eu/sd/a/2c12cea2-f827-4bdb-bb56-3731c9fd8b40/Art17%20-%20Guidelines-final.pdf [Access 06 August 2020].

Foden, J., Rogers, SI., Jones, A. (2010). Recovery of UK seabed habitats from benthic fishing and aggregate extraction-Towards a cumulative impact assessment. *Marine Ecology Progress Series* 411: 259-270.

Forewind (2013a) Dogger Bank Creyke Beck, *Environmental Statement Report*. Chapter 13, Appendix E - Dogger Bank Sandeel Survey Report. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Dogger-Bank-ES-Chapter-13.pdf

Forewind (2013b). Dogger Bank Teesside A and B, *Environmental Statement Report.* Chapter 10, Marine Water and Sediment Quality, Document Reference F-OFC-CH-010 Issue 3, October 2013. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Dogger-Bank-ES-Chapter-10.pdf

Forewind (2013c). Dogger Bank Creyke Beck *Environmental Statement Chapter 9 –* GEMS (2011). Geophysics Results Report Volume 4. Dogger Bank Tranche A, Acoustic and Geophysical Survey. Report (Revision: 01) to Forewind, 73pp.

Genesis: Oil and Gas Consultants. (2021). Review of rock and other protective material use in offshore oil and gas operations in the UK Continental Shelf. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1050281/Technical_Note__Review_of_rock_and_other_protective_materials.pdf

Gray, J. and Elliott, M. (2009). Ecology of Marine Sediments: From Science to Management. Second Edition, Oxford Biology.

Hartley Anderson, Ltd. (2001). Survey report of the North Sea Strategic, Environmental Survey, leg 2, conducted from S/V Kommandor Jack between 5 May and 21 May 2001 (SEA2_K_Jack). Hartley Anderson Ltd: Report to the Department of Trade and Industry. Aberdeen: Hartley Anderson Ltd.

Hattam, C., Atkins, J.P., Beaumont, N.J., Börger, T., Böhnke-Henrichs, A., Burdon, D., de Groot, R., Hoefnagel,E., Nunes, P., Piwowarczyk, J., Sastre, S. and Austen, M.C. (2015). Marine ecosystem services: Linking indicators to their classification. *Ecological Indicators*, 49:61-75.

Hiscock, K., Southward, A., Tittley, I. and Hawkins, S. (2004). Effects of changing temperature on benthic marine life in Britain and Ireland. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 14: 333-362.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S. and Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends Ecological Evolution*, 20: 380–386.

IAMMWG, Camphuysen, C.J. & Siemensma, M.L. 2015. A Conservation Literature Review for the Harbour Porpoise (*Phocoena phocoena*). JNCC Report No. 566, Peterborough. 96pp.

Injuk, J., Otten, Ph., Laane, R., Maenhaut, W. and Van Grieken, R. (1992). Atmospheric concentration and size distribution of aircraft-sampled Cd, Cu, Pb and Zn over the Southern Bight of the North Sea. *Atmospheric Environment*, 26:2499–2508.

Joint Nature Conservation Committee (JNCC) (2004a). Common standards monitoring guidance for inshore sublittoral sediment habitats [online]. Available at: https://hub.jncc.gov.uk/assets/9b4bff32-b2b1-4059-aa00-bb57d747db23#CSM-LittoralSedimentHabitats-2004.pdf

Joint Nature Conservation Committee (JNCC) (2004b). Common standards monitoring guidance for littoral sediment habitats [online]. Available at: https://hub.jncc.gov.uk/assets/9b4bff32-b2b1-4059-aa00-bb57d747db23#CSM-SublittoralSediment-2004.pdf

Joint Nature Conservation Committee (JNCC) (2011). Offshore Special Area of Conservation: *Dogger Bank SAC Selection Assessment*. Available at:

https://hub.jncc.gov.uk/assets/98f5e14d-7242-4b32-84fe-f110c5e37300#DoggerBank-SelectionAssessment-v9.pdf.

Joint Nature Conservation Committee (JNCC) (2017). SAC Selection Assessment: Southern North Sea. January, 2017. Joint Nature Conservation Committee, UK. Available from: https://hub.jncc.gov.uk/assets/206f2222-5c2b-4312-99ba-d59dfd1dec1d#SouthernNorthSea-SAC-selection-assessment-document.pdf

Jones, E., McConnell, B., Sparling, C. and Matthiopoulos, J. (2013). Grey and harbour seal density maps. Sea Mammal Research Unit to Marine Scotland Report [online]. Available at: https://www.webarchive.org.uk/wayback/archive/3000/https://www.gov.scot/Resource/0041/00416981.pdf

Katara, I., Peden, W., Bannister, H., Ribeiro, J., Fronkova, L., Scougal, C., Martinez, R., Downie, AL. and Sweeting, C. (2021). Conservation hotspots for fish habitats: A case study from English and Welsh waters. *Regional Studies in Marine Science*. 44: 101745: 2352-4855.

Klein, H., Konig, P. and Frohse, A. (1999). Currents and near-bottom suspended matter dynamics in the central North Sea during stormy weather - Results of the PIPE'98 field experiment. Deutsche *Hydrographische Zeitschrift*, 51:47-66.

Kröncke, I. (1992). Macrofauna Standing Stock of the Dogger Bank. A Comparison: III.1950-54 versus 1985-87. A Final Summary. *Helgoländer Meeresunters*, 46:137-169.

Kröncke, I. (2011). Changes in Dogger Bank macrofaunal community in the 20th century caused by fishing and climate. *Estuarine, Coastal and Shelf Science*, 94:234-245.

Kröncke, I. and Knust, R. (1995). The Dogger Bank: a special ecological region in the central North Sea. *Helgoländer Meeresunters*, 49:335-353.

Langston, W. J., Burt, G. R. and Pope, N. D. (1999). Bioavailability of Metals in Sediments of the Dogger Bank (Central North Sea): A Mesocosm Study. *Estuarine, Coastal and Shelf Science*, 48:519–540.

Limpenny, S.E., Barrio Frojan, C., Cotterill, C., Foster-Smith, R.L., Pearce, B., Tizzard, L., Limpenny, D.L., Long, D., Walmsley, S., Kirby, S., Baker, K., Meadows, W.J., Rees, J., Hill, K., Wilson, C., Leivers, M., Churchley, S., Russell, J., Birchenough, A.C., Green, S.L. and Law, R.J. (2011). The East Coast Regional Environmental Characterisation. MALSF. Cefas Report No. 08/04.

Lippmann, T., Zandt, M., Van der Putten, N., Busschers, F., Hijma, M., van der Velden, P., de Groot, T., van Aalderen, Z., Meisel, O., Slomp, C., Niemann, H., Jetten, M., Dolman, H., Welte, C. (2021) Microbial activity, methane production, and carbon storage in Early Holocene North Sea peats. *Biogeosciences,* 18: 5491-5511.

Little, C. (2000). The biology of soft shores and estuaries, Oxford University Press.
Marine Physical Processes, Document Reference F-OFC-CH-009, Issue 4, October 2013.

Mathiesen, M. and, E. (2010). Dogger Bank Wind Power Sites Metocean Design Basis. Statoil Report PTM MMG MGE RA 63, Rev no 1, June 2010, 129pp.

Mazik, K., Strong, J., Little, S., Bhatia, N., Mander, L., Barnard, S. and Elliott, M. (2015). A review of the recovery potential and influencing factors of relevance to the management of habitats and species within Marine Protected Areas around Scotland. Scottish Natural Heritage Report No. 771 [online]. Available at: https://www.nature.scot/sites/default/files/2017-07/Publication%202015%20-%20SNH%20Commissioned%20Report%20771%20-%20A%20review%20of%20the%20recovery%20potential%20and%20influencing%20factors%20of%20relevance%20to%20the%20management%20of%20habitats%20and%20species%20within%20Marine%20Protected%20Areas%20around%20Scotland.pdf [Accessed 30 July 2021].

MBIEG (2020). Mapping Anthropogenic Hard Protection in the Marine Environment. A report produced by Intertek Energy and Water for Defra on behalf of the Marine Biodiversity Impacts Evidence Group

McConnell, B.J., Fedak, M. A., Lovell, P. and Hammond, P.S. (1999). Movements and foraging areas of grey seals in the North Sea. *Journal of Applied Ecology,* 36: 573–90.

Mermollid-Blondin, F., and Rosenberg. R. (2006). Ecosystem engineering: The impact of bioturbation on biogeochemical processes in marine and freshwater benthic habitats. Aquatic Sciences 68(4):434-442

Meyer, J., Kroncke, I. (2019). Shifts in trait-based and taxonomic macrofauna community strucutre along a 27-year time-series in the south-eastern North Sea. *PLoS One.* 14(12): e0226410.

Meyer, J., Nehmer, P., Moll, A., Kröncke, I. (2018). Shifting south-eastern North Sea macrofauna community structure since 1986: A response to de-eutrophication and regionally decreasing food supply? *Estuarine, Coastal and Shelf Science*, 213: 115-127.

Meyer, J., Nehmer, P., Kronche, I. (2019). Shifting south-eastern North Sea macrofauna bioturbation potential over the past three decades: a response to increasing SST and regionally decreasing food supply. *Marine Ecology Progress Series*, 609: 17 – 32.

Norberg, S. N. (1990). Is the North Sea really dying? *Ocean*, 1:11-13.

Norling, K., Rosenburg, R., Hulth, S., Gremare, A. and Bonsdorff, E. (2007). Importance of functional biodiversity and species-specific traits of benthic fauna for ecosystem functions in marine sediment. *Marine Ecology Progress Series*, 332: 11-23.

Olin, A., Banas, N., Johns, D., Health, M., Wright, P., Nager, R. (2022). Spatio-temporal variation in the zooplankton prey of lesser sandeels: species and community trait patterns from the Continuous Plankton Recorder. *ICES Journal of Marine Science*, 79: 1649–1661.

OSPAR Commission (2009). Agreement on Coordinated Environmental Monitoring Programme (CEMP) assessment criteria for the QSR 2010. *Monitoring and Assessment Series*. OSPAR Agreement 2009-2002.

OSPAR Commission (2010). Quality Status Report 2010. London.

OSPAR Commission (2012). Coordinated Environmental Monitoring Programme (CEMP) 2011 assessment report.

Peritus International Ltd. (2022). Scour and Cable Protection Decommissioning Study. NECR403. Natural England.

Pinder, J. (2020). Annex I Sandbanks in the UK version 3 - 2019 Methods document [online]. Available at: https://hub.jncc.gov.uk/assets/f4891fa7-5f9e-417c-af88-073f276a4941 [Accessed 30 July 2021].

Posford Duvivier (2001). Withernsea Coastal Defence Strategy Study. Report for the East Riding of Yorkshire, December 2001.

Preston, M. R. and Merrett, J. (1991). The distribution and origins of the hydrocarbon fraction of particulate material in the North Sea atmosphere. *Marine Pollution Bulletin*, 22: 516-522.

Scholten, M. C. Th., Kramer, K. J. M., and Laane, R. W. P. M. (1998). Trends and variation in concentration of dissolved metals (Cd, Cu, Pb, and Zn) in the North Sea (1980–1989). *ICES Journal of Marine Science*, 55:825–834.

Scott, B.E., Sharples, J., Ross, O.N., Wang, J., Pierce, G.J. and Camphuysen, C.J. (2010). Sub-surface hotspots in shallow seas: fine-scale limited locations of top predator foraging habitat indicated by tidal mixing and sub-surface chlorophyll. *Marine Ecology Progress Series,* 408: 207-26.

Scottish Natural Heritage and the Joint Nature Conservation Committee (2012). Advice to the Scottish Government on the selection of Nature Conservation Marine Protected Areas (MPAs) for the development of the Scottish MPA network. Scottish Natural Heritage Commissioned Report No. 547 [online] https://www.nature.scot/sites/default/files/2017-07/Publication%202012%20-%20SNH%20Commissioned%20Report%20547%20-%20SNH%20and%20JNCC%20MPA%20network%20advice.pdf [Accessed 01 December 2022].

Thaxter, C. B., Lascelles, B., Sugar, K., Cook, A., Roos, S., Bolton, M., Langston, R. H. W. and Burton, N. H. K. (2012). Seabird foraging ranges as a preliminary tool for identifying candidate Marine Protected Areas. *Biological Conservation* 156: 53-61.

The Crown Estate. (2022). Offshore Wind Leasing Round 4 - Tender process outcome (2022). Available at: https://www.thecrownestate.co.uk/media/3920/round-4-tender-outcome-dashboard.pdf [Accessed 7 October 2022].

Todd, V., Williamson, L., Couto, A., Todd, I., Clapham, P. (2022). Effect of a new offshore gas platform on harbour porpoises in the Dogger Bank. *Marine Mammal Science* 1-14. DOI: 10.1111/mms.12949

Tumbiolo, M., and Downing, J. (1994). An empirical model for the prediction of secondary production in marine benthic invertebrate populations. Marine Ecology Process Series Volume:114: 165-174, 1994.

UK Technical Advisory Group on the Water Framework Directive (UKTAG) (2008). Proposals for environmental quality standards for Annex VIII Substances.
Van Moorsel, G. W. N. M. (2011). Species and habitats of the international Dogger Bank. *Ecosub, Doorn*. 74 pp.

van Oevelen, D., Soetaert, K., Franco, M.A., Moodley, L., van Ijzerloo, L., Vincx, M. and Vanaverbeke, J. (2009). Organic matter input and processing in two contrasting North Sea sediments: insights from stable isotope and biomass data. *Marine Ecology Progress Series* 380, 19-32.

Ware, S. & McIlwaine, P. 2015. Dogger Bank SCI Monitoring Survey – CEND 10/14 Cruise

Report. Marine Evidence Survey Data, No. 3.

Weston, K., Fernand, L., Mills, D. K., Delahunty, R. and Brown, J. (2005). Primary production in the deep chlorophyll maximum of the central North Sea. *Journal of Plankton Research*, 27:909-922.

Wieking, G. and Kröncke, I. (2001). Decadal changes in macrofauna communities on the Dogger Bank caused by large scale climate variability. *Senckenbergiana Maritima*, 31:25 - 141.

Wieking, G. and Kröncke, I. (2003). Macrofaunal communities of the Dogger Bank (central North Sea) in the late 1990s: Spatial distribution, species composition and trophic structure. *Helgoland Marine Research*, 57:34-46.

Wieking, G. and Kröncke, I. (2005). Is benthic trophic structure affected by food quality? The Dogger Bank example. *Marine Biology*, 146:387- 400.