Supplementary Advice on Conservation Objectives for East of Gannet and Montrose Fields Nature Conservation MPA

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Contents

Introduction

What the conservation advice package includes

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 protected feature condition and General Management Approach;
    - conservation benefits that the site can provide; and
    - conservation measures needed to further the conservation objectives stated for the site (this document).
- **Supplementary Advice on Conservation Objectives** (SACO) providing more detailed and site-specific information on the conservation objectives; and
- **Advice on Operations** providing information on those human activities that, if taking place within or near the site, could impact it and hinder the achievement of the conservation objectives stated for the site.

The most up-to-date conservation advice documents 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 protected features: offshore deep-sea muds and ocean quahog aggregations (including subtidal sands and gravels as their supporting habitat) specified in the site's conservation objectives. These attributes are: 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 structure and function.

Collectively, the attributes set out in Tables 1 and 2 below, along with the objectives set for each of them, describe the desired ecological condition (favourable) for the site's protected features. Each feature within the site must be in favourable condition as set out in the site's conservation objectives. All attributes listed in Tables 1 and 2 must be taken into consideration when assessing impacts from an activity.

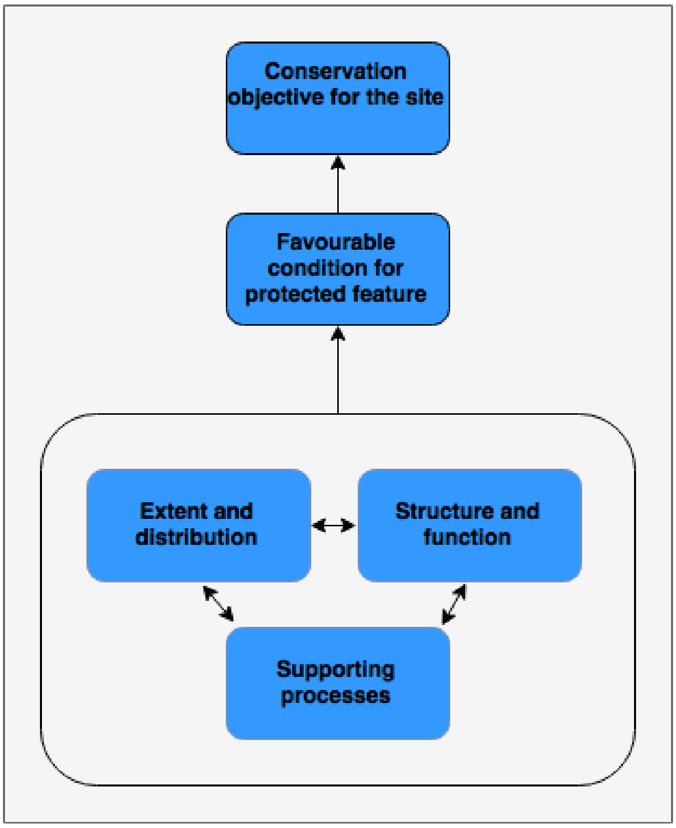

Figure 1. Conceptual diagram showing how a feature's attributes are interlinked and collectively describe favourable condition and contribute to the conservation objectives stated for the site.

The objectives listed in Tables 1 and 2 below reflect our current understanding of each protected feature's condition e.g., where evidence indicates some of a feature's extent has been lost and needs to be recovered, or that extent is not lost and needs to be conserved in order to ensure the feature is in overall favourable condition. The rationale for setting each 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 recover a feature's attribute, a conserve objective is set but accompanied by a statement to reflect the impracticality of restoration. Note also that when a conserve objective is set, this does not preclude the need for management, now or in the future. Please see the conservation measures relating to those activities JNCC consider may require additional management in the conservation statements component of this conservation advice package.

Table 1. Supplementary advice on the conservation objectives for offshore deep-sea muds in the East of Gannet and Montrose Fields Nature Conservation MPA

Attribute: Extent and distribution

Objective: Recover

*JNCC understands that the site has been subject to activities that have resulted in a change to the extent and distribution of the feature within the site. Installation and/or removal of infrastructure will have a continuing effect on extent and distribution. As such, **JNCC advise a recover objective.** This is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. Activities must look to minimise, as far as is practicable, changes in substrata and the biological communities associated with offshore deep-sea muds within the site in order to minimise further impact of the feature's extent and distribution.*

Explanatory notes

Extent refers to the total area in the site occupied by offshore deep-sea muds and must include consideration of distribution, i.e., how spread out the feature is within the site. A reduction in extent has the potential to alter the biological and physical functioning of offshore deep-sea muds (Elliott *et al*., 1998; Tillin and Tyler-Walters, 2014). The distribution of a habitat influences the component communities present and can contribute to the health and resilience of the feature (JNCC, 2004).

Subtidal sedimentary habitats such as offshore deep-sea muds are defined by:

- ***Sediment composition*** (grain size and type) (e.g., Cooper *et al*., 2011; Coates *et al*., 2015; 2016; Coblentz *et al*., 2015). Some species can inhabit all types of sediment, whereas others are restricted to specific types; and
- ***Biological assemblages*** - See JNCC's Marine Habitats Correlation Table for more detail about the range of biological communities (biotopes) that characterise offshore deep-sea muds.

A significant change in sediment composition and/or biological assemblages within an MPA could indicate a change in the distribution and extent of offshore deep-sea muds within the site. Reduction in extent has the potential to affect the functional roles of the biological communities associated with offshore deep-sea muds (Elliott *et al*., 1998; Tillin and Tyler-Walters, 2014). Loss of the characterising offshore deep-sea mud biological assemblages or sediments from the site would constitute a reduction in overall feature extent. Installing infrastructure and depositing materials, essentially replacing the characterising sediments with hard substratum causes, physical seabed changes and habitat loss (Taormina *et al*., 2018). Maintaining extent is therefore critical to maintaining or improving the conservation status of offshore deep-sea muds.

Offshore deep-se muds are often dominated by polychaetes and echinoderms, such as *Amphiura* spp., sea-pens, such as the slender sea-pen (*Virgularia mirabilis*), and burrowing megafauna, such as Norway lobster (*Nephrops norvegicus*) (Connor *et al*., 2004); although sea spiders, molluscs, crustaceans, and fish are also found. Bathymetry, current velocity, bottom water-mass distribution, and particle size of the mud (clay, silty or sandy) have a significant influence on the distribution and composition of the seabed communities present. Subtidal mud is defined by a ratio of mud to sand being greater than 4:1, with particle sizes of less than 0.063 mm for mud and 0.063 mm to 2 mm for sand (McBreen and Askew, 2011). Offshore deep-sea muds directly equate to the EUNIS 2007 habitat A5.3 Subtidal mud[1]. The low-energy hydrodynamic regime associated with offshore deep-sea muds poses a risk from impactful activities such as those associated with offshore industries, e.g. the introduction of discharged material or cabling activities (Cordes *et al.* 2016, Kraus and Carter 2018).

Extent and distribution of the feature within the site

The site map for East of Gannet and Montrose Fields MPA, accessible via the JNCC's Interactive MPA Mapper link on the SIC, provides JNCC's understanding of the extent and distribution of offshore deep-sea muds within the site. The main extent of the habitat is found in the south-eastern half of the site, in addition to two smaller muddy areas in the southwest and north of the site. The remainder of the site comprises sandy and mixed sediments. The total site area is calculated to be 1,839 km^2, with offshore deep-sea muds comprising 49% (approximately 900 km^2) of the seabed. This is based on analysis of evidence from the 2015 JNCC survey of the site (McCabe *et al*., 2020).

Oil and gas extraction occurs in parts of the site where offshore deep-sea muds are present. Operations included over 80 drilled wells, of which at least a dozen is classified as operational, and related infrastructure such as at least 250 km of pipelines. Additionally, over 25 km of cable have been installed within areas of offshore deep-sea muds in the site. These operations have involved the introduction of hard substrata to the seabed; notably protective materials such as rock dump and mattresses. This is particularly prevalent in the southeastern area of the site, in which more than 20 km of cables and pipelines have been covered in rock dump. Due to a lack of information, there is limited certainty on the exact quantity of material introduced and therefore of the habitat lost. Continued addition of hard substratum will affect the extent and distribution of offshore deep-sea muds in this site.

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[1] Note that a new EUNIS classification has become available in 2022: https://mhc.jncc.gov.uk/.
According to the 2022 EUNIS classification the habitat A5.3 Subtidal mud (EUNIS 2007) is MD6 Offshore circalittoral mud.

Evidence indicates that activities are occurring within the site that can affect the extent and distribution of the protected feature. **JNCC therefore advises a recover objective** based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures exerted by ongoing activities including offshore industries. Activities should look to minimise, as far as is practicable, changes in substrata and the biological assemblages within the site to minimise further impact on offshore deep-sea muds feature extent and distribution. For further information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook.

Attribute: Structure and function

Objective: Recover

JNCC understands that the site has been subject to activities that have resulted in a change to the structure and function of the feature within the site; specifically, the characteristic communities of offshore deep-sea muds and consequently function. As such, ***JNCC advise a recover objective.*** *This is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. Our confidence in this objective has been improved by evidence from the 2015 monitoring survey (McCabe* et al*., 2020) and will continue to improve with long-term monitoring information and better access to information on the activities taking place that overlap with the offshore deep-sea muds within the site, as well as an improved understanding of the significance of the role which species play in the function and health of this habitat. Activities must look to minimise, as far as is practicable, changes in substrata and the biological communities associated with offshore deep-sea muds within the site in order to minimise further impact of the feature's structure and function.*

Explanatory notes

Structure refers to the physical structure of offshore deep-sea muds and its biological structure. Physical structure refers to finer scale topography and sediment composition. Biological structure refers to key and influential species and characteristic communities present.

Physical structure: Finer scale topography

The topography of offshore deep-sea muds may be characterised by features such as mega-ripples, banks, and mounds, which are either formed and maintained by ongoing hydrodynamic processes (active bedforms) or the result of long since passed geological processes (relict bedforms). As these bedforms support different sedimentary habitats and associated communities compared to the surrounding seabed, it is important that they are conserved (Elliott *et al*., 1998; Barros *et al*., 2004; Limpenny *et al*., 2011). Recovery of active bedforms is likely, so long as the prevailing hydrodynamic regime remains largely unimpeded. However, the reverse is true with regards to relict bedforms.

Physical structure: Finer scale topography of the feature within the site

JNCC are not aware of any discernible examples of fine-scale topographic features present within the site based on the most recent survey data we have access to from 2015 (McCabe *et al.,* 2020). As such, JNCC **advise a conserve objective** for this sub-attribute of structure and function.

Physical structure: Sediment composition

On the continental shelf, sediment composition is highly dependent on the prevailing hydrodynamic regime. Coarser sediments tend to dominate in high energy environments that are subject to strong prevailing currents. Conversely, finer sedimentary habitats such as offshore deep-sea muds are typically associated with lower energy environments. However, storm conditions can mobilise all sediment types, including the coarser fractions, most notably in shallower waters (Green *et al*., 1995). In deeper waters, bottom currents may impact sediment composition through erosional and depositional processes (Sayago-Gil *et al*., 2010).

As sediment composition may be a key driver influencing biological community composition, it is important that natural sediment composition is conserved (Cooper *et al*., 2011; Coates *et al*., 2015; 2016; Coblentz *et al*., 2015).

Physical structure: Sediment composition of the feature within the site

Evidence from the 2015 monitoring survey shows that the site comprises of areas of sublittoral sand and sublittoral mud; interspersed with smaller areas of subtidal mixed and coarse sediments. Offshore deep-sea muds comprise an estimated 49% (about 900 km^2) of the site's area, located predominately in the south-eastern area of the site. The offshore deep-sea muds within the site are associated with the slightly deeper parts of the site (88-102m) (McCabe *et al*., 2020).

There has been oil and gas activity taking place with the site, with over 80 wells having been drilled in areas of offshore deep-sea muds mapped extent. During well drilling, cuttings of rock layers being penetrated by the drill are discharged, which differ in chemical and mineral composition to the sediment on the seabed. In addition to the rocky material excavated from the well, drilling mud containing weighting substances such as barite might be discharged onto the seafloor (Henry *et al.* 2017). The material sometimes remains as a "cutting pile" surrounding the well. More than half of the drilled wells within the offshore deep-sea muds feature within the site pre-date the OSPAR Decision 2000/3. The OSPAR decision restricts the discharge of oil-based or synthetic drilling mud, as well as drill cuttings contaminated with these fluids, hence material disposed previously might contain hydrocarbons and heavy metals (Breuer *et al.* 2004). The section Biological structure: characteristic communities within the site explains the impact of contaminated discharge more in detail.

Industry activity within the site has further introduced structures and hard substratum, e.g. depositing rock dump, replacing the characteristic mud within the site and offering habitat suitable to be colonised by species that are not typical to mud habitats, capable of shifting the biological assemblage (Taormina *et al*. 2018). The low-energy hydrodynamic regime associated with offshore deep-sea muds allows for impacts from offshore industry, such as introduced material, to persist on longer timescales (Cordes *et al.* 2016, Kraus and Carter 2018).

Offshore industry activities have been impacting the integrity of sediment composition within the offshore deep-sea muds protected feature. Due to the protracted process of recovery in low-energy regimes such as this site, **JNCC advise a recover objective** for offshore deep-sea muds sediment composition. This is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. Activities should look to minimise, as far as is practicable, changes in substrata within the site. Further information on the impacts associated with human activities on offshore deep-sea muds can be found in the Advice on Operations workbook.

Biological structure: Key and influential species

Key and influential species are those that have a core role in determining the structure and function of offshore deep-sea muds. For example, bioturbating species (animals that forage and burrow tunnels, holes, and pits in the seabed) help recycle nutrients and oxygen between the seawater and the seabed, supporting the organisms that live within and on the sediment. Grazers, surface borers, predators or other species with a significant functional role linked to offshore deep-sea muds can also be classed as a key or influential species. Changes to the spatial distribution of communities across offshore deep-sea muds could indicate changes to the overall feature and as a result how it functions (JNCC, 2004). It is important to conserve the key and influential species of offshore deep-sea muds to avoid diminishing biodiversity and the ecosystem functioning provided by the protected offshore deep-sea muds, and to support its conservation status (JNCC, 2004; Hughes *et al*., 2005).

Due to the prevailing influence of the hydrodynamic regime, higher energy, coarser sedimentary habitats show greater recovery potential following impact than lower energy, finer sedimentary habitats (Dernie *et al*., 2003). Recovery of offshore deep-sea muds is thought to be largely dependent on the scale of the disturbance and action of remaining key and influential species, such as burrowers. However, recovery of the communities associated with offshore deep-sea muds also depends on the life-history traits of the species themselves (e.g., their growth rate, longevity) and their interactions with other species, including predators and prey. Furthermore, the environmental connectivity between populations or species patches, the suitability of the habitat (e.g., substrate type), depth, water and sediment quality will also influence the recovery potential of subtidal sedimentary habitats such as offshore deep-sea muds (Mazik *et al*., 2015).

Biological structure: Key and influential species of the feature within the site
The 2015 survey sampled several species of burrowing infauna within the mud area, such as the bivalves *Thyasira* sp., *Timoclea ovata and Mendicula ferruginosa*, and the polychaete worms *Paramphinome jeffreysii*, *Notomastus* sp., *Goniada maculata Spiophanes bombyx* and *Scoloplos armiger* within the offshore deep-sea mud habitat (McCabe *et al*., 2020). Demersal trawling for Norway lobster (*Nephrops norvegicus)* occurs in the south of the site corresponding to the extent of offshore deep-sea muds within the site (JNCC and MMO, 2015; JNCC, 2018). The Norway lobster is a burrowing decapod that forms large burrows, greatly influencing the oxygen availability in the upper sediment layers (Sabatini and Hill, 2008).

These burrowing species can play an important role as bioturbators, increasing the oxygen content of the upper sediment layers within offshore deep-sea muds within the site. Furthermore, megafaunal burrows and three species of sea-pens were observed as part of the 2015 monitoring survey (McCabe *et al*., 2020). The majority of the megafaunal burrows were observed in the offshore deep-sea mud habitat. Their relative abundance, however, did not meet the threshold levels given for the OSPAR threatened/or declining habitat ‘Sea-pens and burrowing megafauna’ (OSPAR 2010); nor the corresponding PMF feature ‘burrowed mud’. It is possible that the burrowing species found in the offshore deep-sea muds within the site play a critical role as key and influential species in maintaining the structure and functioning of the habitat.

Fishing activity within the site includes several types of demersal trawling, which can impact benthic species through surface abrasion and sub-surface penetration. Vessel Monitoring System (VMS) data from 2009-2020 shows that a concentrated effort of moderate to high levels of demersal trawl activity occurs within the southeastern corner of the site, which represents offshore deep-sea muds. This activity could have an impact on key and influential species through non-target species removal and damage, especially if penetrating the seabed. While *V. mirabilis* is capable of retracting into the substrate, other sea pen species as well as other benthic species, target, and non-target, are more vulnerable. The 2015 monitoring survey did record presence of broken sea pens and sea pens lying flat. However, this did not exceed a relative abundance of 0.01 per meter (McCabe *et al*., 2020).

There is insufficient information available to support an understanding of the significance of the role which species observed in the offshore deep-sea mud habitat within the site play in maintaining the function and health of the habitat overall. Therefore, it is not yet possible to advise an objective for this sub-attribute of structure and function and it is not considered further in our advice. It is noteworthy that to the best of our knowledge, there is no evidence of non-native species.

Biological structure: Characteristic communities

The variety of biological communities present make up a habitat and reflect the habitat's overall character and conservation interest. Characteristic communities include, but are not limited to, representative communities, such as those covering large areas, and communities that are nationally or locally rare or scarce, such as OSPAR threatened and/or declining habitats and species or known to be particularly sensitive to pressures from anthropogenic activities.

Biological communities within offshore deep-sea muds may vary greatly depending on location, fine-scale sediment composition and depth, as well as other physical, chemical and biological processes. Changes to the spatial distribution of biological communities across subtidal sedimentary habitats such as offshore deep-sea muds could indicate changes to overall feature structure and function (JNCC, 2004). It is therefore important to conserve the natural spatial distribution, composition, diversity, and abundance patterns of the main characterising biological communities of offshore deep-sea muds within a site to avoid diminishing functioning within the habitat (JNCC, 2004; Hughes *et al*., 2005).

Similar to the biological structure of key and influential species, the recovery of characterising communities is dependent on the influence of prevailing environmental conditions, life-history traits and interactions between species, with environmental connectivity between populations or species patches, the suitability of the habitat (e.g., substrate type), depth, water and sediment quality further influencing the recovery potential of Subtidal sedimentary habitats (Mazik *et al*., 2015).

Biological structure: Characteristic communities of the feature within the site

Results of a community analysis to identify the characteristic communities of offshore deep-sea muds within the site based on 2015 survey data show that the biotope "SS.SMu.OMu.PjefThyAfil" (*Paramphinome jeffreysii*, *Thyasira* spp. and *Amphiura filiformis* in offshore circalittoral sandy mud) describes best the characteristic community of both the offshore deep-sea muds in the site and the communities in the sandy and mixed sediments present. This biotope is typical for this part of the North Sea. However, there seems to be gradual difference in the relative species abundance between the subtidal mud habitat and the subtidal sand and subtidal sand and mixed habitats. For example, the amphinomid polychaete *P. jeffreysi* was the species most consistently occurring in relatively higher abundances in the offshore deep-sea mud habitat by comparison to other seabed habitat types within the site. The ophiuroid *Amphiura filiformis* seemed to occur in slightly lower abundance in the offshore deep-sea muds than in the other occurring sediment types. None of these differences is pronounced and is likely to reflect the gradual change in habitat type across the site.

Evidence indicates the distribution of the biotope “SS.SMu.OMu.Pjef.ThyAfil” in the site is mainly driven by a combination of depth and percentage of particulate fines (McCabe *et al*., 2020). However, it is likely that other environmental factors, such as sediment organic matter content might also be important in the patterns observed, but at this stage JNCC have no information on the influence of such factors on the characteristic communities of offshore deep-sea muds in the site.

Medium to high intensity of demersal trawl activity within the area of offshore deep-sea muds as identified through Vessel Monitoring System (VMS) data from 2009-2020 may impact the characteristic communities by removing benthic species and/or damaging or killing them. Mobile fishing activity in mud habitat may result in lower diversity, reduction or loss of long-lived filter feeding species (Ball *et al*., 2000; Tuck *et al*., 2000). This can further lead to biological community shifts, e.g. by removing predators such as Norway lobster *Nephrops norvegicus* (Sköld *et al*. 2018).

Offshore industry activity in the area, including oil and gas activities and cabling, may also affect the biological communities. The introduction of hard substratum by offshore industry activities can smother individuals, as well as cause physical change of the seabed which might be colonised by species currently not present in the mud habitat (Taormina *et al*. 2018), including invasive species or species that cause shifts in the current community. There was no evidence for occurrence of non-native species in the site from the 2015 monitoring survey. However, due to exclusion zones the survey did not sample closer than 500m to oil and gas infrastructure and 200m to pipelines (McCabe *et al.* 2000). Therefore, sampling had limited chance to cover areas in which protective material has been deposited.

Drilling of oil and gas wells can impact surrounding habitat and biological communities as discharged material such as drill cuttings and drill mud can cause contamination and smothering (Schaaning *et al*., 2008, Trannum *et al.* 2011, Cordes *et al*. 2016). These pressures are capable of changing the density, biomass, and diversity of biological assemblages (Cordes *et al*. 2016). Current drilling practices can have an impact footprint of up to 1 km (Henry *et al.* 2017), while historical drilling with oil-based drilling mud used before regulation through OSPAR (such as OSPAR decision 2000/3) has been documented to impact habitat in up to 6 km distance from the well-head, decreasing suitable habitat

(Olsgard and Gray 1995). Contaminated cutting piles are often associated with pollutant-tolerant indicator species, which in some cases has led to the establishment of a different biotope specifically associated with oil and gas activity (Henry *et al.* 2017). Continued offshore industry activity, trawling, and other physical disturbance can further cause dispersion of material and leakage of contaminants from deeper layers of historical cutting piles (Bakke *et al.* 2013). Recovery from these impacts is especially slow in low energy hydrodynamic environments, with benthic communities in the northern North Sea showing recovery signs up to 8 years later than counterparts in the southern North Sea (Henry *et al*. 2017).

JNCC advise a recover objective for characterising species. This objective is primarily based on expert judgement; specifically, the sensitivity of the protected feature to pressures associated with activities taking place within the site. However, the evidence from the 2015 survey (McCabe *et al*., 2020) increased our understanding of the communities present within the offshore deep-sea muds protected feature of the site. Further information on the impacts associated with human activities on Offshore deep-sea muds can be found in the Advice on Operations workbook.

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., the key and influential species and characteristic communities present. These functions can occur at a range of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC, 2011).

Ecosystem services that may be provided by offshore deep-sea muds include:

- Nutrition: different sediment types offer habitat for various commercial species. For instance, mud habitats can be suitable for Norway lobster (Sabatini and Hill, 2008);
- Climate regulation: providing a long-term sink for carbon within sedimentary habitats.

It is critical to ensure that the extent and distribution of offshore deep-sea muds within a site, along with the composition of any key and influential species and characteristic biological communities, are conserved to ensure the functions they provide are maintained.

Function of the feature within the site

The ecosystem services provided by offshore deep-sea muds in the site include:

- Nutrition – by providing a habitat for the Norway lobster (*Nephrops norvegicus)*, a commercially important shellfish species.
- Climate regulation - offshore deep-sea muds provide a long-term carbon sink (Alonso *et al*., 2012), so are important for climate regulation.

Given that a recover objective is advised for characteristic communities on which these functions rely, as well as the extent of the feature, **JNCC also advise a recover objective** for this sub-attribute. Further information on the impacts associated with human activities on offshore deep-sea muds can be found in the Advice on Operations workbook.

Attribute: Supporting processes

Objective: Conserve

There is limited evidence to suggest that supporting processes that operate at this site are being impeded with respect to supporting the presence of offshore deep-sea muds. As such, ***JNCC advise a conserve objective****. This is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures associated with ongoing activities. Our confidence in this objective would be improved with longer-term monitoring; specifically of contaminant levels within the site and a better understanding of the hydrodynamic regime. Activities must look to avoid, as far as is practicable, exceeding Environmental Quality Standards for contaminants from industry activities within, or in close proximity to, the site.*

Explanatory notes

Subtidal sedimentary habitats and the communities they support rely on a range of natural processes to support function (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 (hyperlink is provided in the box at the top of this document), the following natural supporting processes must remain largely unimpeded - hydrodynamic regime and 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 resources and propagules, as well as influence water properties by distributing dissolved oxygen, and facilitate 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 affects the movement, size, and sorting of sediment particles. Shape and surface complexity within Subtidal sedimentary habitat types can be influenced by hydrographic processes, supporting the formation of topographic bedforms (see finer scale topography). Typically, the influence of the hydrodynamic regime on Subtidal sedimentary habitats is less pronounced in deeper waters, although contour-following currents (e.g., on the continental slope) and occasional episodes of dynamic flow can occur (Gage, 2001).

Hydrodynamic regime of the feature within the site

Tidal flow rates in the region can vary between 0.31 and 0.15 m/s for spring and neap tides (Nexen, 2017). Within this region of the North Sea the mean spring tidal range is recorded as between one and two meters (Holgate *et al*., 2013; PSMSL, 2016). Water masses in the area are influenced by well mixed coastal water from the Atlantic inflow coming in from the north and the Fair Isle/ Dooley current which flows from north of Orkney. The flow recorded in this region of the North Sea is ~0.2 m/s in a southerly direction (Shell UK Ltd, 2017). Turbidity within the area is moderate (SEA3, 2016; Sündermann and Pohlmann, 2011).

The effect of episodic storm events on the site is unknown, but due to the depth range recorded within the site (80-100 m), it is unlikely that any of the site's sediments are above the storm-wave base. However, storm events have been shown to mobilise sediment up to the particle size of medium sand (~0.3mm) in 60 m water depth in the North Sea (Klein *et al*.,1999) and so the composition of the subtidal sedimentary habitats within the site may be affected by natural disturbance events such as storms.

While the presence of wells in the feature may have an extremely localised effect on the hydrodynamic regime within the site, it is not thought to have an adverse impact on the conservation status of the offshore deep-sea muds feature. As such, **JNCC advise a conserve objective** for this sub-attribute. This is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures associated with ongoing activities. Our confidence in this objective would be improved with a better understanding of the hydrodynamic regime within the site and its influence on the feature's conservation status.

Water and sediment quality

Contaminants may affect the ecology of Subtidal sedimentary habitats through a range of effects on different species within the habitat, depending on the nature of the contaminant (JNCC, 2004; UKTAG, 2008; EA, 2014). It is therefore important to avoid changing the natural water quality and sediment quality in a site and, as a minimum, ensure compliance with existing Environmental Quality Standards (EQSs).

The targets listed below for water and sedimentary contaminants in the marine environment are based on existing targets within OSPAR or the Water Framework Directive (WFD) that require concentrations and effects to be kept within levels agreed in the existing legislation and international commitments as set out in The UK Marine Strategy Part 1: The UK Initial Assessment (2012). Aqueous contaminants must comply with water column annual average (AA) EQSs according to the amended EQS Directive (2013/39/EU) or levels equating to (High/Good) Status (according to Annex V of the WFD (2000/60/EC), avoiding deterioration from existing levels).

Surface sediment contaminants (<1 cm 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 1.2 mg/kg. For further information, see Chapter 5 of the Quality Status Report (OSPAR 2010) and associated QSR Assessments.

The following sources of information are available 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 Oil and Gas UK website;
- CSEMP Green Book;
- Strategic Environmental Assessment Contaminant Technical reports available from the British Geological Survey website; and
- 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 the communities living in or on subtidal sedimentary 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. In deeper waters, dissolved oxygen levels are generally lower due to stratification of the water column and the isolation of bottom water masses (Greenwood *et al*., 2010). Salinity also increases with depth, peaking about 50 m down, after which the salinity decreases with increasing depth to a minimum around 1000 m in North Atlantic waters (Talley, 2002).

Water quality can influence habitats and the communities they support by affecting the abundance, distribution, and composition of communities at relatively local scales (Elliott *et al*., 1998; Little, 2000; Gray and Elliott, 2009). For example, a prolonged increase in suspended particulates can also have several implications, such as affecting fish health, clogging filtering organs of suspension feeding animals and affecting seabed sedimentation rates (Elliott *et al.,* 1998). Low dissolved oxygen can also have sub-lethal and lethal impacts on fish, infauna and epifauna (Best *et al*., 2007). Conditions in the deep-sea are typically more stable than in shallower habitats, therefore deep-sea organisms are expected to have a lower resilience to changes in abiotic conditions (Tillin *et al*., 2010). Concentrations of contaminants in the water column must not exceed the EQS.

Water quality within the site

The cool Atlantic waters to the north of the site exhibit seasonal stratification during spring and summer, which increase the prevalence of phytoplankton communities (Salomons *et al*., 1988; Weston *et al*., 2005). The site is also likely to be affected by the warmer central North Sea water to the south, although more data on the site's physicochemical properties are required.

Available evidence indicates relatively low suspended sediment concentrations in the deeper regions (below 50 m) of the North Sea of less than 5 g/m^3 (Eleveld *et al*., 2004). Phytoplankton production in the North Sea throughout the year results in chlorophyll *a* levels up to 5.8 µg/L (Brockmann and Wegner, 1985; Brockmann *et al*., 1990), supporting a high 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).

Evidence indicates that while the site is distant from terrestrial sources of pollution, enrichment of southern water masses due to riverine inputs and climatic variability are thought to affect ecological function of sites in the North Sea (Wieking and Kröncke, 2005). Atmospheric deposition in the North Sea has been highlighted as a major source of contamination of trace metals (cadmium, lead, copper, and zinc; Injuk *et al*., 1992). The site lies within the central North Sea in an area of relatively high human activity. Offshore oil and gas extraction can result in release of hydrocarbons into the water column, with discharges from North Sea offshore installations amounting to 16,000-17,000 tonnes oil/year (Walday and Krogland, 2017).

While this information identifies possible sources of contamination, there is currently no information available to indicate that water quality in the site is falling below environmental quality standards. Indeed, the Charting Progress 2 reports that the open seas are little affected by pollution and levels of monitored contaminants continue to fall, albeit slowly in many cases. Therefore, **JNCC advise a conserve objective** and that aqueous contaminants must be restricted to comply with water column annual average limits according to the amended environmental quality standards Directive (2013/39/EU) or levels equating to high/good status (Annex V of the Water Framework Directive 2000/60/EC), avoiding deterioration from existing levels.

Sediment quality

Various contaminants are known to affect the species that live in or on the surface of Subtidal sedimentary habitats. These include heavy metals like mercury, arsenic, zinc, nickel, chromium, and cadmium, polyaromatic hydrocarbons, polychlorinated biphenyls, organotins (such as Tribotyltin, TBT) and pesticides (such as hexachlorobenzene). These metals and compounds can impact species sensitive to contaminants, degrading the community structure (e.g., heavy metals) and bioaccumulate within organisms thus entering the marine food chain (e.g., polychlorinated biphenyls) (OSPAR 2009; 2010; 2012). The biogeochemistry of mud habitats in particular is such that contaminants could have more severe effects than in sandy habitats leading in some cases to acute or even anoxic conditions for several key and characterising species which could result in a change to species composition. It is therefore important to ensure sediment quality is maintained by avoiding the introduction of contaminants and, as a minimum, ensure compliance with existing EQS as set out above, particularly in mud habitats.

Sediment quality of the feature within the site

There is limited information available to ascertain the sediment contaminant levels within the site. According to the Clean Seas Environment Monitoring Program (CSEMP, 2014) assessment of data supplied by the British Oceanographic Data Centre, samples taken within and adjacent to the site suggest the sediment contaminant levels are below background conditions for the majority of monitored contaminants and would have few effects on marine life. For chlorobiphenyl-118, however, evidence suggests levels may be high enough to have adverse effects on marine organisms (CSEMP, 2014). Polyaromatic hydrocarbon (Benzo[g,h,i]perylene and Indeno[123-cd]pyrene) levels have also been shown to be above background levels, though the impact of this is not known (CSEMP, 2014).

Exploration of North Sea oil and gas reserves has resulted in the accumulation of large quantities of drill cuttings on the seabed surrounding drill sites (Breuer *et al*., 2004). The contamination of drill cuttings depends on the drill fluid used and varies; typically found contaminants include hydrocarbons such as diesel, oil distillates and olefins as well as certain metals (barium, cadmium, copper, nickel, lead, and zinc) (Breuer *et al.,* 2004, OSPAR 2019). As there are oil and gas exploration operations within the site, drill cuttings may present a local pollution pathway at the site. Following the OSPAR decision 2000/3, discharges of organic phase fluids (oil-based and synthetic based drilling fluids) into the marine environment have been restricted, however, more than half of wells drilled within the mud feature were spudded before these regulations came in place. Current drilling practices can have an impact footprint of up to 1 km (Henry *et al*. 2017), while historical drilling with oil-based drilling mud before regulations has been documented to impact fauna in up to 6 km distance from the well-head (Olsgard and Gray 1995). In the hydrodynamic environment of this site, it would take a long time for cuttings piles to be covered by settling sediments. Offshore industry activity and demersal trawling can further disperse the material of the piles and release buried contaminants, capable of causing continuous contamination (Bakke *et al.* 2017). Other related discharges from industry are regulated under the same legislation mentioned above and have only been permitted after sufficient appraisal has been undertaken by the relevant bodies.

Therefore, **JNCC advise a conserve objective** and that activities must look to avoid, as far as is practicable, exceeding Environmental Quality Standards set out above, as well as avoid disturbance of drill cutting piles. Our confidence in this objective would be improved with long term monitoring and a better understanding of contaminant levels in the site.

Table 2. Supplementary advice on the conservation objectives for ocean quahog aggregations (and their supporting habitat) in the East of Gannet and Montrose Fields Nature Conservation MPA

Attribute: Extent and distribution

Objective: Recover

The feature is being exposed to pressures associated with demersal mobile gear and offshore industries which can impact the feature's extent and distribution. Ocean quahog aggregations are highly sensitive to the pressures associated with demersal mobile gear, which are capable of damaging and displacing individuals. ***JNCC advise a recover objective*** *for the feature's extent and distribution based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. JNCC advises this objective acknowledging uncertainty around the ability of the feature to be restored within the site in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. To provide the best chance of any potential settlement for new recruits and to retain existing individuals, activities should look to minimise, as far as is practicable, disturbance to the existing individuals that may result in a change to the extent and distribution of ocean quahog aggregations within the site and changes in substrata that may result in a change to the natural extent of the ocean quahog's supporting habitat. Our confidence in the setting of this objective would be improved with long-term monitoring of their condition and a better understanding of how the activities impact the feature.*

Explanatory notes

Extent describes the occurrence of *Arctica islandica* (herein referred to as ocean quahog), with distribution providing a more detailed overview of the species' location(s) and pattern of occurrence within a site. It is important to consider the life histories and environmental preferences of the species as they have a strong influence on extent and distribution of ocean quahog.

Ocean quahog is found around all British and Irish coasts, as well as offshore. The species has also been recorded from the Baltic, Iceland, the Faroe Islands, Onega Bay in the White Sea to the Bay of Biscay and from Labrador to North Carolina (Tyler-Walters and Sabatini, 2017). Benthic surveys have shown a reduction in North Sea distribution between 1902-1986 (Rumohr *et al*., 1998). The same surveys also show a reduction in species abundance between 1972-1980 and 1990-1994.

It is thought that UK waters are likely to be a sink of new recruits, with larval settlement events originating from Iceland separated by long periods without successful recruitment (Witbaard and Bergman, 2003). These recruits are thought to be carried down the east coast of the UK and into the mid and southern North Sea where the slower moving waters inside gyres allow settlement to occur. Temperature is also thought to play an important role in the successful recruitment of ocean quahog, with increasing temperatures attributed as the cause of low recruitment success in North Sea populations (Witbaard and Bergman, 2003). As the seas around the UK warm, it is expected that southerly populations of ocean quahog may experience increased recruitment failure resulting in a range contraction. Recovery of the feature within a site is therefore likely to be reliant on an infrequent and unpredictable supply of recruits from elsewhere and highly dependent on wider environmental pressures, such as climate change.

As a burrowing species, extent, and distribution of supporting habitats will be important in governing the extent and distribution of the species. Ocean quahog has been found in a range of sediments, from coarse clean sand to muddy sand in a range of depths typically from 4 m to 482 m deep, but most commonly between 10 m to 280 m (Thorarinsdóttir and Einarsson, 1996; Sabatini *et al*., 2008; OSPAR, 2009; Tyler-Walters and Sabatini, 2017). Ocean quahog is thought to have a high sensitivity to physical loss of habitat (Tyler-Walters and Sabatini, 2017). It is therefore important to conserve the extent and distribution of supporting habitats to provide the best chance of any potential settlement for new recruits and to retain existing individuals.

Extent and distribution of the feature within the site

The known extent and distribution of ocean quahog aggregations is available to view via the JNCC's Interactive MPA Mapper link on the SIC. It should be noted that ocean quahog supporting habitat is also discussed under Supporting processes further on in the document.

Samples taken during surveys for oil and gas developments between 1994-2000 provide evidence of ocean quahog aggregations in the north and northwest of the site. This distribution is validated by the recent collaborative survey between JNCC and Marine Directorate in 2015, including the identification of smaller numbers of individuals to the east of the site (McCabe *et al*. 2020). Ocean quahog aggregations found in this survey occurred across the site at a depth of 80 m - 100 m (O'Connor, 2016).

Oil and gas infrastructure activities are present within the site. These include platforms, wells, pipelines and associated hard substrate related to protection and stabilisation of infrastructure. The oil and gas associated infrastructure within the site overlaps with the known extent and distribution of ocean quahog aggregations. The installation of these structures may have resulted in localised physical damage, smothering and mortality through the introduction of concrete mattresses, cuttings piles and rock dump. This type of activity, as well as installation of structures associated with other industry such as cables, has the potential to reduce or alter the extent and distribution of ocean quahog and their supporting habitat within the site.

VMS data from 2009-2020 indicates that there is demersal trawling activity within the north and northeast of the site where Ocean quahog is predominately found. However, this is at relatively low levels. In the southeast of the site, in which fewer individuals of ocean quahog were found, there is medium to high demersal trawling activity. As ocean quahog is highly sensitive to fishing associated pressures, with an individual pass of beam trawl gear potentially resulting in 20% mortality (Bergman and van Santbrink, 2000), even low levels of activity have the potential to reduce or alter the extent and distribution of ocean quahog within the site. Fishing activity penetrating the substrate can further bring buried quahog to the surface of the seabed, making them more accessible to predators such as fish (Thorarindsóttir et al. 2009, Cramer and Daan 1986).

Ocean quahog recovery is likely to be very slow owing to its life-history characteristics (long-lived, sporadic recruitment episodes and the vulnerable nature of the species itself to physical pressures) (Butler *et al*., 2012; Brix, 2013; Ridgeway and Richardson, 2010; Tyler-Walters and Sabatini, 2017). Moreover, environmental factors such as climate change are also likely to be contributing to reduced recruitment and therefore potential recovery of the species.

The feature is being exposed to pressures associated with demersal mobile gear and offshore industries which can impact the feature's extent and distribution. Ocean quahog aggregations are highly sensitive to the pressures associated with demersal mobile gear, which are capable of damaging and displacing individuals. **JNCC advise a recover objective** for the feature's extent and distribution based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. JNCC advises this objective acknowledging uncertainty around the ability of the feature to be restored within the site in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. To provide the best chance of any potential settlement for new recruits and to retain existing individuals, activities should look to minimise, as far as is practicable, disturbance to the existing individuals that may result in a change to the extent and distribution of ocean quahog aggregations within the site and changes in substrata that may result in a change to the natural extent of the ocean quahog's supporting habitat. Our confidence in the setting of this objective would be improved with long-term monitoring of their condition and a better understanding of how the activities impact the feature.

For further information on activities capable of affecting Ocean quahog aggregations and their supporting habitat, please see the Advice on Operations workbook.

Attribute: Structure and function

Objective: Recover

The feature is being exposed to pressures associated with demersal mobile gear and offshore industries which can impact the feature's structure and function. Ocean quahog aggregations are highly sensitive to the pressures associated with demersal mobile gear, which are capable of damaging and displacing individuals. ***JNCC advise a recover objective*** *for the feature's structure and function based on expert judgement, specifically our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. JNCC advises this objective acknowledging uncertainty around the ability of the feature to be restored within the site in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. To provide the best chance of any potential settlement for new recruits and to retain existing individuals, activities should look to minimise, as far as is practicable, disturbance to the ocean quahog aggregations. Our confidence in the setting of this objective would be improved with long-term monitoring of their condition and a better understanding of how the activities impact the feature.*

Explanatory notes

Structure

Structure refers to the densities and age classes of individuals from a population found within a site. Ocean quahog are more prevalent in the northern North Sea than the southern North Sea. Recorded ocean quahog densities typical in the North Sea are outlined in the table below.

The structure of ocean quahog populations tends to be highly skewed in the North Sea, with populations containing either adults or juveniles, as opposed to representatives of both age classes (AquaSense, 2001; Witbaard and Bergman, 2003; OSPAR, 2009). Sporadic recruitment and the detrimental effect of increasing temperature on juveniles is expected to have a significant effect on successful ocean quahog recruitment. Recovery of a population within a site is likely to be reliant on an infrequent supply of recruits from elsewhere and the influence of wider environmental temperature changes brought about by climate change.

Ocean quahog / m^2	**Geographic location**	**Sampling method**	**Reference**
Northern North Sea			
12	Central Fladen grounds	Box coring	De Wilde *et al.* (1986)
286	Northern Fladen	Triple D-dredge	Witbaard and Bergman (2003)
23	Southern Fladen	Triple D-dredge	Witbaard and Bergman (2003)
Southern North Sea			
0.07	Oyster grounds	Triple D-dredge	Witbaard and Bergman (2003)
0.14-0.17	North of Dogger Bank	Triple D-dredge	Witbaard and Bergman (2003)
0.35	Central Oyster ground	Triple D-dredge	Witbaard and Bergman (2003)

It is important to note that distinguishing between adult and juvenile ocean quahog is difficult without in-depth analysis of shell growth, and that individuals of similar size may vary greatly in age. For example, individuals ranging from 50-179 years old showed little discernible difference in mean length (Ropes and Murawski, 1983). However, what is known is that growth rates are relatively fast during the juvenile stage between 3-7 years of age but slow down after 15 years (Thompson *et al*., 1980; Cargnelli *et al*., 1999; Tyler-Walters and Sabatini, 2017). Both sexes have highly variable shell lengths at sexual maturity, between 24 mm and 49 mm reported (Thompson *et al*., 1980; Cargnelli *et al*., 1999). Shell length is therefore not a reliable indicator of age for this species.

Recovery of ocean quahog populations is hard to monitor and likely to be extremely slow (on a scale of centuries rather than decades) due to the species being long-lived (up to 507 years recorded; Brix, 2013) and slow growing, occurring in low densities, having low fecundities, recruiting irregularly, and having high juvenile mortality rates (Ridgeway and Richardson, 2010; Butler *et al*., 2012). For populations in UK waters, this is compounded by the fact that any recovery would likely be dependent on a supply of recruits from elsewhere. It is therefore important that the number and age class of individuals is conserved in the long-term to maintain the population within the site.

Structure of the feature within the site

Information contained within UK Benthos shows 47 ocean quahog individuals were sampled in the site between 1990-2000. A collaborative survey between JNCC and Marine Directorate in 2015 found 69 ocean quahog individuals throughout the site, taking 0.25 m^2 Hamon grab samples at 155 stations across the site (McCabe *et al*. 2020). Most ocean quahogs were found as single individuals (singletons) in the grab samples (20 samples), with nine grab samples containing doubletons, five samples containing three individuals and two samples containing four individuals.

Evidence from the 2015 monitoring survey indicates that the full extent of the site contains habitat suitable for ocean quahog aggregation colonisation but about 80% of individuals found during this survey occurred in the habitat A5.2 Subtidal sand. The average density of the ocean quahog aggregations recorded from 155 Hamon grab samples taken across the site in 2015 was 1.77 individuals/m^2. This is well below the range of documented average densities from the northern North Sea (12-286 individuals/m^2) (Witbaard, 1997; Witbaard and Bergman, 2003). However, the 2015 surveys used a different grab type to sample ocean quahog, i.e., Hamon grabs, which has to be taken into consideration when comparing these numbers. The method used during the 2015 survey is generally not as effective in assessing ocean quahog density compared to trawl-based sampling methods (such as those used by Witbaard and Bergman, 2003). There is currently insufficient evidence available to attribute a reason for the observed lower densities of the species within the site as compared to recorded densities from elsewhere in the North Sea.

During the 2015 survey, 39 of the 69 individuals recorded were juveniles (McCabe 2020). As the species is estimated to mature between 5 and 11 years (Thorarinsdóttir 1999), this indicates successful settlement of larvae in the 2000s. More data are required to develop a time series of ocean quahog population structure to identify any changes to the feature in the site over time. As the monitoring survey of 2015 provided the first data point of a time series for ocean quahog aggregations within the site, it is unclear whether the population is declining, being conserved, or increasing in the site. The age structure, growth rates and reproductive viability of the population located within the site are also currently unknown.

Some types of demersal trawling have been shown to cause varying rates of damage and mortality to ocean quahog based on the size of the individuals, with juvenile shells (up to 4cm) being most vulnerable (Witbaard and Klein 1994), resulting in a skewed impact on the population and therefore structure. For long-lived species such as the ocean quahog, recovery to the structure before adverse impacts from trawling is also considered unlikely if the pressures are ongoing (Hiddink *et al.* 2019).

JNCC acknowledge the significant effect of prevailing sea temperatures on the likely survivorship and recruitment potential of ocean quahog aggregations (Cargnelli *et al*., 1999; Witbaard and Bergman, 2003; Tyler-Walters and Sabatini, 2017) and the reported widespread declines in the abundance of this species throughout the North Sea (Rumohr *et al.,* 1998).

JNCC advise a recover objective for the feature's structure based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. Evidence indicates that activities that are capable of impacting the structure of the ocean quahog aggregations feature are occurring within the site, most notably demersal trawling as it can cause damage, displacement and mortality to ocean quahog. JNCC advises this objective acknowledging uncertainty around the ability of the feature to be restored within the site in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. Our confidence in the setting of this objective would be improved by long-term monitoring information on the population of Ocean quahog aggregations throughout the site. For further information on activities capable of affecting ocean quahog aggregations, please see the Advice on Operations workbook.

Function

Functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition, among others. These functions rely on supporting natural processes and the growth and reproduction of ocean quahog. These functions can occur at a range of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC, 2011).

Ecosystem services that may be provided by ocean quahog include:

- Nutrition: providing food for a broad range of fish and invertebrate species, including commercially important fish species, e.g., cod and haddock (Cramer and Daan 1986, Brey *et al*., 1990; Rees and Dare, 1993; Cargnelli *et al.*, 1999);
- Regulatory processes: providing a bentho-pelagic link by removing plankton and detritus from the water column;
- Carbon cycling and nutrient regulation: maintaining healthy and productive ecosystems through the laying down of carbonate during shell growth and filter-feeding; and
- Scientific study: ocean quahog longevity enables the construction of 'master chronologies' over hundreds of years to study climatic and environmental change (Butler *et al*., 2012; Schöne, 2013). Ocean quahog also provide a key role in ageing research and are an indicator

of heavy metal pollution in sediments and historical environmental change (Weidman *et al*., 1994; Zettler *et al*., 2001; Liehr *et al*., 2005; Schöne, 2005).

Function of the feature within the site
Whilst there is no direct evidence on the ecosystem services provided by the species in the site, ocean quahog are filter feeders and remove plankton and detritus from the water column, playing a role in carbon cycling and nutrient regulation (Tyler-Walters and Sabatini, 2017). The longevity of ocean quahog also enables scientists to construct 'master chronologies' over tens or hundreds of years to study changes in climate and environmental change using the biogenic carbonates stored in the growth rings of ocean quahog (Schöne, 2013). This data can be used to: investigate the mechanisms driving ocean circulation and temperature variability in North Atlantic waters over the past millennia; understand the significance of external forcing (solar and volcanic), internal variability and climate oscillations (North Atlantic Oscillation and Atlantic Multidecadal Oscillation) in a coupled ocean-atmosphere model of the last 1000 years; and to research the mechanisms of longevity to better understand human ageing.

The feature is being exposed to pressures associated with demersal mobile gear and offshore industries, which may be impacting the feature's function by altering population density, structure, and numbers. Therefore, **JNCC advise a recover objective** for the feature's function based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities. JNCC advises this objective acknowledging uncertainty around the ability of the feature to be restored within the site in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes*.* Activities should look to minimise, as far as is practicable, disturbance to individuals within the site. Our confidence in the setting of this objective would be improved by long-term monitoring information on the population of Ocean quahog aggregations throughout the site. For further information on activities capable of affecting ocean quahog aggregations, please see the Advice on Operations workbook.

Attribute: Supporting processes

Objective: Recover

JNCC consider there is limited evidence to suggest that supporting processes are being impeded with respect to supporting the ocean quahog aggregations within the site. This is with the exception of supporting habitat, where evidence suggests that the introduction of hard substrata associated with industry activities may have reduced the availability of suitable seabed substrate for ocean quahog colonisation. As such, ***JNCC advise a recover objective*** *for this attribute based the supporting habitat sub-attribute and advise that activities must look to avoid, as* *far as is practicable, exceeding Environmental Quality Standards set out below, as well as change in substrate extent and distribution. Our confidence in this objective would be improved with long-term monitoring, a better understanding of contaminant levels in the site and how contaminants can impact Ocean quahog aggregations.*

Explanatory notes

Ocean quahog rely on a range of supporting natural processes to support function (ecological processes) and help any recovery from adverse impacts. Supporting processes can be physical, biological, and chemical in nature (Alexander *et al*., 2014). In the case of ocean quahog, these are the environmental conditions that can affect species persistence, growth, and recruitment. For the site to fully deliver the conservation benefits set out in the statement on conservation benefits, hydrodynamic regime, supporting habitat and water and sediment quality must remain largely unimpeded.

Hydrodynamic regime

Hydrodynamic regime refers to the speed and direction of currents, seabed shear stress and wave exposure. These mechanisms circulate food resources and propagules, as well as influence water properties by distributing dissolved oxygen and transferring oxygen 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, and sorting of sediment particles, which as filter-feeders could affect the feeding behaviour, growth and survival of ocean quahog. Alterations to the natural movement of water and sediment could affect the presence and distribution of ocean quahog, particularly given the reliance on larvae from Icelandic waters to re-stock populations in the North Sea (Witbaard and Bergman, 2003). The natural movement of water and sediment should therefore not be hindered.

Hydrodynamic regime of the feature within the site

The hydrodynamic regime in the site is seasonally stratified (van Leeuwen *et al*., 2015), with thermal stratification occurring in the spring as the air temperatures start to increase, reducing mixing of the water. The water masses remain stratified through-out summer until autumn when falling air temperatures and high winds cause a mixing of the water column (Sündermann and Pohlmann, 2011; van Leeuwen *et al*., 2015). The low air temperature and pressure during winter results in continuous mixed hydrodynamic conditions in this region of the North Sea. Seasonal stratification results in a seasonal pattern of nutrient availability and therefore food supply for ocean quahog aggregations varies throughout the year (Witbaard, 1996).

Tidal flow rates in the region can vary between 0.31 and 0.15 m/s for spring and neap tides (Nexen, 2017). Within this region of the North Sea the mean spring tidal range is recorded as between one and two meters (Holgate *et al*., 2013; PSMSL, 2016). Fair Isle/ Dooley current which flows from north of Orkney, as a result turbidity is moderate (SEA3, 2016; Sündermann and Pohlmann, 2011). Water masses in the area are influenced by well mixed coastal water from the Atlantic inflow coming in from the north and the Fair Isle/ Dooley current which flows from north of Orkney. The flow recorded in this region of the North Sea is ~0.2 m/s in a southerly direction (Shell UK Ltd, 2017). Movement of the water masses from the Northeast Atlantic to central North Sea could help carry recruits for new Ocean quahog populations into the area from locations around Iceland (Sündermann and Pohlmann 2011). The depth of the site is 80-100m (thus below the storm base water depth) suggesting that it is unlikely for the sediments of the site to be affected by storm events.

While infrastructure known to be present within the site may be having a localised effect on the hydrodynamic regime within the site, this is not likely to have an adverse impact on the conservation status of ocean quahog aggregations which are present. As such, **JNCC advise a conserve objective** for this sub-attribute. For further information on activities capable of affecting Ocean quahog aggregations and their supporting habitat, please see the Advice on Operations workbook.

Supporting habitats

The extent and distribution of supporting habitat plays an important role in determining the extent and distribution of the species. As a burrowing species, ocean quahog has been found in a range of sediments; from coarse clean sand to muddy sand ranging in depth typically from 4 m to 482 m, but most commonly between 10 m and 280 m (Thorarinsdóttir and Einarsson, 1996; Sabatini *et al*., 2008; OSPAR, 2009). Ocean quahog are thought to have a high sensitivity to physical change to or loss of habitat (Tyler-Walters and Sabatini, 2017). It is therefore important to conserve the extent and distribution of supporting habitats within the site to conserve ocean quahog populations and provide the best chance of any potential settlement for new recruits.

Supporting habitats within the site

As previously mentioned the extent and distribution of supporting habitat is available to view via the JNCC's Interactive MPA Mapper link on the SIC.

Based on what is known about the habitat preferences of ocean quahog (Witbaard and Bergman, 2003), >99% (~1,839km^2) of the seabed habitats present within the site are considered suitable for ocean quahog colonisation (based on UKSeaMap modelled habitat data; JNCC, 2018). Evidence from the 2015 monitoring survey corroborates this assumption. The supporting habitats within the site include subtidal sand and subtidal mixed sediments, with the latter habitat found only in small pockets across the site.

JNCC understands that the site includes locations where offshore infrastructure has been installed, such as oil platforms, subsea structures, and pipelines. Such installation practices often result in a change in substrate on the seafloor through the introduction of concrete mattresses, cuttings piles and rock dump. This type of activity has the potential to reduce or alter the natural extent of supporting habitat for ocean quahog aggregations within the site.

JNCC advise a recover objective for this attribute and that, as far as is practicable, changes in substrata within the site is kept to an absolute minimum. For further information on activities capable of affecting Ocean quahog aggregations and their supporting habitat, please see the Advice on Operations workbook.

Water and sediment quality

Ocean quahog is considered not sensitive to contaminants at Environmental Quality Standards (EQS) levels (Tyler-Walters and Sabatini, 2017). However, above this baseline, some contaminants may impact the conservation status of Ocean quahog depending on the nature of the contaminant (UKTAG, 2008; EA, 2014). Ocean quahog has a medium sensitivity to other water qualities, such as increases in temperature (Tyler-Walters and Sabatini, 2017). It is important therefore to avoid changing water and sediment quality properties of a site and as a minimum ensure compliance with existing EQSs.

The targets listed below for water and sedimentary contaminants in the marine environment are based on existing targets within OSPAR or the Water Framework Directive (WFD) that require concentrations and effects to be kept within levels agreed in the existing legislation and international commitments as set out in The UK Marine Strategy Part 1: The UK Initial Assessment (2012). Aqueous contaminants must comply with water column annual average (AA) EQSs according to the amended EQS Directive (2013/39/EU) or levels equating to (High/Good) Status (according to Annex V of the WFD (2000/60/EC), avoiding deterioration from existing levels).

The following sources of information are available 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 Oil and Gas UK website;
- CSEMP Green Book; and
- Cefas' Containment Status of the North Sea Report (2001) and Contaminant Status of the Irish Sea Report (2005)

The water quality properties that influence ocean quahog include salinity, pH, temperature, suspended particulate concentration, nutrient concentrations, and dissolved oxygen. These parameters can act alone or in combination to affect Ocean quahog according to species-specific tolerances. In fully offshore habitats these parameters tend to be more stable, particularly so for deeper waters, although there may be some natural seasonal variation. Changes in any of the water quality properties through human activities may impact habitats and the communities they support (Elliot *et al*., 1998; Little, 2000; Gray and Elliot, 2009).

Salinity does not appear to be a limiting factor for the distribution of ocean quahog, since the species is found in the Baltic Sea at 16 ppt (OSPAR, 2009), in the mid-Atlantic Bight at 32-34 ppt (Cargnelli *et al*., 1999) and Oeschger and Storey (1993) successfully kept adult quahog at 22 ppt in the laboratory for several weeks.

Experimental evidence has shown that lower pH (380-1120 µatm pCO_2), has no effect on shell growth or crystalline microstructure in Ocean quahog as the species can actively pump protons to drive increased calcification (Stemmer *et al*., 2013; 2014). This suggests that although Ocean quahog can buffer against the effects of short-term acidification, longer-term acidification may have energetic consequences and ultimately restrict growth and/or reproductive output.

Adult ocean quahog have a medium sensitivity to increases in water temperature. Evidence suggests that the optimal temperature for ocean quahog survival, spawning and recruitment is 6-16°C (Loosanoff, 1953; Merrill *et al*., 1969; Golikov and Scarlato, 1973; Jones, 1981; Mann, 1989; Cargnelli *et al*., 1999; Harding *et al*., 2008). Temperature change can be local (associated with localised effects, such as warm-water effluents, are, however, highly unlikely to have a significant impact in offshore environments) or global (associated with climate change). The impacts on habitats and species from global temperature change can be direct, e.g., changes in breeding or growing seasons, predator-prey interactions, symbiotic relationships, and species' physiologies, or indirect, e.g., changes in habitat conditions (Begum *et al.,* 2010). Although our understanding of climate trends and their consequent impacts on habitats and species has improved, we still face many uncertainties in predicting how climate change may impact on the distribution of Ocean quahog.

Temperature has been attributed as the cause of low recruitment in North Sea populations, potentially increasing larval mortality and consequently restricting their southernmost extent (Witbaard and Bergman, 2003; Harding *et al*., 2008). Temperature-induced changes in phytoplankton communities can also have knock-on effects on zooplankton communities, which can in turn impact filter-feeding organisms, such as Ocean quahog (Witbaard *et al*., 2003). Witbaard *et al*. (2003) found that at high densities, copepods associated with warming seas intercept the downward flux of food particles to benthic communities. For ocean quahog this can lead to slower shell growth. It is therefore important to conserve the natural temperature regime of the water column as far as is practicable against wider environmental pressures.

Ocean quahog are thought to have a low sensitivity to deoxygenation, nutrient enrichment, organic enrichment, changes in suspended sediments and smothering (Tyler-Walters and Sabatini, 2017). Although low levels of smothering via siltation events are unlikely to affect Ocean quahog, high levels of smothering could restrict their ability to feed or breathe (Elliot *et al*., 1998; Morton, 2011). Adult ocean quahog can switch from aerobic to anaerobic respiration and are able to resurface post-smothering (Sabatini *et al*., 2008). Powilleit *et al*. (2009) documented a high burrowing potential in ocean quahog after experimental burial, successfully burrowing to the sediment surface through a covering layer of 32-41 cm. Although ocean quahog can survive low dissolved oxygen levels, it could have sub-lethal and lethal affects under long-term anoxia (Taylor, 1976; Weigelt, 1991; Strahl *et al*., 2011).

Ocean quahog are not considered sensitive to organic and inorganic pollutants (Tyler-Walters and Sabatini, 2017). However, JNCC advise that aqueous contaminants should be restricted to comply with water column annual average limits according to the amended environmental quality standards Directive (2013/39/EU) or levels equating to high/good status (Annex V of the Water Framework Directive 2000/60/EC), avoiding deterioration from existing levels. It is important therefore to carefully consider any proposals or human activity that could change the natural water quality properties affecting a site and as a minimum ensure compliance with existing EQS.

Water and sediment quality of the feature within the site

The site lies within the central North Sea in an area of relatively high levels of human activity. Shipping and oil and gas operations occur within the site and could impact the water quality. Offshore oil and gas extraction can result in release of hydrocarbons into the water column, with discharges from offshore installations in the North Sea amounting to 16,000-17,000 tonnes of oil per year (Walday and Krogland, 2017). There is no evidence available to reach a conclusion on the impact of hydrocarbons on ocean quahog aggregations within the site.

Available evidence indicates relatively low suspended sediment concentrations in the deeper regions (below 50 m) of the North Sea of less than 5 g/m^3 (Eleveld *et al*., 2004). Phytoplankton production in the North Sea throughout the year results in chlorophyll *a* levels as high as 5.8 µg/ L (Brockmann and Wegner, 1985; Brockmann *et al*., 1990), supporting a high biomass of species at higher trophic levels year-round and creating a region that is biologically unique (Kröncke and Knust, 1995).

Evidence from the Charting Progress 2 report indicates that while the site is distant from terrestrial sources of pollution, enrichment of southern water masses due to riverine inputs and climatic variability may affect ecological function of sites in the North Sea. Atmospheric deposition in the North Sea has been highlighted as a major source of contamination with trace metals (cadmium, lead, copper, and zinc; Injuk *et al*., 1992).

It is unclear whether sediment quality is impacted to the extent that it may affect the conservation status of ocean quahog aggregations. Information on pollution by heavy metals is sparse with considerably more data required. Studies from 1992 indicated no evidence of pollution accumulation by heavy metals in North Sea sediments (Chapman, 1992; Chapman *et al*., 1992), whereas older studies showed evidence of high concentrations of heavy metals in North Sea sediments, except in the central North Sea (Salomons *et al*., 1988).

There is limited information available on the sediment contaminant levels within the site. According to Clean Seas Environment Monitoring Program (CSEMP, 2014), samples taken within and adjacent to the site suggest the sediment levels for the majority of monitored contaminants are below background levels and thus such contaminants will have limited impact on marine life. For chlorobiphenyl-118, however, evidence suggests levels may be high enough to have adverse effects on marine organisms (CSEMP, 2014). Polyaromatic hydrocarbon (Benzo[g,h,i]perylene and Indeno[123-cd]pyrene) levels have also been shown to be above background levels, though it is not known whether such levels have any effects on the biology (CSEMP, 2014).

Furthermore, the exploration and exploitation of North Sea oil and gas reserves has resulted in the accumulation of large quantities of drill cuttings on the seabed surrounding drill sites (Breuer *et al*., 2004). These drill cuttings contain higher concentrations of certain metals (barium, cadmium, copper, nickel, lead, and zinc) and hydrocarbons than found in natural sediments (Breuer *et al.,* 2004). As there are oil and gas infrastructures within the site, drill cuttings, especially older drill cuttings potentially containing oil-based muds may present a pollution pathway at a local scale. Following changes to the Offshore Petroleum Activities (Oil Pollution, Prevention and Control) Regulations 2005, discharges of untreated Oil Based Mud (OBM) into the marine environment have now ceased, however, more than two thirds of wells drilled within the MPA were spudded before these regulations came in place. Continued offshore industry activity, trawling and other physical disturbance can further cause dispersion of material and leakage of contaminants from deeper layers of historical cutting piles (Bakke *et al.* 2013). Contamination with copper and lead has been suggested to impact ocean quahog population structure, where less animals, especially recruits, were found at a polluted site (Liehr *et al.* 2005).

Due to the lack of evidence on the sediment and water quality affecting ocean quahog aggregations within the site, **JNCC advise a conserve objective** and that activities must look to avoid, as far as is practicable, exceeding EQSs set out above. Activities further should avoid disturbance of drill cutting piles to avoid the release of contaminants. Our confidence in this objective would be improved with long term monitoring, a better understanding of contaminant levels in the site and how contaminants can impact ocean quahog. For further information on activities capable of affecting Ocean quahog aggregations and their supporting habitat, please see the Advice on Operations workbook.

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