Supplementary Advice on Conservation Objectives for Holderness Offshore MCZ

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NATURAL ENGLAND

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Contents

Introduction

What the conservation advice package includes

The information provided in this document sets out JNCC and Natural England's supplementary advice on the conservation objectives set for this site. This forms part of JNCC and Natural England'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 and Natural England'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 features condition and General Management Approach;
    - conservation benefits that the site can provide; and
    - conservation measures needed to support achievement of the conservation objectives set for the site.
- Supplementary Advice on Conservation Objectives (SACO) providing more detailed and site-specific information on the conservation objectives (this document);
- Advice on Operations providing information on those human activities that, if taking place within or near the site, can impact it and present a risk to the achievement of the conservation objectives stated for the site.

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 protected features: Subtidal coarse sediment, Subtidal sand, Subtidal mixed sediments and Ocean quahog (*Arctica islandica*), specified in the site's conservation objectives. These attributes are: extent and distribution, structure and function, and supporting processes. Supplementary advice on the conservation objectives for the geomorphological feature: North Sea glacial tunnel valleys is not currently provided in this document. Further information regarding this feature can be found on the Site Information Centre or by contacting JNCC at OffshoreMPAs@jncc.gov.uk.

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 the following tables describe the desired ecological condition (favourable) for the site's features. Each feature within the site must be in favourable condition as set out in the site's conservation objective. All attributes listed in the following tables must be taken into consideration when assessing impacts from an activity.

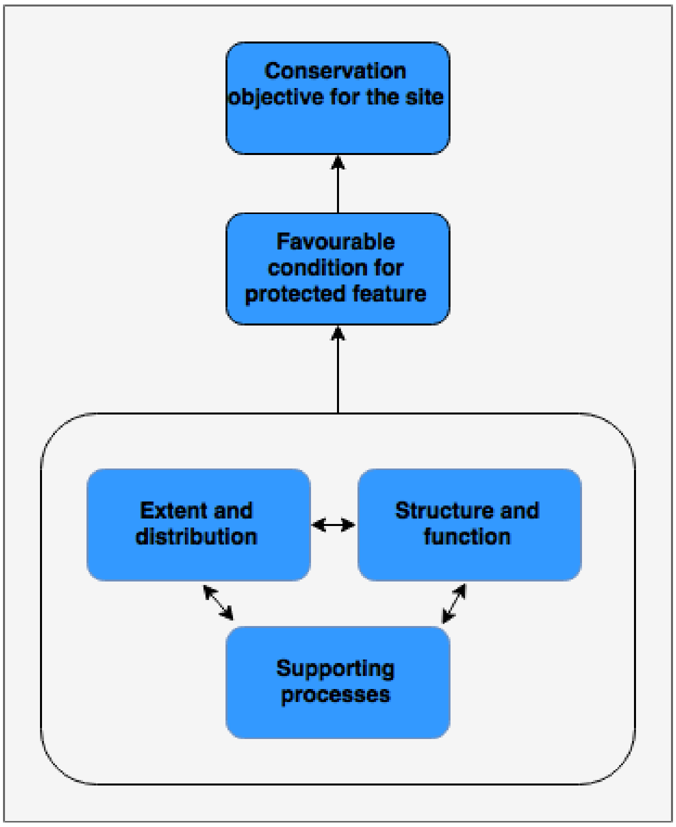

Figure 1. Conceptual diagram showing how a feature's attributes are interlinked and collectively describe favourable condition and contribute to the conservation objectives stated for the site.

In Table 1 below, the attributes for the broad-scale habitats (Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments) are listed and a description provided in explanatory notes. In Table 2, the attributes for the species Feature of Conservation Importance (Ocean quahog) are listed and a description provided in explanatory notes.

Table 1: Supplementary advice on the conservation objectives for the sedimentary broad-scale habitats (Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments) in Holderness Offshore MCZ.

Attribute: Extent and distribution
Objective: Recover **JNCC and Natural England understand that the site has been subjected to activities, notably those associated with oil and gas infrastructure, that have resulted in a change to the extent and distribution of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on extent and distribution. As such, we advise a recover objective for the extent and distribution of Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments. These objectives are based on expert judgment, specifically our understanding of feature sensitivity to pressures associated with ongoing activities. Our confidence in these objectives would be improved with long term monitoring, better access to activities information, and a better understanding of how the activity impacts the features within the site. Activities should look to minimise, as far as is practicable, changes in substrata within the site.**
Explanatory notes Extent refers to the total area in the site occupied by Subtidal sedimentary habitats and must include consideration of their distribution, i.e. how spread out they are within a site. A reduction in extent has the potential to alter the biological and physical functioning of Subtidal sedimentary habitat types (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). The extent of the Subtidal sedimentary habitats within the site must be conserved to their full known distribution. Subtidal sedimentary habitats 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 Subtidal sedimentary habitats in the UK marine environment. In offshore environments, note that Subtidal sedimentary habitats are not typically dominated by algal communities.

A significant change in sediment composition and/or biological assemblages within an MPA could indicate a change in the distribution and extent of Subtidal sedimentary habitats within a site (see UK Marine Monitoring Strategy for more information on significant change). Reduction in extent has the potential to affect the functional roles of the biological communities associated with Subtidal sedimentary habitats (Elliott *et al.,* 1998; Tillin and Tyler-Walters, 2014), e.g. a change from coarser to finer sediment would alter habitat characteristics, possibly favouring deposit feeders over suspension feeders (Tillin and Tyler-Walters, 2014). Maintaining extent is therefore critical to maintaining or improving conservation status of Subtidal sedimentary habitats.

A general description of the different types of Subtidal sedimentary habitats found in the UK offshore marine environment of relevance to this MPA is provided below:

- *A5.1 Subtidal coarse sediment* – Comprises of coarse sand, gravel, pebbles, shingle and cobbles. These sediments typically have low silt content and are characterised by robust fauna, including venerid bivalves (Connor *et al.,* 2004). The particle sizes of Subtidal coarse sediments are classed as more than 0.063 mm but predominantly contain grains sizes in excess of 2 mm (McBreen and Askew, 2011).
- *A5.2 Subtidal sand* – Comprises of clean medium to fine sands or non-cohesive slightly muddy sands. Such habitats are often subject to a degree of wave action or tidal currents which restrict the silt and clay content to less than 15%. This habitat is characterised by a range of taxa including polychaetes, bivalve molluscs and amphipods (Connor *et al.,* 2004). Subtidal sand is defined by the ratio of mud to sand being lower 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).
- *A5.4 Subtidal mixed sediments* – Comprises of mixed sediments found from extreme low water to deep, offshore circalittoral habitats. These habitats include a range of sediments, such as heterogeneous muddy gravelly sands and mosaics of cobbles and pebbles embedded in or lying upon sand, gravel or mud. Mixed sediments include mosaic habitats, such as superficial waves or ribbons of sand on a gravel bed or areas of lag deposits with cobbles/pebbles embedded in sand or mud and are less well defined, sometimes overlapping other habitat or biological subtypes. These habitats may support a wide range of infauna and epibionts, including polychaetes, bivalves, echinoderms, anemones, hydroids and bryozoans (Connor *et al.,* 2004). Subtidal mixed sediments are classed by a range sediment sizes, predominantly more than 0.063 mm, but mud may also be present (McBreen and Askew, 2011).

Extent and distribution of the sedimentary broad-scale habitats within the site

The site map for Holderness Offshore MCZ is available to view on JNCC's Interactive MPA Mapper. The site area is calculated to be 1176 km^2 , dominated by EUNIS habitat A5.1: Subtidal coarse sediment, covering an area of approximately 1070 km^2. There are patches of A5.4: Subtidal mixed sediments located throughout the site with the largest patch located in the centre. Another patch lies over the northern tip of the North-valley glacial tunnel geomorphological feature, which is located in the south-east corner of the site. Small patches of A5.2: Subtidal sand, covering a total area of less than 25 km^2 are located within the site and are predominately situated near the edges of the site boundary.

Fishing activities, specifically benthic trawling and dredging, occur throughout the site and overlap with the site's mapped broad-scale habitat features. These habitats are sensitive to the pressures associated with benthic trawling and dredging activities, notably abrasion/disturbance of the substrate on the surface of the seabed and physical changes to the seabed or sediment type. These pressures are not typically associated with the large-scale physiographic or hydrodynamic pressures capable of impacting the extent and distribution of the protected broad-scale habitats, and therefore it is less likely that this attribute will be impacted by the fishing activity occurring within the site.

Oil and gas infrastructure activities are present within the site: these include platforms, wells, pipelines and associated hard substrate related to protection and stabilisation. To date (March 2021), there are 6 subsurface platforms, 19 pipelines (consisting of trenched and buried pipelines, as well as pipelines that are protected by concrete mattresses or rock rubble) and 26 wells associated with oil and gas extraction.

All of the platforms, pipelines and wells intersect with the extent of the Subtidal coarse sediment feature. Given the relatively large number of oil and gas infrastructure in place and the fact that it is dispersed throughout the site, Subtidal coarse sediment is considered to be exposed to moderate levels of pressures associated with this activity, and subsequently is considered to be moderately vulnerable..

The extent of subtidal mixed sediment is partially overlapped by one of the wells and 5 of the 19 pipelines associated with oil and gas extraction occurring within the site. The pipelines overlap with a large proportion of the feature's extent within the site, and therefore Subtidal mixed sediment is considered to be exposed to moderate levels of associated pressures. Itis considered to be highly vulnerable to the oil and gas infrastructure activities occurring.

Subtidal sand is partially overlapped by one of the 19 pipelines associated with oil and gas extraction occurring within the site and is exposed to low levels of associated pressures. Although Subtidal sand is exposed to low levels of associated pressures it is highly sensitive and therefore is considered to have a moderate vulnerability to the oil and gas infrastructure activities occurring within the site.

All three broad-scale habitat features will be exposed to these pressures for as long as the infrastructure remains in place.

It is understood that a consented pipeline route for Tolmount offshore development will cross the site and intersect directly with a portion of the extent of Subtidal sand and Subtidal mixed sediments features. Once initial installment of the pipeline has commended, associated pressures may directly impact the extent and distribution of these habitats. As construction has yet to commence, the features are not currently exposed to any pressures from this development and are not considered further in this advice.

JNCC and Natural England understand that the activities, notably the oil and gas infrastructure (pipelines, platforms and wells) occurring in the area of Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments habitat features are capable of impacting their extent and distribution within the site. Some protected broad-scale habitat extent is considered to be lost due to the ongoing presence of large-scale and widespread infrastructure associated with offshore oil and gas activities, which have resulted in changes to the substratum. This includes the placement of scour protection and protection of pipelines using rock dumping and mattressing, which provide an artificial hard/coarse substratum habitat in areas of softer sediment. For this reason we believe that some of the extent of the broad-scale habitat features have been lost. In addition, the impact to the extent and distribution of the protected features may also be caused by the pressures associated with physical changes to the seabed through, for example, the creation of cutting piles. Please see the attribute physical structure: sediment composition and distribution within the site for more information on the substrate types that compose the protected broad-scale habitat features within the site. For more information on how activities can impact the broad-scale habitat features within the site please refer to the Advice on Operations for the site.

JNCC and Natural England advise a recover objective for the extent and distribution of Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments. These objectives are based on expert judgment, specifically our understanding of feature sensitivity to pressures associated with ongoing activities. Our confidence in these objectives would be improved with long term monitoring, better access to activities information (specifically total volumes of rock protection and concrete mattressing used within the site and the location and number of drilling piles), and a better understanding of how the activity impacts the features within the site. Activities should look to minimise, as far as is practicable, changes in substrata within the site. For further information on activities capable of affecting the protected sedimentary broad-scale features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Structure and function

Objective: Recover

JNCC and Natural England understands that the site has been subjected to activities that have resulted in a change to the sediment composition and distribution, characteristic communities, and function of the protected broad-scale habitats within the site. Installation and/or removal of infrastructure may have a continuing effect on structure and function, specifically the characteristic communities and sediment composition and distribution. Demersal fishing activities may also have an ongoing effect on the characteristic communities. As such, JNCC and Natural England advise a recover objective based on expert judgment; specifically, our understanding of the sensitivity of the features to pressures which can be exerted by ongoing activities i.e. demersal trawling, dredging and oil and gas industry activities. Our confidence in this objective would be improved 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, disturbance and changes to sediment composition and biological communities found within the site.

Explanatory notes

Structure refers to the physical structure of a Subtidal sedimentary habitat and its biological structure. Physical structure refers to finer scale topography and sediment composition. Biological structure refers to the key and influential species and characteristic communities present.

Physical structure: Finer scale topography

The topography of Subtidal sedimentary habitats 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 sedimentary broad-scale habitats within the site

Evidence is very limited regarding the presence of fine-scale topographical features within the site. A better understanding, obtained through further monitoring, of the finer scale topography that may be present within the site is required to determine how activities such as demersal fishing and oil and gas associated infrastructure may impact the fine-scale topographic features. As such, **JNCC and Natural England advise a maintain objective**. This is based on expert judgement; specifically, our understanding of the sensitivity of the features to pressures exerted by the activities present. Our confidence in this objective would be improved by long term monitoring and a better understanding of the finer scale topography within the site.

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 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). The continental shelf edge and upper continental slope (>200 m) have been shown to be impacted by currents, influencing sediment composition by depositing finer particles in deeper waters (Hughes, 2014). Indeed, mud content can increase exponentially with depth as hydrodynamic influence is reduced (Bett, 2012).

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 sedimentary broad-scale habitats within the site
Several habitat types are present at the site, including A5.1: Subtidal coarse sediment, A5.2: Subtidal sand and A5.4: Subtidal mixed sediments. Although A5.1: Subtidal coarse sediment dominates, A5.2: Subtidal sand and A5.4: Subtidal mixed sediments are patchily distributed throughout the site, with verified small patches of Subtidal sand distributed around the edges of the MPA boundary, and the largest patch of mixed sediment located in the centre of the site, with smaller patches of this habitat in the north and south areas of the site.

Particle size analysis was used to classify and determine the composition the sedimentary broad-scale habitat features within the site. Available evidence shows that the composition of Subtidal coarse sediment within the site predominately consists of sand followed closely by gravel with a small proportion of silt/clay (40.31 ± 15.16%, 56.38 ± 14.60%, and 3.31 ± 1.30%: gravel, sand and silt/clay contribution respectively). Subtidal sand's composition mainly consists of sand with smaller amounts of gravel and silt/clay (1.725 ± 1.29%, 98.261 ± 1.32%, and 0.02 ± 0.01%: gravel, sand and silt/clay respectively). The composition of Subtidal mixed sediments consists of predominately sand, followed closely by gravel and then silt/clay (35.78 ± 15.62%, 42.42 ± 16.59%, and 21.44 ± 17.77%: gravel, sand and silt/clay respectively) (DEFRA, 2017).

The relatively dynamic nature of the currents around the site may mobilise finer surface sediments and it is expected that the spatial distribution of the surface sediments could change naturally over time. It is clear, however, from available survey data that A5.1: Subtidal coarse sediment is the dominant habitat type with patches of A5.2: Subtidal sand and A5.4: Subtidal mixed sediment distributed across the site.

Fishing activities as described previously under the extent and distribution attribute, may have a localised, short-term effect on sediment composition within the site. Given the low levels of demersal fishing activity (predominantly benthic trawling and dredging) it is unlikely that the pressures, for example smothering and siltation rate changes and changes in suspended solids, from these activities would be significant enough impact the protected broad-scale habitats within this site.

However, all protected broad-scale habitats within the site have been exposed to oil and gas activities that may have resulted in a change to their sediment composition. As mentioned previously under the extent and distribution attribute, oil and gas infrastructure has been introduced throughout the site. This results in changes to substratum from, for example, sedimentary to hard substrate in places, such that these areas no longer represent the protected broad-scale habitats as defined. Other protective materials regularly used within the site are rock dump, consisting of gravel and grout or gabion bags of a man-made material filled with grout which will also be capable of changing the substrate. Where wells are drilled, drill cuttings are produced which are again capable of changing the substrate type and sediment composition. The oil and gas infrastructure (pipelines, platforms and wells) occurring in the area of Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediments habitats are therefore capable of impacting the sediment composition of the protected broad-scale habitat within the site. The impact to the sediment composition of the protected features is predominately caused by the placement of scour protection and infrastructure protection where soft sediment habitats are replaced by hard/coarse substratum habitats i.e. rock dumping and mattressing to protect pipelines as well as the creation of cuttings piles. For this reason, we believe that the sedimentary composition of the broad-scale habitat features has been changed. For more information on how activities can impact the broad-scale habitat features within the site please refer to the Advice on Operations for the site.

The installation and/or removal of infrastructure may have a continuing effect on sediment composition of the protected broad-scale habitat features located within this site. It is understood that a consented pipeline route for Tolmount offshore development will cross the site and intersect directly with a portion of the extent of Subtidal sand and Subtidal mixed sediments features. Once initial installation of the pipeline has commended, associated pressures may directly impact the extent and distribution of these habitats. As construction has yet to commence, the features are not currently exposed to any pressures from this development and are not considered further in this advice.

JNCC and Natural England advise a recover objective for sediment composition of Subtidal coarse sediment, Subtidal sand and Subtidal mixed sediment habitats within the site. This objective is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. oil and gas infrastructure. Our confidence in this objective would be improved 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. For further information on activities capable of affecting the protected broad-scale features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Biological structure: Key and influential species

Key and influential species are those that have a core role in determining the structure and function of Subtidal sedimentary habitats. 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 the Subtidal sedimentary habitats can also be classed as key or influential species. Changes to the spatial distribution of communities across a Subtidal sedimentary habitat 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 a site to avoid diminishing biodiversity and the ecosystem functioning provided by the protected Subtidal sedimentary habitats, and to support their 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 the feature 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 Subtidal sedimentary habitats 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 (Mazik *et al.,* 2015).

Biological structure: Key and influential species of the sedimentary broad-scale habitats within the site

A variety of bioturbators, predators and grazers have been recorded from surveys within the Holderness Offshore MCZ, such as, squat lobsters (*Munida rugosa*), Common sun stars (*Crossaster papposus*), Dead man's fingers (*Alcyonium digitatum*), sea urchins (*Echinus esculentus*), common shore crabs (*Carcinus maenas*) and other unidentified crustaceans (Sotheran *et al.,* 2016). However, there is insufficient information available to support an understanding of the significance of the role that these species play in maintaining the function and health of the protected Subtidal sedimentary habitats.

A habitat suitability model suggested that there is potential for the OSPAR threatened or declining Ross worm (*Sabellaria spinulosa*) reefs to be present in the site (Tappin *et al.,* 2011). Although more recent assessments of reef quality did not find any conclusive evidence of medium/high quality Ross worm (*Sabellaria spinulosa*) reefs within their samples (Ocean Ecology, 2018; Premier, 2018), it is recognised that there is the potential for this habitat to occur within the site.

The bivalve *Arctica islandica*, commonly known as Ocean quahog, a notable species and listed OSPAR threatened or declining species is also present within the site. Ocean quahog is a protected Feature of Conservation importance of this site and further information can be found in Table 2. It is possible that these species play a critical role in maintaining the structure and function of the protected Subtidal sedimentary habitats. However, no further information is currently available to draw conclusions with any degree of certainty.

Since there is insufficient information available to support an understanding of the significance of the role that these species play in maintaining the function and health of the protected broad-scale habitat features, it cannot be determined how the activities occurring within the site may impact these key and influential species. Therefore, it is not possible to set an objective for this sub-attribute and is not considered further in our advice.

Biological structure: Characteristic communities

The variety of biological 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, such as those covering large areas, and notable communities, such as those that are nationally or locally rare or scarce, listed as OSPAR threatened and/or declining, or known to be particularly sensitive to anthropogenic activities.

Biological communities within Subtidal sedimentary habitats vary greatly depending on location, sediment type and depth, as well as other physical, chemical and biological processes. Burrowing bivalves and infaunal polychaetes thrive in coarse sedimentary habitats where the sediment is well-oxygenated, with animals such as hermit crabs, flatfish and starfish living on the seabed. In deeper and more sheltered areas, the effects of wave action and prevailing currents may be diminished, resulting in finer sedimentary habitats where burrowing species may have a key role to play in maintaining the biological diversity of the habitat.

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

Similar to the biological structure and function of key and influential species, the recovery of characterising species' 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 sedimentary broad-scale habitats within the site

There is limited information available about the biological structure of the broad-scale habitat features within Holderness Offshore MCZ. The following biological communities have been recorded within Holderness Offshore MCZ (Tappin *et al.,* 2011; Sotheran *et al*., 2016; Premier, 2018):

- Circalittoral fine sand (A5.25) – This community was found to be present in small patches within the north-west of the site. Circalittoral fine sand is a more stable habitat than shallower, infralittoral sands and thereby supports a more diverse community, characterised by a wide range of echinoderms, including the *Echinocyamus pusillus*, polychaetes such as *Ophelia borealis* and bivalves.
- Circalittoral mixed sediments (A5.44) – This community consists of a wide range of infaunal polychaetes, bivalves, echinoderms and burrowing anemones such as *Cerianthus lloydii* and epifaunal species such as the hydroids *Nemertesia* spp. and *Hydrallmania falcata*. This biotope was found to be present throughout the central area of the site with primary in areas of Subtidal coarse sediment and Subtidal mixed sediment.
- Circalittoral coarse sediment (A5.14) – This community was found across the site and consists of tide-swept circalittoral coarse sands, gravel and shingle. Typically found along exposed coasts and offshore, it is characterised by robust infaunal polychaetes, including *Glycera lapidum, Spiophanes bombyx* and *Ampelisca spinipes,* mobile crustacea and bivalves such as *Pecten maximus*.

The soft coral *Alcyonium digitatum*, anemone *Edwardsia claparedii*, gastropods of the family *Buccinidae*, sea urchin *Echinus esculentus* and the crustacean *Liocarcinus depurator* also occurred at high abundance throughout the site. In addition, a habitat suitability model suggested that there is potential for the OSPAR threatened or declining Ross worm (*Sabellaria spinulosa*) reefs to be present within the site (Tappin *et al*., 2011). Although more recent assessments of reef quality did not find conclusive evidence of medium/high quality Ross worm (*Sabellaria spinulosa*) reefs within their samples (Ocean Ecology, 2018; Premier, 2018), it is recognised that there is the potential for this habitat to occur within the site. The OSPAR threatened and/or declining species Ocean quahog, is also present and is a protected feature within the site (see Table 2 for more information).

Vessel monitoring services (VMS) gridded data, indicate that fishing activities, specifically benthic trawling and dredging, occurred throughout the site up to 2017, overlapping with the mapped protected sedimentary broad-scale habitats.

Subtidal coarse sediment has been exposed to high levels of pressures associated with benthic trawling from 2009 - 2016, with the highest level of effort focused in the north of the site. Since JNCC's post-consultation advice provided in 2018, benthic trawling effort has marginally decreased across the areas of Subtidal coarse sediment. However, dredging activity has increased across areas of Subtidal coarse sediment, most notably in the centre of the site.

Subtidal sand has been exposed to high levels of pressures associated with benthic trawling from 2009 – 2016, with low to moderate levels of effort overlapping with the entire extent of the feature. Since JNCC's post-consultation advice provided in 2018, benthic trawling effort has overall decreased across areas of Subtidal sand, with only one patch of Subtidal sand, located in the north of the site exposed to this activity. However, dredging effort has remained consistent across areas of Subtidal sand.

Subtidal mixed sediment has been exposed to high levels of pressures associated with benthic trawling from 2009 – 2016, with low to moderate levels of effort overlapping with the entire extent of the feature. Since JNCC's post-consultation advice provided in 2018, benthic trawling effort has marginally decreased across the feature. However, dredging activity effort levels have increased, most notably across the largest patch of Subtidal mixed sediment that is located in centre of the site.

The protected broad-scale habitats found within this site are sensitive to the pressures associated with benthic trawling and dredging activities, notably surface abrasion: damage to seabed surface features and the removal of non-target species. These pressures are capable of impacting the characteristic communities found within these habitats through the disturbance of the upper layers of the seabed which can damage, displace or cause death to benthic flora and fauna residing at or beneath the surface of the seabed. Furthermore, the close contact interaction between the fishing gear and seabed can also alter the habitat structure and attract short-term scavengers. For more information on how activities can impact the broad-scale habitat features within the site please refer to the Advice on Operations for the site.

As mentioned under the extent and distribution attribute, oil and gas infrastructure activities are widespread across the site and overlap with all of the protected sedimentary broad-scale habitats. The oil and gas infrastructure activities, including the protection of pipelines using rock dumping and mattressing techniques and placement of cuttings piles, are capable of impacting the surface of the seabed through the abrasion/disturbance of the substrate on the surface of the seabed, physical change to the seabed and sediment type and through the potential introduction or spread of invasive species. These pressures may result in a loss or change of subtidal sedimentary habitats from areas of the site and consequently loss of the subtidal sedimentary communities they support. All three broad-scale habitat features will be exposed to these pressures for as long as the infrastructure remains in place. Furthermore, a consented pipeline route for Tolmount offshore development will also cross the site and intersect directly with a portion of the extent of Subtidal sand and Subtidal mixed sediment. The pressures associated with the initial instalment of the pipeline may directly impact the extent and distribution of these habitats, but as construction has yet to commence, the features are not currently exposed to any pressures from this development.

JNCC and Natural England advise a recover objective for characteristic communities of the feature within the site based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. demersal fishing and oil and gas industry activities. Our confidence in this objective would be improved 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 the biological communities within the site. Further information on the impacts associated with human activities can be found in the Advice on Operations workbook for the site (hyperlink is provided in the box at the top of this document).

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 number 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 Subtidal sedimentary habitats 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) and shallow sandy sediments can offer habitat for sand eels (Rowley, 2008), which in turn are prey for larger marine species, including birds and mammals (FRS, 2017);
- Bird and whale watching: Foraging seals, cetaceans and seabirds may also be found in greater numbers near some Subtidal sedimentary habitats due to the common occurrence of prey for the birds and mammals (e.g. Daunt *et al.,* 2008; Scott *et al.,* 2010; Camphuysen *et al.,* 2011; McConnell *et al.,* 1999, Jones *et al.,* 2013);
- Climate regulation: Providing a long-term sink for carbon within sedimentary habitats.

The biological structure of key and influential species and characterising species are dependent on the influence of prevailing environmental conditions, life-history traits and interactions between species: 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). It is critical to ensure that the extent and distribution of Subtidal sedimentary habitats 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 sedimentary broad-scale habitats within the site

The broad-scale habitat features within the site support a wide variety of fauna, including polychaetes, burrowing anemones, echinoderms, small crustaceans and bivalves such as Ocean quahog (*Arctica islandica*). These in turn provide important feeding opportunities for fish, including some commercially important species. The entirety of this site has been identified as important spawning and nursery grounds for a variety of fish species, including Lemon sole (*Microstomus kitt*), Plaice (*Pleuronectes platessa*) and Sprat (*Sprattus sprattus*) (Net Gain, 2011). In turn, the presence and abundance of these fish species supports the foraging behaviour of seabirds and marine mammals (Camphuysen *et al*., 2011) that have been found within the site.

The location of Holderness Offshore MCZ and its proximity to the Flamborough Head and Bempton Cliffs SPA and RSPB reserve is of particular importance to several breeding seabird species that forage in the area, including common guillemot (*Uria aalge*), black legged kittiwake (*Rissa tridactyla*), and northern gannet (*Morus bassanus*) (Tappin *et al.,* 2011), all of which are listed as either red or amber under the latest birds of conservation concern (Eaton *et al.,* 2015). There are two main species of marine mammals which have been record in Holderness Offshore MCZ: grey seal (*Halichoerus grypus*) and harbour porpoise (*Phocoena phocoena*) (Net gain, 2011; García *et al.,* 2019). These species have been found to forage in this area as it is rich in a variety of fish species of which they consume (Tappin *et al.,* 2011). This site overlaps with the Southern North Sea SAC, which is designated for the protection of harbour porpoise. In addition, harbour porpoise is listed on the OSPAR list of threatened and/or declining species (OSPAR, 2008) and therefore Holderness Offshore MCZ is considered as providing a supporting function to the wider population of harbour porpoise. Further information on the Southern North Sea SAC can be found on the Southern North Sea MPA site information centre.

Given that a recover objective is advised for characteristic communities on which these functions rely, **JNCC and Natural England advise a recover objective** for this sub-attribute. Our confidence in the objective would be improved by long term monitoring, access to better information on the activities taking place within the site and a better understanding of the role which biological communities play in the function and health of the feature.

Attribute: Supporting processes

Objective: Maintain

JNCC and Natural England consider that there is limited evidence to suggest that supporting processes are being impeded with respect to supporting the function of the protected broad-scale habitats within the site. As such, JNCC and Natural England advise a maintain objective for supporting processes based on expert judgment; specifically, our understanding of the impacts of ongoing activities on the feature attributes. Our confidence in this objective would be improved with long-term monitoring, specifically of contaminant levels within the site and a better understanding of the hydrodynamic regime within the site. Activities must look to avoid, as far as is practicable, impairing the hydrodynamic regime within the site and exceeding Environmental Quality Standards set out in the relevant section below.

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 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 flows can occur (Gage, 2001).

Hydrodynamic regime within the site

Hydrodynamic regime in Holderness Offshore MCZ generally consists of moderate wave and current energy at the seabed, with lower wave energy towards the east of the site (McBreen *et al.*, 2011). Waves and tidal currents predominantly occur in a southwest and northeast direction with tidal currents running at between 0.28 ms^{-1} and 0.62 ms^{-1} (EMODnet, 2012). The average annual height of waves is less than 2m, but with wave height reaching 6m in some instances (Net gain, 2011; EMODnet, 2012). The relatively dynamic and unstable conditions occurring within the site are believed to be responsible for the dominance of A5.1: Subtidal coarse sediment found within this site (Tappin *et al.,* 2011). A significant oceanographic feature occurring in the area of Holderness Offshore MCZ is an area of upwelling, or 'front', at Flamborough, where the cold, deeper, stratified waters of the northern North Sea meet the warmer, shallower, well-mixed waters of the southern North Sea. This is considered to give the site increased ecological significance as it provides nutrient-rich warm waters, enhancing primary production via plankton growth (Net gain, 2011).

The effect of episodic storm events on the site is unknown, but due to the depth range recorded within the site, it is unlikely that any part of the site is above the storm-wave base. However, storm events have been shown to mobilise sediment up to the particle size of medium sand in 60m water depth in the North Sea (Klein *et al*.,1999) and so the composition of the protected broad-scale habitats within the site may be affected by natural disturbance events. While oil and gas associated infrastructure known to be present may be having a localised effect on the hydrodynamic regime within the site, it is unclear whether this is having an adverse impact on the conservation status of the protected sedimentary broad-scale habitats present. As such, **JNCC and Natural England advise a maintain 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 and 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 per kg. For further information, see Chapter 5 of the Quality Status Report (OSPAR, 2010) and associated QSR Assessments.

The following sources of information regarding historic or existing contaminant levels in the marine environment are available:

- Marine Environmental and Assessment National Database (MERMAN)
- The UK Benthos database available to download from the Oil and Gas UK website;
- Cefas' 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 near bed salinity within the site ranges from 33 - 34.5 PSU with lower salinities as expected toward the west, inshore region of the site. Near bed temperatures of 7 - 9°C persist, with cooler Atlantic waters coming from the north of the site (Tappin *et al.,* 2011). The predominant stratification in the North Sea begins in spring in the north and extends southwards as the season progresses, which increases the prevalence of phytoplankton communities (Weston *et al*., 2005; Bloomfield *et al.,* 2011). 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 physiochemical properties is required.

Available evidence indicates relatively high suspended sediment concentrations in the shallower regions (0 - 30 m) of the North Sea of more 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 $\mu g\ L^{-1}$ (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 from the Charting Progress 2 report indicates that there is a marginal rise in sea temperature in the region of the site's location that has the potential to change plankton community, lengthen the growing season and change the distribution of some fish species, and consequently may reduce the diversity of the communities associated with the site's protected broad-scale habitats. Furthermore, although inputs of many hazardous substances are decreasing in the site's region, persistence of some substances continue to rise in industrialised estuaries found within the region. 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). While this information identifies possible sources of contamination, there is currently no information available to determine whether water column contaminant levels in Holderness Offshore MCZ are exceeding any EQSs. 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 and Natural England advise a maintain 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 (PAHs), polychlorinated biphenyls (PCBs), organotins (such as tributyltin (TBT)) and pesticides (such as hexachlorobenzene (HCB)). These metals and compounds can impact species sensitive to contaminants, degrading the community structure (e.g. heavy metals) and bioaccumulating within organisms, thus entering the marine food chain (e.g. PCBs) (OSPAR, 2009a; 2010; 2012). The biogeochemistry of mud habitats in particular is such that the effects of contaminants are greater (Sciberras *et al.,* 2016), leading in some cases to anoxic or intolerant conditions for several key and characterising species and resulting 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 contaminant levels are below existing EQSs, as set out above, particularly in mud habitats.

Sediment quality within the site

It is unclear whether sediment quality is currently being impacted within the site. In relation to pollution by heavy metals, available information is contradictory and not directly available for this site. For example, studies from 1992 indicated no evidence of pollution accumulation by heavy metals in North Sea sediments (Chapman, 1992; Chapman *et al*., 1992), whereas other studies showed evidence of areas in the North Sea with high concentrations of heavy metals in sediments that were bioavailable to benthic organisms (Salomons *et al*., 1988; Scholten *et al*., 1998). OSPAR Co-ordinated Environmental Monitoring Programme (CEMP) assessment, which uses data extracted from the Marine Environment Monitoring and Assessment National (MERMAN) database, indicated that in the Humber/Wash region in which the site is located, the main metals above the concentration range for potential effects on marine organisms are mercury, lead and chromium. All other remaining contaminants assessed within this region, including PAHs, PCBs and organotins, are considered to be at levels below environmental assessment criteria. However this data does not provide direct evidence for concentrations of contaminants found within the site.

The historical 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). These drill cuttings may contain higher concentrations of certain metals (barium, cadmium, copper, nickel, lead and zinc) and hydrocarbons than found in natural sediments (Breuer *et al*., 2004). During any further oil and gas exploration operations taking place within Holderness Offshore MCZ, drill cuttings may present a local pollution pathway at the site. Following changes to the Offshore Petroleum Activities (Oil Pollution, Prevention and Control) Regulations 2005, discharges of Oil Based Mud (OBM) have now ceased, removing this potential pollution pathway. Other related discharges from industry are regulated under the same regulations and are only permitted after sufficient appraisal has been undertaken by the relevant bodies. As available evidence is sparse and inconclusive, **JNCC and Natural England advise a maintain objective**. This objective is based on expert judgement, specifically our understanding of the feature’s sensitivity to pressures associated with ongoing activities. Activities must look to avoid, as far as is practicable, exceeding sediment EQSs set out above.

Table 2: Supplementary advice on the conservation objectives for the species Feature of Conservation Importance (Ocean quahog) in Holderness Offshore MCZ.

Attribute: Extent and distribution
Objective: Recover **Ocean quahog are exposed to activities that are capable of impacting their extent and distribution, most notably benthic trawling and dredging. Ocean quahog are highly sensitive to the pressures associated with these activities, which are capable of damaging and displacing individuals. JNCC and Natural England therefore advise a recover objective for Ocean quahog extent and distribution 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 would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature. Activities should look to minimise, as far as is practicable, changes in substrata that may result in a change to the natural extent of the Ocean quahog's supporting habitat, or removal of the species that may result in a change to the extent and distribution within the site.**
<u>Explanatory notes</u> 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 these will have a strong influence on extent and distribution. 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, and 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, 2009a; 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 species Feature of Conservation Importance within the site

There is very limited information available on the extent and distribution of Ocean quahog in the site. The known extent and distribution of Ocean quahog within the site is available to view via the JNCC's Interactive MPA Mapper. Based on what is known about the habitat preferences of Ocean quahog, usually having a preference for finer sediments (Witbaard and Bergman, 2003), the site, predominately covered by coarse sediments, is not considered best suited for high density Ocean quahog colonisation. However, although higher densities of Ocean quahog are commonly found in finer sediments, smaller densities have also been found to occur in coarser sediments and are therefore not limited to a specific sediment type (Witbaard and Bergman, 2003). Survey data have identified a limited extent of Ocean quahog within Holderness Offshore MCZ, with a patchy distribution primarily located in the north of the site along with one survey record located in the south-west of the site (DEFRA, 2017; García *et al.*, 2019).

Fishing activities, specifically benthic trawling and dredging, occur throughout the site and overlap with the Ocean quahog survey records. Ocean quahog are exposed to high levels of pressures associated with demersal trawling from 2009 – 2016, with the highest levels of effort focussed in the north of the site. Although, benthic trawling effort levels have decreased since JNCC's post-consultation advice in 2018, Ocean quahog continue to be exposed to moderate levels of pressures associated with demersal trawling. Furthermore, Ocean quahog has been exposed to consistent high levels of pressures associated with dredging activities from 2009 – 2018. Ocean quahog are highly sensitive pressures associated with benthic trawling and dredging activities, notably penetration and/or disturbance of the substrate below the surface of the seabed, shallow abrasion/penetration: damage to seabed surface and removal of non-target species. These activities and associated pressures have the potential to damage, displace or can be lethal to Ocean quahog. These activities are therefore seen as capable of impacting the extent and distribution of Ocean quahog found within Holderness Offshore MCZ.

Oil and gas infrastructure activities are present within the site, these include platforms, wells, pipelines and associated hard substrate related to protection and stabilisation. Currently, the oil and gas associated infrastructure within Holderness Offshore MCZ does not overlap with the know extent and distribution of Ocean quahog. However, a number of pipelines lay close to the known extent of Ocean quahog which are predominately found in the north of the site, and 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 has the potential to reduce or alter the extent and distribution of Ocean quahog within the site. Whilst future decommissioning activities that do not require rock dump may result in the introduction of habitat that is suitable for colonisation by Ocean quahog (once oil and gas operations within a site have ceased), this is likely to be a very slow process due to the long lifespan, slow reproduction and vulnerable nature of the species (Butler *et al*., 2012; Brix, 2013; Ridgeway and Richardson, 2010; Tyler-Walters and Sabatini, 2017). For more information on how activities can impact the Ocean quahog feature within the site please refer to the Advice on Operations.

JNCC and Natural England advise a recover objective for the extent and distribution of Ocean quahog 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 extent and distribution of the Ocean quahog feature are occurring within the site, most notably demersal trawling and dredging. The pressures associated with these activities are capable of damaging and/or displacing and are potentially lethal to Ocean quahog. Our confidence in this objective would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature. Activities should look to minimise, as far as is practicable, changes in substrata that may result in a change to the natural extent of the Ocean quahog's supporting habitat, or removal of the species that may result in a change to the extent and distribution within the site. For further information on activities capable of affecting Ocean quahog and their supporting habitat, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Structure and function

Objective: Recover

Ocean quahog are exposed to activities, that are capable of impacting the feature's structure and function, most notably benthic trawling and dredging. Ocean quahog are highly sensitive and vulnerable to the pressures associated with the activities occurring within the site. As such, JNCC and Natural England advise a recover objective 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 would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature's structure and function.

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.

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

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, 2009a). 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.

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, it is known 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,with lengths of 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 (over centuries) due to the species' long lifespan (up to 507 years recorded; Brix, 2013), slow growth, low density, irregular recruitment, high juvenile mortality and low fecundity (Ridgeway and Richardson, 2010; Butler *et al*. 2012). For the UK, 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 species Feature of Conservation Importance within the site

No living individual Ocean quahog were sampled across Holderness Offshore MCZ between 1972 and 2000 (Witbaard and Bergman, 2003). Limited data are available on the population density of this feature within the site. Surveys within the site recorded 5 living Ocean quahog individuals between 2007 and 2016 between 9 m and 49m depth (Sotheran *et al*., 2016; DEFRA, 2013, 2017; García *et al*., 2019). 4 individuals were found in the north of the site and one in the south-west of the site. As there are few records of Ocean quahog found within the site, it is difficult to determine their distribution. As there are no time series data available for Ocean quahog within the site, it is unclear whether the population is declining, being maintained or increasing in the site. The age structure, growth rates and reproductive viability of the population located within site are also currently unknown.

Widespread declines in the abundance of Ocean quahog have been reported throughout the North Sea (Rumohr *et al*., 1998). Evidence indicates that this decline in abundance is related to the prevailing sea temperatures in the North Sea which are having a significant effect on the likely survivorship and recruitment potential of Ocean quahog (Cargnelli *et al*., 1999; Witbaard and Bergman, 2003; Tyler-Walters and Sabatini, 2017) a

Fishing activities, specifically benthic trawling and dredging occur throughout the site and overlap with all Ocean quahog survey records. Ocean quahog has been exposed to high levels of pressures associated with demersal trawling from 2009 – 2016, with the highest levels of effort focussed in the north of the site. Although, benthic trawling effort levels have decreased since JNCC's post-consultation advice in 2018, Ocean quahog continue to be exposed to moderate levels of pressures associated with demersal trawling. Furthermore, Ocean quahog has been exposed to high levels of pressures associated with dredging activities from 2009 – 2018. Ocean quahog are highly sensitive to exposure of the pressures related with benthic trawling and dredging activities, notably penetration and/or disturbance of the substrate below the surface of the seabed, shallow abrasion/penetration: damage to seabed surface and removal of non-target species, as these activities and associated pressures have the potential to damage, displace or can be lethal to Ocean quahog. These activities are therefore seen as capable of impacting the structure of Ocean quahog found within Holderness Offshore MCZ.

Oil and gas infrastructure activities are present within the site, these include platforms, wells, pipelines and associated hard substrate related to protection and stabilisation. Currently, the oil and gas infrastructure within the site does not overlap with the known extent and distribution of Ocean quahog. However, a number of pipelines lay close to the known extent of Ocean quahog which are predominately found in the north of the site, and 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 has the potential to impact the structure of the Ocean quahog population within the site. Whilst future decommissioning activities that do not require rock dump may result in the introduction of habitat that is suitable for colonisation by Ocean quahog (once oil and gas operations within a site have ceased), this is likely to be a very slow process due to the long lifespan, slow reproduction and vulnerable nature of the species (Butler *et al*., 2012; Brix, 2013; Ridgeway and Richardson, 2010; Tyler-Walters and Sabatini, 2017). For more information on how activities can impact the Ocean quahog population structure within the site please refer to the Advice on Operations for the site.

JNCC and Natural England advise a recover objective for the structure of Ocean quahog 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 feature are occurring within the site, most notably demersal trawling and dredging. The pressures associated with these activities are capable of damaging, displacing and are potentially lethal to Ocean quahog. Our confidence in this objective would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature. For further information on activities capable of affecting Ocean quahog and its supporting habitat, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Function

Functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition. These functions rely on supporting natural processes and the growth and reproduction of Ocean quahog. These functions can occur at several 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 (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;
- 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 *et al.,* 2005); and

- Climate change regulation: Ocean quahog take up carbon from the environment during the process of shell growth.

Function of the species Feature of Conservation Importance within the site

Whilst there is no direct evidence on the ecosystem services provided by the species in Holderness Offshore MCZ, Ocean quahog are filter feeders that remove plankton and detritus from the water column and have 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; Poitevin *et al.,* 2019). 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 research the mechanisms of longevity to better understand human ageing. JNCC and Natural England 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; Rees *et al.,* 2007).

As activities occurring within the site, most notably demersal trawling and dredging, are capable of impacting Ocean quahog population structure and extent, the functions that this feature could provide are also likely to be impacted. Therefore, **JNCC and Natural England advise a recover objective,** 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 function of the Ocean quahog feature are occurring within the site, most notably demersal trawling and dredging. The pressures associated with these activities are capable of damaging, displacing and are potentially lethal to Ocean quahog. Our confidence in this objective would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature's function. For further information on activities capable of affecting Ocean quahog and its supporting habitat, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Supporting processes

Objective: Recover

Although there is limited information available for the impact of activities occurring within the site on the supporting processes of Ocean quahog, JNCC and Natural England advise a recover objective for this attribute reflecting the need to recover the supporting habitats of Ocean quahog which have been considered lost due to the presence of large-scale and widespread infrastructure associated with offshore oil and gas activities (as described in the sub-attribute: supporting habitats). As far as is practicable, changes in substrata within Holderness Offshore MCZ are kept to an absolute minimum in order to conserve Ocean quahog populations and provide the best chance of any potential settlement for new recruits. Our confidence in this objective would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature's structure and function.

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 affects 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 within the site

Hydrodynamic regime in Holderness Offshore MCZ generally consists of moderate wave and current energy at the seabed, with lower wave energy towards the east of the site (McBreen *et al.*, 2011). Waves and tidal currents predominantly occur in a southwest and northeast direction with tidal currents running at between 0.28 ms^{-1} and 0.62 ms^{-1} (EMODnet, 2012). It is likely that the predominantly southward current that passes through this site carries Ocean quahog spat down from Iceland into the Humber region and Holderness Offshore MCZ, along with other populations in the southern North Sea (OSPAR, 2009b; Witbaard and Bergman, 2003; Holmes *et al*., 2003). Maintaining the hydrodynamic regime within the site is therefore important for maintaining the supply of new recruits as well as ensuring a sufficient flow of water across the siphons of Ocean quahog to support respiratory and feeding processes (Morton, 2011). Although demersal fishing and oil and gas infrastructure known to be present may be having a localised effect on the hydrodynamic regime within the site, it is unclear whether these are having an adverse impact on the conservation status of Ocean quahog present within the site. As such, **JNCC and Natural England advise a maintain objective** for this sub-attribute, and that activities must look to avoid, as far as is practicable, altering the hydrodynamic regime. Our confidence in this objective would be improved with long-term monitoring, a better understanding of the hydrodynamic regime in the site and its impact on Ocean quahog.

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 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, 2009a). Ocean quahog are 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 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. Based on what is known about the habitat preferences of Ocean quahog, usually having a preference for finer sediments (Witbaard and Bergman, 2003), the site, predominately covered by coarse sediments, is not considered best suited for Ocean quahog colonisation. However, although higher densities of Ocean quahog are commonly found in finer sediments, they have also been found to occur in coarser sediments and gravels and are therefore not limited to a specific sediment type (Witbaard and Bergman, 2003). This suggests that the supporting habitats for Ocean quahog within Holderness Offshore MCZ may include, A5.1: Subtidal coarse sediment, A5.2: Subtidal sand and A5.4: Subtidal mixed sediment. These habitats cover almost the entirety of the site (with the exception of where substrates have been lost as set out under extent and distribution attribute for the broad-scale habitat features) and therefore may be suitable for colonisation. Ocean quahog are patchily distributed in the north of the site, all occurring within areas of A5.1: Subtidal coarse sediment, although one record of Ocean quahog was found in close proximity to a small patch of A5.2: Subtidal sand (DEFRA, 2017; García *et al.*, 2019). Another record of Ocean quahog was also identified in the south-west of the site within an area of A5.1: Subtidal coarse sediment (DEFRA, 2017; García *et al.*, 2019).

JNCC and Natural England has advised recover objectives for the extent and distribution and sedimentary composition attributes of the broad-scale habitat features within the site. These habitats provide a supporting function to the Ocean quahog feature and as such **JNCC and Natural England advise a recover objective** for the supporting habitats and that, as far as is practicable, changes in substrata within the site are to be kept to an absolute minimum in order to conserve Ocean quahog populations and provide the best chance of any potential settlement for new recruits. Our confidence in this objective would be improved with longer term monitoring, better access to activities information and a better understanding of how the activity impacts the feature's structure and function. For further information on activities capable of affecting Ocean quahog and their supporting habitat, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

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 and 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);
- An Analysis of UK Offshore Oil and Gas surveys 1975-1995;
- Cefas' 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 relatively 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, 2009a), 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 Ocean quahog 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 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). Many uncertainties exist in predicting our future climate and the impacts on habitats and species (EC, 2013).

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 Ocean quahog, leading 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 the ability of Ocean quahog to feed or breathe (Elliot *et al.,* 1998; Morton, 2011). Adult Ocean quahog can switch from aerobic to anaerobic respiration and will be 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 and Natural England 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 within the site

JNCC and Natural England advises a maintain objective for the water and sediment quality attributes for the Ocean quahog supporting habitats i.e. broad-scale habitat features within the site. **JNCC and Natural England therefore advise a maintain objective** for Ocean quahog water and sediment quality accordingly and advises 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. This objective is based on expert judgement, specifically our understanding of the feature's sensitivity to pressures associated with ongoing activities. Activities must look to avoid, as far as is practicable, exceeding sediment EQSs set out above.

References

Alexander, D., Colcombe, A., Chambers, C. and Herbert, R.J.H. (2014). Conceptual Ecological Modelling of Shallow Sublittoral Coarse Sediment Habitats to Inform Indicator Selection. JNCC Report No. 520 [online]. Available at: http://eprints.bournemouth.ac.uk/22354/1/Conceptual%20Model%20Shallow%20Sublittoral%20Coarse%20Sediment%202014.pdf [Accessed 23 November 2020].

AquaSense. (2001). Distribution and threats of *Arctica islandica* as an example for listing of species and habitats subject to threat or rapid decline. *North Sea Directorate*, 1738- 39.

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.

Begum, S., Basova L., Heilmayer, O., Philipp, E.E.R., Abele, D. and Brey, T. (2010). Growth and energy budget models of the bivalve *Arctica islandica* at six different sites in the north-east Atlantic realm. *Journal of Shellfish Research*, 29 (1): 107-115.

Best, M.A., Wither, A.W. and Coates, S. (2007). Dissolved oxygen as a physicochemical supporting elements in the Water Framework Directive. *Marine Pollution Bulletin*, 55: 53-64 [online]. Available at: http://www.sciencedirect.com/science/article/pii/S0025326X06003171 [Accessed 23 November 2020].

Bett, B.J. (2012). Seafloor biotope analysis of the deep waters of the SEA4 region of Scotland's seas. JNCC Report No. 472 [online]. Available at: https://hub.jncc.gov.uk/assets/25c92d5c-4136-431f-896d-42855782485e [Accessed 23 November 2020].

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: 165-177.

Bloomfield H.J., Allcock Z., Bos O., Paramor O.A.L., Allen K.A., Aanesen M., Armstrong C., Hegland T., Le Quesne W., Piet G.J., Raakær J., Rogers S., van Hal R., van Hoof L.J.W., van Overzee H.M.J. and Frid, C.L.J. 2011. MEFEPO North Sea Atlas, 2nd Edition - August (2011). University of Liverpool. ISBN 978-0-906370-67-4. [online] Available at https://www.liverpool.ac.uk/media/livacuk/mefepo/pdf/NS_Atlas_2nd_Edition.pdf [Accessed 23 November 2020]

Breuer, E., Stevenson, A.G., Howe, J.A., Carroll, J. and Shimmield, G.B. (2004). Drill cutting accumulations in the Northern and Central North Sea: A review of environmental interactions and chemical fate*. Marine Pollution Bulletin*, 48 (1): 12-25.

Brey, T., Arntz, W.E. Pauly, D. and Rumohr, H. (1990). *Arctica (Cyprina) islandica* in Kiel Bay (western Baltic): growth, production and ecological significance. *Journal of Experimental Marine Biology and Ecology*, 136: 217-235.

Brix, L. (2013). New records: World's oldest animal is 507 years old [online]. Available at: http://sciencenordic.com/new-record-world%E2%80%99s-oldest-animal-507-years-old [Accessed 23 November 2020].

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

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

Butler, P., Wanamaker Jr., A.D., Scourse, J.D., Richardson, C.A. and Reynolds, D.J. (2012). Variability of marine climate on the North Icelandic Shelf in a 1357-year proxy archive based on growth increments in the bivalve *Arctica islandica*. *Palaeogeography, Palaeoclimatology and Palaeoecology*, 373: 141-151.

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: https://www.abdn.ac.uk/staffpages/uploads/nhi635/ZSLpaper-kees.pdf [Accessed 23 November 2020].

Cargnelli, L.M., Griesbach, S.J., Packer, D.B. and Weissberger, E. (1999). Essential fish habitat source document: Ocean quahog, *Arctica islandica*, life history and habitat characteristics. *NOAA Technical Memorandum*, 148: 12.

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 Jr., G.A. (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 23 November 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 23 November 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]. Available at: https://dx.doi.org/10.7717/peerj.1014 [Accessed 23 November 2020].

Connor, D.W., J.H. Allen, N. Golding, K.L. Howell, L.M. Lieberknecht, K.O. Northen and J.B. Reker. (2004). The Marine Habitat Classification for Britain and Ireland Version 04.05 ISBN 1 861 07561 8. In: JNCC. (2015). The Marine Habitat Classification for Britain and Ireland Version 15.03 [online] Available from: https://mhc.jncc.gov.uk/resources#version0405 [Accessed 19 November 2020].

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.

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 north-western North Sea. *Canadian Journal of Fisheries and Aquatic Science*, 65: 362-81.

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.

Department for Environment, Food and Rural Affairs (DEFRA). (2013). In-depth review of evidence supporting the recommended Marine Conservation Zones. Project Code: MB0116 Marine Biodiversity R&D Programme [online]. Available at: http://randd.defra.gov.uk/Document.aspx?Document=10698_MB0116FinalReport.pdf [Accessed 18 November 2020].

Department for Environment, Food and Rural Affairs (DEFRA). (2017). Holderness Offshore rMCZ Post-survey Site Report. Report No. 44 [online]. Available at: http://randd.defra.gov.uk/Document.aspx?Document=14047_HoldernessOffshorerMCZPost-surveySiteReportV4.pdf [Accessed 16 November 2020].

De Wilde, P.A.W.J., Berghuis, E.M. and Kok, A. (1986). Biomass and activity of benthic fauna on the Fladen Ground (northern North Sea). *Netherlands Journal of Sea Research,* 20: 313-323.

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.

Eaton, M.A., Aebischer, N.J., Brown, A.F., Hearn, R.D., Lock, L., Musgrove, A.J., Noble, D.G., Stroud, D.A. and Gregory, R.D. (2015). Birds of Conservation Concern 4: the population status of birds in the United Kingdom, Channel Islands and Isle of Man. *British Birds*, 108: 708–746. [online]. Available at https://www.researchgate.net/publication/286883061_Birds_of_Conservation_Concern_4_the_population_status_of_birds_in_the_UK_Channel_Islands_and_Isle_of_Man [Accessed 16 November 2020]

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 2001 SeaWiFS data. *EARSeL eProceeding*, 3 (2): 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.

EMODnet. (2012). 2012 Cefas North Sea EUNIS habitat map for Civil Hydrography Programme Areas HI1083 and HI1153. Information contained here has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats initiative (http://www.emodnet-seabedhabitats.eu/), financed by the European Union under Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund.

Environment Agency (EA). (2014). Water Framework Directive: Surface water classification status and objectives [online]. Available at: https://data.gov.uk/dataset/1b96de41-148c-4280-a244-de0124b2bd8e/wfd-cycle-1-surface-water-classification-status-and-objectives [Accessed 20 November 2020].

European Commission (EC). (2013). Guidelines on climate change and Natura 2000: Dealing with the impact of climate change on the management of the Natura 2000 Network of areas of high biodiversity value. Technical Report 068 [online]. Available at: http://ec.europa.eu/environment/nature/climatechange/pdf/Guidance%20document.pdf [Accessed 16 November 2020].

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

Fisheries Research Services (FRS). (2017). Sandeels in the North Sea. Scottish Government [online]. Available at: https://www2.gov.scot/Uploads/Documents/ME01ASandeels.pdf [Accessed 10 November 2020].

Gage, J.D. (2001). Deep-sea benthic community and environmental impact assessment at the Atlantic Frontier. *Continental Shelf Research*, 1: 957-986.

García, S., Perry, A.L., Blanco, J., Álvarez, H., Petersen, H.C., Aguilar, R. (2019). Protecting the North Sea: Holderness. Oceana, Madrid. 32 p.

Golikov, A.N. and Scarlato, O.A. (1973). Method for indirectly defining optimum temperatures of inhabitancy for marine cold-blooded animals. *Journal of Marine Biology*, 20: 1-5.

Gray, J. and Elliott M. (2009). Ecology of Marine Sediments: From science to management, Second edition, Oxford Biology. Oxford University Press.

Green M.O., Vincent C.E., McCave I.N., Dickson R.R., Rees J.M., Pearsons N.D. (1995). Storm sediment transport: observations from the British North Sea shelf. *Continental Shelf Research,* 15: 889-912.

Greenwood, N., Parker, E.R., Fernand, L., Sivyer, D.B., Weston, K., Painting, S.J., Kröger, S., Forster, R.M., Lees, H.E., Mills, D.K., Laane, R.W.P.M. (2010). Detection of low bottom water oxygen concentrations in the North Sea; implications for monitoring and assessment of ecosystem health. *Biogeoscience*, 7: 1357-1373.

Harding, J.M., King, S.E., Powell, E.N. and Mann, R. (2008). Decadal trends in age structure and recruitment patterns of ocean quahogs *Arctica islandica* from the mid-Atlantic bight in relation to water temperature. *Journal of Shellfish Research*, 27 (4): 667-690.

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

Holmes, S.P., Witbaard, R., Van der Meer, J. (2003). Phenotypic and genotypic population differentiation in the bivalve mollusc *Arctica islandica*: results from RAPD analysis. *Marine Ecology Progress Series*, 254: 163–176.

Hughes, D.J. (2014). Benthic habitat and megafaunal zonation across the Hebridean Slope, western Scotland, analysed from archived seabed photographs. *Journal of the Marine Biological Association of the UK,* 94: 643-658.

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.

Injuk, J., Otten, P.H., Lanne, 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). (2004). Common standards monitoring guidance for inshore sublittoral sediment habitats. [online]. Available at: https://hub.jncc.gov.uk/assets/9b4bff32-b2b1-4059-aa00-bb57d747db23 [Accessed 20 November 2020].

Jones, D.S. (1981). Reproductive cycles of the Atlantic surf clam *Spisula solidissima*, and the Ocean quahog *Arctica islandica* off New Jersey. *Journal of Shellfish Research*, 1: 23-32.

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: http://www.scotland.gov.uk/Resource/0041/00416981.pdf [Accessed 20 November 2020].

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

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.

Liehr, G.A., Zettler, M.L., Leipe, T. and Witt, G. 2005. The Ocean quahog *Arctica islandica* L: A bioindicator for contaminated sediments. *Marine Biology*, 147: 671–679.

Little, C. (2000). The biology of soft shores and estuaries, Oxford University Press.

Loosanoff, V. (1953). Reproductive Cycle in *Cyprina islandica*. *Biological Bulletin, Marine Biological Laboratory*, 104: 146-155.

Mann, R. (1989). Larval ecology of *Arctica islandica* on the inner continental shelf of the eastern United States. *Journal of Shellfish Research*, 8, 464.

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 20 November 2020].

McBreen, F. and Askew N. (2011). UKSeaMap 2010 Technical Report 3. Substrate Data. Joint Nature Conservation Committee, Peterborough.

McBreen, F., Askew, N., Cameron, A., Connor, D., Ellwood, H., Carter, A. (2011). UKSeaMap 2010: Predictive Mapping of Seabed Habitats in UK Waters. JNCC Report No. 446. pp.

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.

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

Merrill, A.S. and Ropes, J.W. (1969). The general distribution of the surf clam and Ocean quahog. *Proceedings of the National Shellfish Association*, 59: 40-45.

Morton, B. (2011). The biology and functional morphology of *Arctica islandica* (Bivalvia: Arcticidae) - A gerontophilic living fossil. *Marine Biology Research*, 7 (6): 540-553.

Net Gain. (2011). Final Recommendations. Submission to Natural England and JNCC.Hull, 856 pp. Net gain: The North Sea Marine Conservation Zones Project. [online]. Available at: http://publications.naturalengland.org.uk/publication/1466980 [Accessed 11 November 2020].

Ocean Ecology (2018). Tolmount Area Development – Tolmount to Easington Pipeline Route Habitat Assessment. Document reference: OEL_HORGEO_HAR_V01. Version 0.1 issued 13th August 2018.

Oeschger, R. and Storey, K.B. (1993). Impact of anoxia and hydrogen sulphide on the metabolism of *Arctica islandica* L. (Bivalvia). *Journal of Experimental Marine Biology and Ecology*, 170: 213-226.

OSPAR Commission. (2008). OSPAR List of Threatened and/or Declining Species and Habitats (Reference Number:2008-6). OSPAR Secretariat, London.

OSPAR Commission (2009a). Agreement on coordinated environmental monitoring programme assessment criteria for the QSR 2010. Monitoring and Assessment Series. OSPAR Agreement 2009-2002.

OSPAR Commission. (2009b). Background Document for ocean quahog Arctica islandica. Biodiversity Series. Publication Number: 407/2009. OSPAR Commission, London. Available from: https://qsr2010.ospar.org/media/assessments/Species/P00407_Ocean_quahog.pdf

OSPAR Commission. (2010). Quality status report 2010. London.

OSPAR Commission. (2012). Coordinated environmental monitoring programme 2011 assessment report.

Poitevin, P., Thébault, J., Siebert, V., Donnet, S., Archambault, P., Doré, J., Chauvaud, L. and Lazure, P. (2019). Growth Response of *Arctica Islandica* to North Atlantic Oceanographic Conditions Since 1850. *Frontiers in Marine Science,* 6, 483: doi: 10.3389/fmars.2019.00483.

Powilleit, M., Graf, G., Kleine, J., Riethmüller, R., Stockmann, K., Wetzel, M.A. and Koop, J.H.E. (2009). Experiments on the survival of six brackish macro-invertebrates from the Baltic Sea after dredged spoil coverage and its implications for the field. *Journal of Marine Systems*, 3: 441-451.

Premier (2018).Tolmount Area Development Offshore Environmental Statement. November 2017. DBEIS Reference Number D/4225/2018. 422 pp.

Rees, H.L. and Dare, P.J. (1993). Sources of mortality and associated life-cycle traits of selected benthic species: a review. MAFF Fisheries Research Data Report No. 33.

Rees, H. L., Eggleton, J. D., Rachor, E., and Vanden Berghe, E. (Eds). (2007). Structure and dynamics of the North Sea benthos. ICES Cooperative Research Report No. 288. 258 pp. https://doi.org/10.17895/ices.pub.5451

Ridgeway, I.D. and Richardson, C.A. (2010). *Arctica islandica*: the longest lived non-colonial animal known to science. *Reviews in Fish Biology and Fisheries*, 21: 297-310.

Ropes, J.W. and Murawski, S. (1983). Maximum shell length and longevity in ocean quahog, *Arctica islandica* Linne. In ICES Council Meeting 1983 (Collected Papers), 8pp.

Rowley, S.J. (2008). *Ammodytes tobianus* Lesser sand eel. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews. Plymouth: Marine Biological Association of the United Kingdom [online]. Available from: http://www.marlin.ac.uk/species/detail/2067 [Accessed 10 October 2020].

Rumohr, H., Ehrlich, S., Knust, R., Kujawsik, T., Philippart, C.J.M and Schroder, A. (1998). Long-term trends in demersal fish and benthic invertebrates. In: Lindeboom, H.J. and de Groot, S.J. 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems.

Sabatini, M. and Hill, J.M. (2008). *Nephrops norvegicus* Norway lobster. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews. Plymouth: Marine Biological Association of the United Kingdom [online]. Available at: http://www.marlin.ac.uk/species/detail/1672 [Accessed 28 September 2020].

Sabatini, M., Pizzolla, P. and Wilding, C. (2008). Icelandic cyprine (*Arctica islandica*). Marine life information network: Biology and sensitivity key information sub-programme [online]. Marine Biological Association of the United Kingdom. Available at: http://www.marlin.ac.uk/species/detail/1519 [Accessed 20 September 2020].

Salomons, W., Bayne, B.L., Duursma, E.K. and Foerstner, U. (1988). Pollution of the North Sea: An assessment. Springer-Verlag, Berlin Heidelberg.

Sayago-Gil, M., Long, D., Hitchen, K., Díaz-del-Río, V., Fernández-Salas, L.M. and Durán-Muñoz, P. (2010). Evidence for current-controlled morphology along the western slope of Hatton Bank (Rockall Plateau, NE Atlantic Ocean). *Geo-Marine Letters*, 30: 99-111.

Scholten, M.C.T.H., 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.

Schöne, B.R., Fiebig, J., Pfeiffer, M., Glecargnellireß,R., Hickson, J., Johnson, A.L.A., Dreyer, W. and Oschmann W. (2005). Climatic records from a bivalved Methuselah (Arctica islandica, Mollusca; Iceland). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 228 (1): 130-148.

Schöne, B.R. (2013). Arctica islandica (Bivalvia): A unique paleoenvironmental archive of the northern North Atlantic Ocean. *Global and Planetary Change,* 111: 199-225.

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.

Sciberras, M., Parker, R., Powell, C., Robertson, C., Kroger, S., Bolam, S. and Hiddink, J. (2016). Impacts of Bottom Fishing on Sediment Biogeochemical and Biological Parameters in Cohesive and Non-Cohesive Sediments*. Limnology and Oceanography*, 61: 2076-2089.

Sotheran, I., Welch, R., Benson, A. and Jones, L. (2016). Marine Conservation Zone Benthic Community Analysis Phase 1. A report by Envision Mapping Ltd to JNCC. JNCC Report No. 595. JNCC, Peterborough.

Stemmer, K., Nehrke, G. and Brey, T. (2013). Elevated CO_2 levels do not affect the shell structure of the bivalve *Arctica islandica* from the Western Baltic. PloS One, **8** (7), p.e70106.

Stemmer, K., Brey, T, Glas, M., Beutler, M., Schalkhausser, B. and de Beer, D. (2014). In-situ measurements of pH, Ca^{2+} and DIC dynamics within the extrapallial fluid of the ocean quahog *Arctica islandica*. Thesis from the University of Bremen.

Strahl, J., Brey, T., Phillip, E.E.R., Thorarinsdottir, G., Fishcher, N., Wessels, W. and Abele, D. (2011). Physiological responses to self-induced burrowing and metabolic rate depression in the ocean quahog *Arctica islandica*. *Journal of Experimental Biology*, 214: 4223-4233.

Talley L.D. (2002). Salinity Patterns in the Ocean. *The Earth System: Physical and Chemical Dimensions of Global Environmental Change*, 1: 629-640 in Encyclopedia of Global Environmental Change.

Tappin, D R, Pearce, B, Fitch, S, Dove, D, Gearey, B, Hill, J M, Chambers, C, Bates, R, Pinnion, J, Diaz Doce, D, Green, M, Gallyot, J, Georgiou, L, Brutto, D, Marzialetti, S, Hopla, E, Ramsay, E, and Fielding, H. (2011). The Humber Regional Environmental Characterisation. British Geological Survey Open Report OR/10/54. 357pp.

Taylor, A.C. (1976). Burrowing behaviour and anaerobiosis in the bivalve *Arctica islandica* (L.). *Journal of the Marine Biological Association of the United Kingdom*, 56: 95-109.

Thompson, I., Jones, D.S and Ropes, J.W. (1980). Advanced age for sexual maturity in the Ocean quahog *Arctica islandica* (Mollusca: Bivalvia). *Marine Biology*, 57: 35-39.

Thorarinsdóttir, C.G. and Einarsson, S.T. (1996). Distribution, abundance, population structure and mean yield of the Ocean quahog, *Arctica islandica*. *Journal of Shellfish Research*, 15: 729-733.

Tillin, H.M., Hull, S.C., Tyler-Walters, H. (2010). Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network. Plymouth: Marine Biological Association of the UK. Defra Contract No. MB0102 Task 3A, Report No. 22 [online]. Available at: http://www.marlin.ac.uk/assets/pdf/MB0102_Task3-PublishedReport.pdf [Accessed 10 October 2020].

Tillin, H.M. and Tyler-Walters, H. (2014). Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities: Phase 2 Report – Literature review and sensitivity assessments for ecological groups for circalittoral and offshore Level 5 biotopes. JNCC Report No. 512B [online]. Available at: https://hub.jncc.gov.uk/assets/4204b127-cda2-418c-abd1-ba3589341535 [Accessed 10 October 2020].

Tyler-Walters, H. and Sabatini, M. (2017). *Arctica islandica* Icelandic cyprine. In Tyler-Walters H. and Hiscock K. (eds) Marine life information network: Biology and sensitivity key information reviews [online]. Marine Biological Association of the United Kingdom. Available at: http://www.marlin.ac.uk/species/detail/1519 [Accessed 21 September 2020].

UK Technical Advisory Group on The Water Framework Directive (UKTAG). (2008). Proposals for Environmental Quality Standards for Annex VIII Substances. UK Technical Advisory Group on the Water Framework Directive.

Weidman, C.R., Jones, G.A. and Lohmann, K.C. (1994). The long-lived mollusc *Arctica islandica*: a new paleoceanographic tool for the reconstruction of bottom water temperatures for the continental shelves of the northern North Atlantic Ocean. *Journal of Geophysical Research*, 99: 18305-18314.

Weigelt, M. (1991). Short and long-term changes in the benthic community of the deeper parts of Kiel Bay (western Baltic) due to oxygen depletion and eutrophication. *Meeresforsch,* 33: 197-224.

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 (9): 909–922.

Witbaard, R. and Bergman, M.J.N. (2003). The distribution and population structure of the bivalve *Arctica islandica* L. in the North Sea: what possible factors are involved? *Journal of Sea Research,* 50: 11-25.

Witbaard, R., Jansma, E., Sass Klaassen, U. (2003). Copepods link quahog growth to climate. *Journal of Sea Research*, 50 (1): 77-83.

Zettler, M.L., Bönsch, R. and Gosselck, F. (2001). Distribution, abundance and some population characteristics of the Ocean quahog, *Arctica islandica* (Linneaus, 1767), in the Mecklenburg Bight (Baltic Sea). *Journal of Shellfish Research*, 20 (1): 161-169.