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

February 2018

www.jncc.defra.gov.uk

Contents

Introduction

What the conservation advice package includes

The information provided in this document sets out JNCC's supplementary advice on the conservation objectives set for this site. This forms part of JNCC's conservation advice package for the site and must be read in conjunction with all parts of the package as listed below:

- Background document explaining where to find the advice package, JNCC's role in the provision of conservation advice, how the advice has been prepared, when to refer to it and how to apply it;
- Conservation Objectives setting out the broad ecological aims for the site;
- Statements on:
  - the site's protected feature condition and General Management Approach;
  - conservation benefits that the site can provide; and
  - conservation measures needed to further the conservation objectives stated for the site.
- Supplementary Advice on Conservation Objectives (SACO) providing more detailed and site-specific information on the conservation objectives (this document); and
- Advice on Operations providing information on those human activities that, if taking place within or near the site, could impact it and hinder 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: Offshore deep-sea muds and Ocean quahog aggregations (including subtidal sedimentary habitats as their supporting habitat) specified in the site's conservation objectives. These attributes are: extent and distribution, structure and function and supporting processes.

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

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

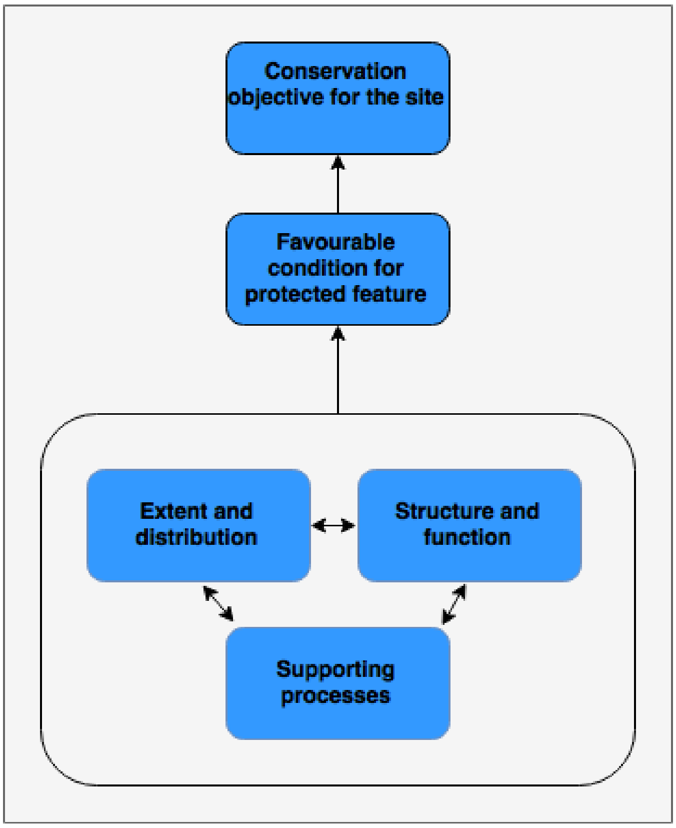

Figure 1. Conceptual diagram showing how a feature's attributes are interlinked and collectively describe favourable condition and contribute to the conservation objectives stated for the site.

The objectives listed in Tables 1 and 2 below reflect our current understanding of each protected feature's condition e.g. where evidence indicates some of a feature's extent is lost and needs to be recovered or that extent is not lost and needs to be conserved in order to ensure the feature is in overall favourable condition. The rationale for setting each objective is also provided in the explanatory notes, along with reference to supporting evidence from the site. Note that where it is not practical through human intervention to recover a feature's attribute, a conserve objective is set, accompanied by a statement to reflect the impracticality of restoration. Note also that when a conserve objective is set, this does not preclude the need for management, now or in the future. Please see the conservation measures relating to those activities JNCC consider may require additional management.

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

Attribute: Extent and distribution

Objective: Conserve

JNCC advise a conserve objective *which is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures exerted by the activities present. Our confidence in the setting of this objective would be improved by long-term monitoring information. Activities should look to minimise, as far as is practicable, changes in substrata and the biological communities associated with Offshore deep-sea muds.*

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.

A5.3 Subtidal mud/Offshore deep-sea muds comprises mud and cohesive sandy mud. This habitat is predominantly found in stable deeper/offshore areas where the reduced influence of wave action and/or tidal streams allow fine sediments to settle. These habitats are often dominated by polychaetes and echinoderms, such as *Amphiura* spp., sea-pens, such as the slender sea-pen (*Virgularia mirabilis*), and burrowing megafauna, such as the Norway lobster (*Nephrops norvegicus*) (Connor *et al.,* 2004), although polychaetes, sea spiders, molluscs, crustaceans and fish are also found. Bathymetry, current velocity, bottom water-mass distribution and particle size of the mud (clay, silty or sandy) have a significant influence on the distribution and composition of the seabed communities present. Subtidal mud is defined by a ratio of mud to sand being greater than 4:1, with particle sizes of less than 0.063 mm for mud and 0.063 mm to 2 mm for sand (McBreen and Askew, 2011). On the continental shelf, the Priority Marine Feature (PMF) Offshore deep-sea muds directly equates to the EUNIS habitat A5.3 Subtidal mud, but the PMF also covers deep-water examples that occur on or beyond the continental slope (Tyler-Walters *et al.,* 2016).

Extent and distribution within the site

The site map for East of Gannet and Montrose Fields NCMPA is available to view on JNCC's Interactive MPA Mapper. It should be noted that this will be updated to include data from the 2015 survey of the site in due course. The site area is calculated to be 1,839 km^2, with Offshore deep-sea muds comprising an estimated 6% (112km^2) of the seabed habitat type according to the modelled 2016 UKSeaMap habitat data (JNCC, 2016).

There has been some very limited oil and gas activity with the site, with 4 abandoned wells located over the Offshore deep-sea muds mapped extent. There is little information, however, to indicate that the extent and distribution of the Offshore deep-sea muds needs to be recovered. **JNCC advise a conserve objective** for Offshore deep-sea muds extent and distribution which is based on expert judgment; 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.

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 features of the site, please see the Advice on Operations workbook.

Attribute: Structure and function

Objective: Recover

*JNCC understands that the Offshore deep-sea muds within the site has been subjected to activities that have resulted in a change to the structure and function of the protected feature, specifically the characteristic communities and consequently function. As such, **JNCC advise a recover objective** which is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures exerted by the activities present i.e. demersal trawling. Our confidence in this objective would be improved by long-term monitoring information and an improved understanding of the finer scale topography within the site and the significance of the role which species play in the function and health of Offshore deep-sea muds. Activities must look to minimise, as far as is practicable, changes in substrata and biological communities within the site.*

<u>Explanatory notes</u>

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 within the site

JNCC is not aware of any discernible examples of fine-scale topographic features present within the site. There is no evidence to indicate that the finer scale topography in the site has been impacted and so we **advise a conserve objective**. This is based on expert judgement; specifically, our understanding of the feature's sensitivity 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 within the site

The site map for East of Gannet and Montrose Fields NCMPA is available to view on JNCC's Interactive MPA Mapper. The site area is calculated to be 1,839 km^2, with Offshore deep-sea muds comprising an estimated 6% (112km^2) of the seabed habitat type according to the modelled 2016 UKSeaMap habitat data (JNCC, 2016). Data from the 2015 survey has yet to be prepared to show sediment composition in the site. It is expected that sedimentary habitat composition within the site could change naturally over time as a result of wider environmental processes. Our advice will be updated following the analysis of the 2015 survey data.

There has been some very limited oil and gas activity with the site, with 4 abandoned wells located over the Offshore deep-sea muds mapped extent. There is little information, however, to indicate that the sediment composition of the Offshore deep-sea muds needs to be recovered. **JNCC advise a conserve objective** for Offshore deep-sea muds sediment composition which is based on expert judgment; 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.

Activities should look to minimise, as far as is practicable, changes in substrata within the site. Further information on the impacts associated with human activities on Offshore deep-sea muds can be found in the Advice on Operations workbook.

Biological structure: Key and influential species

Key and influential species are those that have a core role in determining the structure and function of 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 a 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 within the site

The 2015 survey sampled several species of burrowing infauna, such as the bivalves *Timoclea ovata, Mendicula ferruginosa* and *Abra nitida*, and the polychaete worms *Paramphinome jeffreysii, Spiophanes bombyx* and *Scoloplos armiger* within the Offshore deep-sea muds habitat (O'Connor, 2016). These burrowing species can play an important role as bioturbators, increasing the oxygen content of the upper sediment layers within Offshore deep-sea muds within the site. Demersal trawling for Norway lobster (*Nephrops norvegicus)* occurs in the south of the site corresponding to the predicted extent of Offshore deep-sea muds within the site (JNCC and MMO, 2015; JNCC, 2016). This is a burrowing decapod that forms large burrows, greatly influencing the oxygen availability in the upper sediment layers (Sabatini and Hill, 2008). It is possible that the burrowing species characterising the Offshore deep-sea muds within the site play a critical role as key and influential species in maintaining the structure and functioning of the habitat. However, no further information is available at the present time with which to conclude on this statement with any degree of certainty.

There is insufficient information available to support an understanding of the significance of the role which these species play in maintaining the function and health of the habitat. Therefore, it is not yet possible to advise an objective for this sub-attribute and it 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 pressures from 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 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 within the site

Work is ongoing to undertake a community analysis to identify the characteristic communities of Offshore deep-sea muds within the site based on survey data collected in 2015. Initial results show an abundance of polychaete worms associated with the modelled extent of Offshore deep-sea muds habitat, including *Paramphinome jeffreysii*, *Scoloplos armiger* and *Spiophanes bombyx* and more sparsely recorded bivalves such as *Timoclea ovata, Mendicula ferruginosa* and *Abra nitida* (O'Connor, 2016). The brittlestar *Amphiura filiformis* was recorded in most of the sample stations in areas of modelled Offshore deep-sea mud. The 2015 survey data will be used to characterise the biological communities present within Offshore deep-sea muds habitat within the site, but at the present time relatively little is known.

Demersal trawling is known to occur at varying intensities across the mapped Offshore deep-sea mud feature. This activity is capable of impacting the characteristic communities through removing benthic species and damaging or killing them by abrasion. **JNCC therefore advise a recover objective** for characterising species. This objective is based on expert judgment, specifically the sensitivity of the feature to pressures associated with activities taking place within the site. Our confidence in this objective would be improved by long-term monitoring information. Further information on the impacts associated with human activities on Offshore deep-sea muds can be found in the Advice on Operations workbook.

Function

Functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition. These functions rely on the supporting natural processes and the growth and reproduction of those biological communities which characterise the habitat and provide a variety of functional roles within it (Norling *et al.,* 2007), i.e. the key and influential species and characteristic communities present. These functions can occur at a range of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC, 2011).

Ecosystem services that may be provided by 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);
- Climate regulation: Providing a long-term sink for carbon within sedimentary habitats.

Similar to the biological structure of key and influential species and characterising species is 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 feature within the site

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

- Nutrition – by providing a habitat for *Nephrops norvegicus*, a commercially important shellfish species.
- Climate regulation - sedimentary habitats provide a long-term carbon sink (Alonso *et al.,* 2012), so are important for climate regulation.

Given that a recover objective is advised for characteristic communities on which these functions rely, **JNCC also advise a recover objective** for this sub-attribute. Our confidence in this objective would be improved by long term monitoring and a better understanding of the role which biological communities play in the function and health of the feature. Further information on the impacts associated with human activities on Offshore deep-sea muds can be found in the Advice on Operations workbook.

Attribute: Supporting processes

Objective: Conserve

There is limited evidence to suggest that supporting processes are being impeded with respect to supporting the function of Offshore deep-sea muds within the site. As such, ***JNCC advise a conserve objective*** *which 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 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, exceeding Environmental Quality Standards set out above.*

<u>Explanatory notes</u>

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

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

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

(~0.3mm) in 60 m water depth in the North Sea (Klein *et al.,*1999) and so the composition of the subtidal sedimentary habitats within the site may be effected by natural disturbance events.

While the presence of 4 abandoned wells over the feature may have an extremely localised effect on the hydrodynamic regime within the site, it is not thought to have an adverse impact on the conservation status of the Offshore deep-sea muds feature. As such, **JNCC advise a conserve objective** for this sub-attribute. This is based on expert judgment, specifically our understanding of the feature's sensitivity to pressures associated with ongoing activities. Our confidence in this objective would be improved with a better understanding of the hydrodynamic regime within the site and its influence on the feature's conservation status.

Water and sediment quality

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

The targets listed below for water and sedimentary contaminants in the marine environment 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 are available regarding historic or existing contaminant levels in the marine environment:

- Marine Environmental and Assessment National Database (MERMAN)
- The UK Benthos database available to download from the Oil and Gas UK website;
- 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 cool Atlantic waters to the north of the site exhibit seasonal stratification during spring and summer, which increase the prevalence of phytoplankton communities (Salomons *et al.,* 1988; Weston *et al.,* 2005). The site is also likely to be affected by the warmer central North Sea water to the south, although more data on the site's physicochemical properties is required.

Available evidence indicates relatively low suspended sediment concentrations in the deeper regions (below 50 m) of the North Sea of less than 5 g/m^3 (Eleveld *et al.,* 2004). Phytoplankton production in the North Sea throughout the year results in chlorophyll *a* levels up to 5.8 $\mu g\ L^{-1}$ (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 indicates that while the site is distant from terrestrial sources of pollution, enrichment of southern water masses due to riverine inputs and climatic variability are thought to affect ecological function of sites in the North Sea (Wieking and Kröncke, 2005). Atmospheric deposition in the North Sea has been highlighted as a major source of contamination of trace metals (cadmium, lead, copper and zinc; Injuk *et al.,* 1992). The site lies within the central North Sea in an area of relatively high human activity. Offshore oil and gas extraction can result in release of hydrocarbons into the water column, with discharges from offshore installations amounting to 16,000-17,000 tonnes of oil per year (Walday and Krogland, 2017).

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

Sediment quality

Various contaminants are known to affect the species that live in or on the surface of Subtidal sedimentary habitats. These include heavy metals like mercury, arsenic, zinc, nickel, chromium and cadmium, polyaromatic hydrocarbons, polychlorinated biphenyls, organotins (such as TBT) and pesticides (such as hexachlorobenzene). These metals and compounds can impact species sensitive to contaminants, degrading the community structure (e.g. heavy metals) and bioaccumulate within organisms thus entering the marine food chain (e.g. polychlorinated biphenyls) (OSPAR 2009; 2010; 2012). The biogeochemistry of mud habitats in particular is such that 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 compliance with existing EQS as set out above, particularly in mud habitats.

Sediment quality within the site

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

Exploration of North Sea oil and gas reserves has resulted in the accumulation of large quantities of drill cuttings on the seabed surrounding drill sites (Breuer *et al.,* 2004). These drill cuttings contain higher concentrations of certain metals (barium, cadmium, copper, nickel, lead and zinc) and hydrocarbons than found in natural sediments (Breuer *et al.,* 2004). As there have been some oil and gas exploration operations within the site in the past, as evidenced by the presence of 4 abandoned wells, drill cuttings may present a local pollution pathway at the site. However, the limited samples taken from the site and adjacent suggest that Offshore deep-sea muds are not being impacted by contaminants. Therefore, **JNCC advise a conserve objective** and that activities must look to avoid, as far as is practicable, exceeding Environmental Quality Standards set out above. Our confidence in this objective would be improved with long term monitoring and a better understanding of contaminant levels in the site.

Table 2. Supplementary advice on the conservation objectives for Ocean quahog aggregations in East of Gannet and Montrose Fields Nature Conservation MPA.

Attribute: Extent and distribution
Objective: Conserve *The feature is being exposed to damaging pressures associated with oil and gas operations and this may be impacting the feature's extent and distribution. Despite this,* ***JNCC advises a conserve objective*** *acknowledging the substantial uncertainty around the ability of any site-based measures to support restoration of the feature within the site, in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. Activities should look to minimise, as far as is practicable, disturbance to individuals that may result in a change to the extent and distribution of Ocean quahog aggregations within the site. Our confidence in the setting of this objective would be improved by a better understanding of the distribution of Ocean quahog aggregations throughout the site and monitoring of their condition.*
<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 this 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 in a range of depths typically from 4 m to 482 m deep, but most commonly between 10 m to 280 m (Thorarinsdóttir and Einarsson, 1996; Sabatini *et al.,* 2008; OSPAR, 2009; Tyler-Walters and Sabatini, 2017). Ocean quahog is thought to have a high sensitivity to physical loss of habitat (Tyler-Walters and Sabatini, 2017). It is therefore important to conserve the extent and distribution of supporting habitats to provide the best chance of any potential settlement for new recruits and to retain existing individuals.

Extent and distribution within the site

The known extent and distribution of Ocean quahog aggregations is available to view via the JNCC's Interactive MPA Mapper. It should be noted that ocean quahog supporting habitat is also available to view on this map and is discussed under Supporting processes further down. The map will be updated to include data from the 2015 survey of the site in due course.

A collaborative survey between JNCC and Marine Scotland in 2015 shows that the depth at which Ocean quahog aggregations have been recorded across the site ranges between 80m-100m (O'Connor, 2016).

Samples taken during surveys for oil and gas developments between 1994-2000 provide evidence of Ocean quahog aggregations in the north and northwest of the site. This distribution is validated by the recent collaborative survey between JNCC and Marine Scotland survey in 2015. (O'Connor, 2016). This survey also shows that the depth at which Ocean quahog aggregations have been recorded across the site ranges between 80m-100m (O'Connor, 2016).

Offshore infrastructure, such as oil platforms and pipelines, which occur within the site could impact the extent and distribution of Ocean quahog aggregations. Such installation practices can often result 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 aggregations within the site.

Whilst future decommissioning activities, that do not require rock dump, may result in habitat being introduced that is suitable for Ocean quahog colonisation (once oil and gas operations within a site have ceased), this is likely to be a very slow process due to the long-lived, slow reproducing and vulnerable nature of the species (Butler *et al*. 2012; Brix, 2013; Ridgeway and Richardson, 2010; Tyler-Walters and Sabatini, 2017).

The feature is being exposed to damaging pressures associated with oil and gas operations and this may be impacting the feature's extent and distribution. Despite this, **JNCC advises a conserve objective** acknowledging the substantial uncertainty around the ability of any site-based measures to support restoration of the feature within the site, in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit/reproduce. Activities should look to minimise, as far as is practicable, a change in substrata that may result in a change to the natural extent of the ocean quahog's supporting habitat within the site

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

Attribute: Structure and function

Objective: Conserve

*The feature is being exposed to damaging pressures associated with oil and gas operations and this may be impacting the feature's structure and function. Despite this, **JNCC advises a conserve objective** acknowledging the substantial uncertainty around the ability of any site-based measures to support restoration of the feature within the site, in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. Activities should look to minimise, as far as is practicable, disturbance to individuals within the site. Our confidence in the setting of this objective would be improved by long-term monitoring information on the population of Ocean quahog aggregations throughout the site.*

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, 2009). Sporadic recruitment and the detrimental effect of increasing temperature on juveniles is expected to have a significant effect on successful Ocean quahog recruitment. Recovery of a population within a site is likely to be reliant on an infrequent supply of recruits from elsewhere and the influence of wider environmental temperature changes brought about by climate change.

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

Recovery of Ocean quahog populations is hard to monitor and likely to be extremely slow (over centuries) due to the long-lived (up to 507 years recorded; Brix, 2013), slow-growing, low density, irregularly recruiting, high juvenile mortality and low fecundity of the species (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 within the site
Information contained within UKBenthos shows 47 Ocean quahog individuals were sampled in site between 1990-2000. In 2015, survey efforts sampled 70 Ocean quahog individuals throughout the site (O'Connor, 2016). A maximum sample size of 4 individuals were recorded in a single station, with the greatest number of grab sample records taken in the north and east of the site. Assuming that the near full extent of the site

contains habitat suitable for Ocean quahog aggregation colonisation (Witbaard and Bergman, 2003), average density of the Ocean quahog recorded across the site in 2015 was 0.03 individuals per km^2. This is significantly lower than documented averages from the northern North Sea (16,000 ind/km^2) (Witbaard, 1997; Witbaard and Bergman, 2003). However, the 2015 surveys used Hamon grabs and drop-down video sampling techniques which are not as effective in assessing ocean quahog density compared to trawl-based sampling methods (such as those used by Witbaard and Bergman, 2003). There is currently not enough evidence available to attribute a cause for the observed decline in density in the northern North Sea.

During the 2015 survey, 39 of the individuals recorded were juveniles (O'Connor, 2016). More data are required to develop a time series of Ocean quahog population structure to identify any changes to the feature in the site over time. As there are no time series data for Ocean quahog aggregations within the site, it is unclear whether the population is declining, being conserved or increasing in the site. The age structure, growth rates and reproductive viability of the population located within the site are also currently unknown.

JNCC acknowledge the significant effect of prevailing sea temperatures on the likely survivorship and recruitment potential of Ocean quahog aggregations (Cargnelli *et al.,* 1999; Witbaard and Bergman, 2003; Tyler-Walters and Sabatini, 2017) and the reported widespread declines in the abundance of this species throughout the North Sea (Rumohr *et al.,* 1998). The feature is being exposed to damaging pressures associated with oil and gas operations and this may be impacting the feature's structure. Despite this, **JNCC advises a conserve objective** acknowledging the substantial uncertainty around the ability of any site-based measures to support restoration of the feature within the site, in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. Activities should look to minimise, as far as is practicable, disturbance to individuals within the site. Our confidence in the setting of this objective would be improved by long-term monitoring information on the population of Ocean quahog aggregations throughout the site. For further information on activities capable of affecting Ocean quahog aggregations, please see the Advice on Operations workbook.

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 a range 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, 2005); and
- Carbon cycling and nutrient regulation: Maintaining healthy and productive ecosystems through the laying down of carbonate during shell growth and filter-feeding.

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

JNCC acknowledge the significant effect of prevailing sea temperatures on the likely survivorship and recruitment potential of Ocean quahog aggregations (Cargnelli *et al.,* 1999; Witbaard and Bergman, 2003; Tyler-Walters and Sabatini, 2017) and the reported widespread declines in the abundance of this species throughout the North Sea (Rumohr *et al.,* 1998). The feature is being exposed to damaging pressures associated with oil and gas operations and this may be impacting the feature's function. Despite this, **JNCC advises a conserve objective** acknowledging the substantial uncertainty around the ability of any site-based measures to support restoration of the feature within the site, in light of wider environmental impacts such as climate change and the feature's limited capacity to recruit or reproduce as described in the explanatory notes. Activities should look to minimise, as far as is practicable, disturbance to individuals within the site. Our confidence in the setting of this objective would be improved by long-term monitoring information on the population of Ocean quahog aggregations throughout the site. For further information on activities capable of affecting Ocean quahog aggregations, please see the Advice on Operations workbook.

Attribute: Supporting processes

Objective: Conserve

Supporting habitats are also important in governing the extent and distribution of the species. 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. JNCC consider there is limited evidence to suggest that supporting processes are being impeded with respect to supporting the Ocean quahog aggregations within the site. As such, ***JNCC advise a conserve objective*** *and that activities must look to avoid, as far as is practicable, exceeding Environmental Quality Standards set out below, as well as change in substrate extent and distribution. Our confidence in this objective would be improved with long-term monitoring, a better understanding of contaminant levels in the site and how contaminants can impact Ocean quahog aggregations.*

Explanatory notes

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

Hydrodynamic regime

Hydrodynamic regime refers to the speed and direction of currents, seabed shear stress and wave exposure. These mechanisms circulate food resources and propagules, as well as influence water properties by distributing dissolved oxygen and transferring oxygen from the surface to the seabed (Chamberlain *et al.,* 2001; Biles *et al.,* 2003; Hiscock *et al.,* 2004; Dutertre *et al.,* 2012). Hydrodynamic regime also effects the movement, size and sorting of sediment particles, which as filter-feeders could affect the feeding behaviour, growth and survival of Ocean quahog. Alterations to the natural movement of water and sediment could affect the presence and distribution of Ocean quahog, particularly given the reliance on larvae from Icelandic waters to re-stock populations in the North Sea (Witbaard and Bergman, 2003). The natural movement of water and sediment should therefore not be hindered.

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

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

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

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

Supporting habitats within the site
As previously mentioned the extent and distribution of supporting habitat is available to view via the JNCC's Interactive MPA Mapper.

Based on what is known about the habitat preferences of Ocean quahog (Witbaard and Bergman, 2003), >99% (~1,839km^2) of the seabed habitats present within the site are considered suitable for Ocean quahog colonisation (based on UKSeaMap modelled habitat data; JNCC, 2016). The supporting habitats within the site include Offshore deep-sea muds (Table 1) and Offshore subtidal sands and gravels.

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

Whilst future decommissioning activities, that do not require rock dump, may result in habitat being introduced that is suitable for Ocean quahog colonisation (once oil and gas operations within a site have ceased), this is likely to be a very slow process due to the long-lived, slow reproducing and vulnerable nature of the species (Butler *et al*. 2012; Brix, 2013; Ridgeway and Richardson, 2010; Tyler-Walters and Sabatini, 2017). There is insufficient information available to assess the nature or scale of the impact of current activities on the extent and distribution of Ocean quahog aggregations. In addition, it is unclear if human intervention within the site is capable of ensuring recovery of the feature due to the influence of wider environmental parameters, such as climate change. **JNCC advise a conserve objective** for this attribute and that, as far as is practicable, changes in substrata within the site is kept to an absolute minimum. For further information on activities capable of affecting Ocean quahog aggregations and their supporting habitat, please see the Advice on Operations workbook.

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

The targets listed below for water and sedimentary contaminants in the marine environment 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, 2009), in the mid-Atlantic Bight at 32-34 ppt (Cargnelli *et al.,* 1999) and Oeschger and Storey (1993) successfully kept adult quahog at 22 ppt in the laboratory for several weeks.

Experimental evidence has shown that lower pH (380-1120 µatm pCO_2), has no effect on shell growth or crystalline microstructure in Ocean quahog as 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 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

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

Available evidence indicates relatively low suspended sediment concentrations in the deeper regions (below 50 m) of the North Sea of less than 5 g/m^3 (Eleveld *et al.,* 2004). Phytoplankton production in the North Sea throughout the year results in chlorophyll *a* levels up to 5.8 µg 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 (Kröncke and Knust, 1995).

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

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

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

Additional literature has also noted that the exploration and exploitation of North Sea oil and gas reserves has also resulted in the accumulation of large quantities of drill cuttings on the seabed surrounding drill sites (Breuer *et al.,* 2004). These drill cuttings contain higher concentrations of certain metals (barium, cadmium, copper, nickel, lead and zinc) and hydrocarbons than found in natural sediments (Breuer *et al.,* 2004). As there are oil and gas infrastructures within the site, drill cuttings may present a pollution pathway at a local scale.

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

References

Alonso I., Weston K., Gregg R. and Morecroft M. (2012). Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources. Natural England Research Report NERR043 [online]. Available at: publications.naturalengland.org.uk/file/1438141 [Accessed 20 September 2017].

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 20 September 2017].

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.

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., Phillipp, 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 northeast Atlantic realm. *Journal of Shellfish Research*, 29 (1): 107-115.

Best, M.A., Wither, A.W. and Coates, S. (2007). Dissolved oxygen as a physico-chemical supporting elements in the Water Framework Directive. *Marine Pollution Bulletin,* 55: 53-64 [online]. Available at: http://www.sciencedirect.com/science/article/pii/S0025326X06003171 [Accessed August 2017].

Bett, B.J. (2012). Seafloor biotope analysis of the deep waters of the SEA4 region of Scotland's seas. JNCC Report No. 472.

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

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 (1-2): 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 20 September 2017].

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

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

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.

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, T.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.

Clean Seas Environment Monitoring Programme (CSEMP) (2014). Assessment viewer tool of Marine Environment Monitoring and Assessment National database (MERMAN) [online]. Available at: https://www.bodc.ac.uk/projects/data_management/uk/merman/assessments_and_data_access/ [Accessed 24 August 2017].

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. Marine Ecological Surveys Ltd - A report for the Joint Nature Conservation Committee. JNCC Report No: 557.

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. Marine Ecological Surveys Ltd - A report for the Joint Nature Conservation Committee, JNCC Report No: 585.

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: 20 September 2017].

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. and Reker, J.B. (2004). The Marine Habitat Classification for Britain and Ireland, Version 04.05

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.

Curtis, M., Archer, S. and Jenkins, C. (2015). Fulmar rMCZ post-survey site report. Department for Environment Food and Rural Affairs. Report 42 version 4.

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.

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., Chavalier, 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.

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). Volume II intertidal sand and mudflats and subtidal mobile sandbanks. An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. UK Marine SACs Project. Oban, Scotland, English Nature.

Environment Agency (EA) (2014). Water Framework Directive: Surface water classification status and objectives. Available at: https://data.gov.uk/dataset/wfd-surface-water-classification-status-and-objectives could be re-issued on the data.gov.uk [Accessed 20 August 2017].

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 26 September 2017].

European Topic Centre (ETC) (2011). Assessment and reporting under Article 17 of the Habitats Directive. Explanatory notes and guidelines for the period 2007-2012. Available at:

https://circabc.europa.eu/sd/a/2c12cea2-f827-4bdb-bb56-3731c9fd8b40/Art17%20-%20Guidelines-final.pdf [Accessed 20 September 2017].

European Commission (2013) DG MARE Interpretation manual of European Union habitats EUR28.

Fisheries Research Services (FRS) (2017). Sandeels in the North Sea. Scottish Government [online]. Available at: http://www.gov.scot/Uploads/Documents/ME01ASandeels.pdf [Accessed October 2017].

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

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.

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.

Holgate, S.J, Matthews, A., Woodworth, P.L., Rickards, L.J., Tamisiea, M.E., Bradshaw, E., Foden, P.R., Gordon, K.M., Jevrejeva, S. and Pugh, J. (2013). New Data Systems and Products at the Permanent Service for Mean Sea Level. *Journal of Coastal Research,* 29 (3): 493-504.

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.

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.

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: http://jncc.defra.gov.uk/PDF/CSM_marine_sublittoral_sediment.pdf [Accessed 20 September 2017].

Joint Nature Conservation Committee (JNCC) and Marine Management Organisation (MMO) (2015) Vessel Monitoring System data 2009 - 2015.

Joint Nature Conservation Committee (JNCC) (2016). UKSeaMap 2016: A broadscale seabed habitat map for the UK [online]. Available: http://jncc.defra.gov.uk/ukseamap [Accessed October 2017].

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.

Klein, H., Konig, P. and FROHSE, A. (1999). Currents and near-bottom suspended matter dynamics in the central North Sea during stormy weather: Results of the PIPE 1998 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.

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.

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 Open report 08/04.

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, Woods Hole, 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., Bhantia, 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 Commissioned.* Report No. 771 [online]. Available at: http://www.snh.org.uk/pdfs/publications/commissioned_reports/771.pdf August 2017].

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

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.

Nexen Petroleum U.K. Ltd (Nexen) (2017). Glengorm Geophysical Site Survey: 2017 Environmental Justification.

Norling, K., Rosenburg, R., Hulth, S., Gremare, A. and Bonsdorff, E. (2011). Importance of functional biodiversity and specific-specific traits of benthic fauna for ecosystem functions in marine sediment. *Marine Ecology Progress Series,* 332: 11-23.

O'Connor, J. (2016). Cruise report 1515S: Monitoring survey of East of Gannet and Montrose Fields and Norwegian Boundary Sediment Plain Scottish Nature Conservation Marine Protected Areas, JNCC Report 580. [online]. Available at: http://jncc.defra.gov.uk/page-7181 [Accessed 20 September 2017].

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

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

OSPAR Commission (2011). Background document for sea-pen and burrowing megafauna communities. OSPAR Commission.

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

Permanent Service for Mean Sea Level (PSMSL) (2017). Tide Gauge Data. [online]. Available at: http://www.psmsl.org/data/obtaining/ [Accessed 10 October 2017].

Powilleit, M., Graf, G., Kleine, J., Riethmüller, R., Stockmann, K., Wetzel, M.A., 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*, 75 (3–4): 441-451.

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.

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. Marine Biological Association of the United Kingdom [online]. Available at: http://www.marlin.ac.uk/species/detail/2067 [Accessed: 17 October 2017].

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 [online]. Marine Biological Association of the United Kingdom [online]. Available at: http://www.marlin.ac.uk/species/detail/1672 [Accessed 28 September 2017].

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 2017].

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.

Schöne, B.R., Fiebig, J., Pfeiffer, M., Gleß,R., Hickson, J., Johnson, A.L.A., Dreyer, W. and Oschmann W. (2005). Climatic records from a bivalved Methuselah *(Arctica islandica*, Mollusca; Island). *Palaeogeography, Palaeoclimatology, Palaeoecology,* 228 (1-2): 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.

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.

Shell UK Limited (2017). Gannet F Bundle Marine Licence EIA Justification.

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*. *Journal of Experimental Marine biology and Ecology*.

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.

Sündermann, J. and Pohlmann, T. (2011). A brief analysis of North Sea physics, *Oceanologia*, 53 (3): 663-689.

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.

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.

Thoransdóttir, 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 (MarLIN) 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 2017]

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: http://jncc.defra.gov.uk/PDF/Report%20512-A_phase1_web.pdf [Accessed 10 October 2017]

Tyler-Walters, H., James, B., Carruthers, M. (eds.), Wilding, C., Durkin, O., Lacey, C., Philpott, E., Adams, L., Chaniotis, P.D., Wilkes, P.T.V., Seeley, R., Neilly, M., Dargie, J. and Crawford-Avis, O.T. (2016). Descriptions of Scottish Priority Marine Features (PMFs). Scottish Natural Heritage Commissioned Report No. 406 [online]. Available at: http://www.marlin.ac.uk/assets/pdf/406.pdf [Accessed 10 October 2017].

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 2017].

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.

van Leeuwen, S., Tett, P., Mills, D. and van der Molen, J. (2015). Stratified and non-stratified areas in the North Sea: Long-term variability and biological and policy implications. *Journal of Geophysical Research Oceans*, 120: 4670-4686.

Walday, M. and Krogland, T. (2017). The North Sea, European Environment Agency [online]. Available at: https://www.eea.europa.eu/publications/report_2002_0524_154909/regional-seas-around-europe/page131.html [Accessed 20 August 2017].

Weidman, C.R., Jones, G.A. and Lohmann, K.C. (1994). The long-lived mollusk *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: 909-922.

Wieking, G. and Kröncke, I. (2005). Is Benthic Trophic Structure Affected by Food Quality? The Dogger Bank Example. *Marine Biology,* 146: 387- 400.

Witbaard R., (1996). Growth variations in *Arctica islandica* L. (Mollusca): a reflection of hydrography-related food supply, *ICES Journal of Marine Science*, 53 (6): 981–987.

Witbaard, R. (1997). Tree of the Sea. The use of the internal growth lines in the shell of *Arctica islandica* (Bivalvia, Mollusca) for the retrospective assessment of marine environmental change. Thesis: University of Groningen, pp 149.

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* (Linnaeus, 1767), in the Mecklenburg Bight (Baltic Sea). *Journal of Shellfish Research*, 20 (1): 161-169.