Supplementary Advice on Conservation Objectives for Firth of Forth Banks Complex Nature Conservation MPA

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Contents

Introduction

What the conservation advice package includes

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

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

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

The advice presented here describes the ecological characteristics or 'attributes' of the site's protected features: Offshore subtidal sands and gravels, Ocean quahog aggregations, Shelf banks and mounds large-scale feature and Wee Bankie Key Geodiversity Area 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 – 4 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 – 4 must be taken into consideration when assessing impacts from an activity.

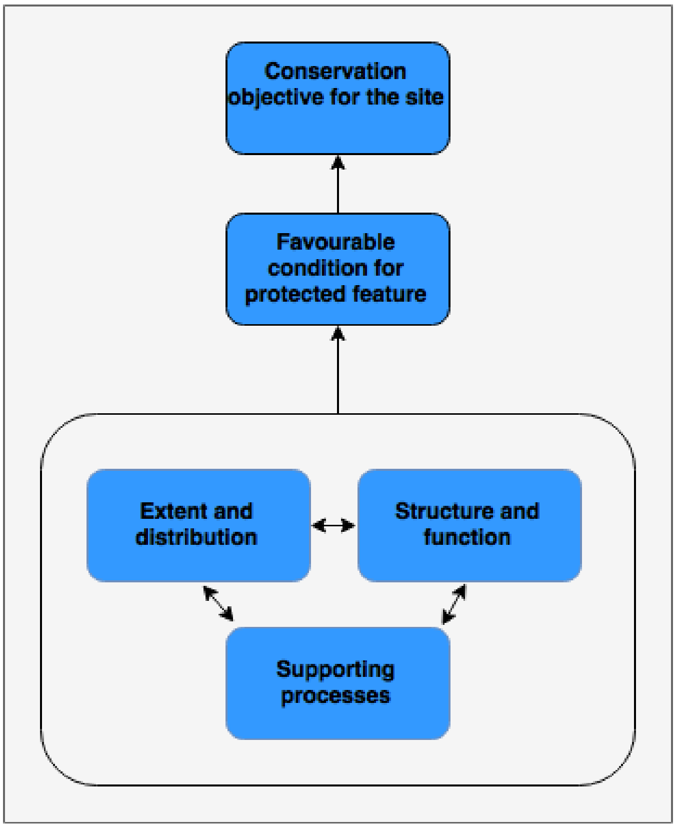

Figure 1. Conceptual diagram showing how a feature's attributes are interlinked and collectively describe favourable condition and contribute to the conservation objectives stated for the site.

The attributes for the Offshore subtidal sands and gravels, Ocean quahog aggregations, Shelf banks and mounds large-scale feature and Wee Bankie Key Geodiversity Area and their objectives are listed in Tables 1-4 (respectively). The attributes are described in the explanatory notes within these tables. An objective of recover or conserve is set for each feature attribute. The objective reflects our current understanding of a feature's condition e.g. where evidence indicates some of a feature's extent is lost and needs to be 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 an objective is also provided in the explanatory notes, along with reference to supporting evidence from the site. Note that where it is not practical through human intervention to 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 regarding our advice on those activities occurring in or near the site which may require additional management.

Table 1. Supplementary advice on the conservation objectives for Offshore subtidal sands and gravels in Firth of Forth Banks Complex 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 activities taking place. 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, the changes in substrata that may result in a change to the extent and distribution of Offshore subtidal sands and gravels in the site.*

Explanatory notes

Extent refers to the total area in the site occupied by Offshore subtidal sands and gravels 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 Offshore subtidal sands and gravels (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 Offshore subtidal sands and gravels within the site must be conserved to their full known distribution.

Offshore subtidal sands and gravels 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 Offshore subtidal sands and gravels 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 Offshore subtidal sands and gravels (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). Conserving extent is therefore critical to conserving or improving conservation status of Offshore subtidal sands and gravels.

Offshore subtidal sands and gravels are more stable than their shallower equivalents with diverse infaunal communities dominated by polychaetes; hatchet shells and small bivalves e.g. the little tellin. Offshore fine to muddy sands support a diversity of tube building polychaetes, burrowing brittlestars and bivalves, while the pea urchin occurs in medium sands and amphipods and hooded shrimp in fine sands. Mobile predators include flatfish, starfish, crabs and hermit crabs. On the continental shelf, this habitat equates to the EUNIS habitats A5.1: Subtidal coarse sediments, A5.2: Subtidal sand, and A5.4: Subtidal mixed sediments, but the Priority Marine Feature also covers bathyal and abyssal examples of the habitat which occur on and beyond the continental slope in Scotland (Tyler-Walters et al., 2016).

Extent and distribution of the feature within the site

The site map for Firth of Forth Banks Complex MPA is available to view on JNCC's Interactive MPA Mapper. The site is 2,130 km^2 in area, of which >99% has been modelled as Offshore subtidal sands and gravels. The habitat has been mapped using full coverage bathymetry and backscatter data, as well as benthic video and image sample data collected during a 2011 survey undertaken by Marine Scotland Science and JNCC (Sotheran and Crawford-Avis 2014a; Sotheran and Crawford-Avis 2014b). The Offshore subtidal sands and gravels feature comprises a heterogeneous mosaic of coarse, sandy and mixed sediments, and the feature is interspersed with small patches of rock and mud (not considered part of the feature) in the Wee Bankie and Montrose Bank sections of the site. JNCC consider the heterogeneity of the habitat types present to be a consequence of localised hydrodynamic processes acting on the site (JNCC, 2014).

JNCC consider that there are currently no activities occurring capable of significantly affecting the extent and distribution of Offshore subtidal sands and gravels within the site. As such, **JNCC advise a conserve objective** is set. Our confidence in this objective would be improved with long-term monitoring.

Activities should look to minimise, as far as is practicable, a change in substrata that may result in a change to the extent and distribution of Offshore subtidal sands and gravels within the site. For further information on human activities capable of affecting Offshore subtidal sands and gravels, please see the Advice on Operations workbook.

Attribute: Structure and function

Objective: Recover

JNCC understands that the Offshore subtidal sands and gravels feature is subject to activities that could impact the structure and function of the feature, specifically the characteristic communities and consequently function. While the feature is naturally exposed to moderate energy levels (due to the tidal currents present in the site), the level of fishing activity present in the site suggests the structure and function of the *feature has been impacted as a result of this activity. As such,* ***JNCC advise a restore objective*** *which is based on expert judgement. Our confidence in this objective would be improved by long-term monitoring of the feature's condition and a better understanding of the role that species play in the function and health of Offshore subtidal sands and gravels. Activities should look to minimise, as far as practicable, changes in substrata and biological communities within the site.*

Explanatory notes

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

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

The site includes a series of banks and mounds formed by the action of strong currents. The banks and mounds rise with a slope greater than 2% from the seafloor and reach a height of ~30m below sea level (Sotheran and Crawford-Avis, 2014a; Heriot-Watt University, 2012; Marine Scotland, 2016), compared to a depth of ~60-80m in the surrounding seabed. There are three distinct areas of banks and mounds within the site boundary (Wee Bankie including Scalp Bank, Berwick Bank and Montrose Bank) which have been mapped using multibeam, backscatter and particle size analysis (PSA) data and are available to view on JNCC's Interactive MPA Mapper (Sotheran and Crawford-Avis, 2014a; JNCC, 2016). The banks and mounds interact with prevailing currents in the region, resulting in fine-scale hydrodynamic processes that serve to increase levels of biological productivity (Scott *et al.,* 2010).

Whilst it is highly unlikely that human activities will affect the persistence of the relict bank and mound features, the persistence of finer scale topographic features within the site may be affected by the installation of offshore infrastructure by virtue of influence on localised hydrographic processes that maintain such features. Indeed, sand ripples have been recorded in the site (Allen *et al.*, 2014). However, to the best of our knowledge no such activities are currently taking place within the site. As such, **JNCC advise a conserve objective** is set for this sub-attribute of physical structure.

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).

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

Physical structure: Sediment composition of the feature within the site

The Offshore subtidal sands and gravels feature within the site comprises a mosaic of circalittoral coarse sediment, circalittoral sand and circalittoral mixed sediments. During the 2011 survey undertaken by JNCC and Marine Scotland Science, 11 grab samples recorded coarse sediment, 12 samples recorded sand and one sample recorded mixed sediments (out of 24 samples taken within the feature). Average grain sizes from samples taken within the Offshore subtidal sands and gravels feature were 5.6 ± 2.7%, 80.4 ± 15.5% and 14.3 ± 15.5% (mean ± SD) for gravel, sand and silt/clay, respectively. The sand component of the feature is characterised by non-cohesive muddy sand with occasional patches of coarse material (Allen *et al.*, 2014). The coarse sediment of the Offshore subtidal sands and gravels feature within the site is characterised by a mixture of gravel, pebbles and cobbles overlying finer sediment (Allen *et al.,* 2014). Mixed sediment within the Offshore subtidal sands and gravels within the site is characterised by boulders, cobbles or pebbles with gravel and sand (Allen *et al.,* 2014).

The mosaic of sediment types recorded throughout the site is considered to be a result of the interaction between the banks and mounds and tidal currents, causing varying levels of sediment deposition (JNCC, 2014) The banks and mounds within the Offshore subtidal sands and gravels feature are predominantly formed of circalittoral coarse sediment as a result of the tidal currents removing smaller grains (Scott *et al.,* 2010; Sotheran and Crawford-Avis, 2014a; Sotheran and Crawford-Avis, 2014b). Circalittoral sand is found around the deeper areas of the site where less sediment transport occurs due to lower exposure to tidal currents. However, video and still samples show the presence of sand ripples as a result of localised currents caused by the banks and mounds (Allen *et al.,* 2014).

JNCC consider that there are currently no activities capable of affecting the sediment composition of Offshore subtidal sands and gravels within the site. As such, **JNCC advise a conserve objective** is set. This is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures exerted by the activities present. Activities should look to minimise, as far as is practicable, a change in substrata that may result in a change to the sediment composition of Offshore subtidal sands and gravels within the site.

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 such as Offshore subtidal sands and gravels. 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 can also be classed as a key or influential species. Changes to the spatial distribution of communities across Offshore subtidal sands and gravels 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 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 Offshore subtidal sands and gravels also depends on the life-history traits of the species themselves (e.g. their growth rate, longevity) and their interactions with other species, including predators and prey. Furthermore, the environmental connectivity between populations or species patches, the suitability of the habitat (e.g. substrate type), depth, water and sediment quality will also influence the recovery potential of Subtidal sedimentary habitats (Mazik *et al.,* 2015).

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

Ocean quahog aggregations have been recorded in Offshore subtidal sands and gravels within the site during the 2011 survey (Allen *et al.,* 2014). Ocean quahogs (*Arctica islandica*) create burrows ~5cm deep in sediment, but can burrow deeper if disturbed or when food is sparse (Ragnarsson *et al.*, 2002; Sabatini *et al.*, 2008). Ocean quahog is also a protected feature of the site (see Table 2) and is an OSPAR Threatened and/or Declining Species (OSPAR, 2009c). The 2011 survey recorded a high density of burrowing polychaete worms including *Spiophanes bombyx, Galathowenia oculata* and *Owenia fusiformis* (Pearce *et al.,* 2014), as well as burrowing bivalve molluscs such as *Abra prismatica* and *Dosinia exolete.* Evidence of these burrowing species was found throughout the site (Pearce *et al.,* 2014). It is possible that these species play a critical role in maintaining the structure and functioning of the protected Offshore subtidal sands and gravels, but there is limited information available to confirm this.

There is insufficient information available to support an understanding of the significance of the role which these species play in maintaining the structure and function of the habitat. Therefore, it is not yet possible to set 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 of the feature within the site
An analysis of the biotopes present within the site was performed on grab sample and video transect data collected during the 2011 survey (Pearce *et al*., 2014; Allen *et al.*, 2014). The communities identified within the Offshore subtidal sands and gravels feature included:

- Circalittoral coarse (SS.SCS.CS) and offshore circalittoral coarse (SS.SCS.OCS) sediment communities: including unstable circalittoral cobble and pebble communities throughout the site, with polychaete species, such as *Spiophanes bombyx*, within the upper sediment layer (based on grab sample data) and squat lobster *Galathea intermedia* and sea spider *Callipallene brevirostris* on the surface of the sediment identified from video and stills samples (Allen *et al.,* 2014; Pearce *et al*., 2014).
- Circalittoral sand (SS.SSa.CSa), circalittoral fine sand (SS.SSa.CFSa), circalittoral muddy sand (SS.SSa.CMuSa) and offshore circalittoral sand (SS.SSa.OSa) communities: characterised by a wide variety of polychaetes, bivalves such as *Abra prismatica* and echinoderms such as *Amphiura spp* and *Ophiura spp* (Allen *et al*., 2014; Pearce *et al*., 2014). These sediments are typically non-cohesive muddy sands, although larger, coarse grain sizes are found in some locations (Connor *et al.*, 2004) and video and still samples also recorded sand ripples with some coarse material and shell between them (Allen *et al*., 2014).
- Circalittoral mixed sediments (SS.SMx.CMx) and offshore circalittoral mixed sediments (SS.SMx.OMx) communities: including *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment (SS.SMx.CMx.FluHyd) and a polychaete-rich *Galathea* community with encrusting bryozoans and other epifauna identified from video and still samples (Allen *et al*., 2014).

The Offshore subtidal sands and gravels present in the site experience moderate energy levels (JNCC, 2016). This energy mobilises the sediment, suggesting that the communities present may be relatively robust and able to tolerate some level of abrasion pressure from mobile fishing gear. However, the dredge fishing activity penetrates >5cm into the sea bed and is considered to be damaging to the communities present (Klein and Witbaard, 1993; Tillin *et al*., 2010). This activity is capable of impacting the characteristic communities through removing benthic species and damaging or killing them by abrasion. Therefore, **JNCC advise a recover objective** for the characterising communities. This objective is based on expert judgment, specifically the sensitivity of the feature to pressures associated with activities taking place within the site. There is currently no information on the longevity of species and communities associated with offshore subtidal sand and gravel habitats with which to comment on whether the protected feature will persist naturally through time or exhibit successional/cyclical tendencies (JNCC, 2014). Our confidence in the setting of this objective would be improved with long-term site condition monitoring information.

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

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 subtidal sands and gravels in the site may include:

- Biological productivity – the banks and mounds within the Offshore subtidal sands and gravels feature increase turbulence of tidal currents resulting in the formation of internal waves. These internal waves cause cooler, nutrient rich deep waters to mix with shallower waters, increasing the primary productivity and providing a greater food source for species such as sandeels (*Ammodytes marinus*)

(Scott *et al.,* 2010). In turn, this enhanced productivity is functionally significant for the health and biodiversity of Scotland's seas, as sandeels are a key prey item for top predators in the North Sea food web (Scott *et al*., 2010).

- Nutrition – the Offshore subtidal sands and gravels in the site provide a habitat for commercially important species, such as king scallops (*Pecten maximus*). Berwick Bank is a spawning ground for plaice, the larvae of which may be important for repopulating exploited stocks along the east coast of England (Lockwood and Lucassen, 1984). Commercial fish species (including sandeels) benefit from the increased biological productivity of the Offshore subtidal sands and gravels caused by the topography and hydrodynamics of the site (Scott *et al.,* 2010).
- Climate regulation – sedimentary habitats provide a long-term carbon sink through bioturbation, living biomass and calcification of benthic organisms (Alonso *et al.,* 2012, Hattam *et al.,* 2015).

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.

For further information on human activities capable of affecting Offshore subtidal sands and gravels, please see 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 subtidal sands and gravels 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 below.*

Explanatory notes

Offshore subtidal sands and gravels 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, 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 Offshore subtidal sand and gravel habitat types can be influenced by hydrographic processes, supporting the formation of topographic bedforms (see finer scale topography).

Hydrodynamic regime within the site

The tidal regime within the site is semi-diurnal with a variable mean spring tide of between 4.5m to 4.8m (Seagreen Wind Energy Ltd, 2010). Tidal currents within the site flow parallel to the coast in a southerly or northerly direction, with a peak tidal velocity of 0.5m/s within the site (Seagreen Wind Energy Ltd, 2010; Seagreen Wind Energy Ltd, 2011). These strong tidal currents result in moderate energy levels which influence the topography and sediment composition of Offshore subtidal sands and gravels. The exposure of fine-grained sediments to these currents causes the formation of banks and mounds, transporting the smallest grains of sediment from the tops of these bedforms and down into surrounding, deeper areas (Scott *et al.,* 2010). The relatively strong southward flowing current, the Scottish Coastal Current, brings waters from the northern North Sea to the site. The current exhibits spatial variation driven by winds and atmospheric pressure gradients, suggesting that the energy levels exacted on Offshore subtidal sands and gravels are not constant (SEA3, 2016).

The variable depth of the site suggests that it could be affected by storm events, as surges may cause increased sediment movement in the shallower areas of the site. However, the impact of storms on Offshore subtidal sands and gravels and the biological communities they support is unknown.

It is important to conserve the hydrodynamic regime within the site to ensure that key attributes, such as the structure of Offshore subtidal sands and gravels, remain unimpacted. There is no evidence to suggest that existing activities in the site impact the hydrodynamic regime. As such, **JNCC advise a conserve objective** based on expert judgment, specifically our understanding of the feature's sensitivity to pressures associated with ongoing activities.

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 Offshore subtidal sands and gravels 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 evidence on the site's physicochemical properties is required. The dominant factors in the stratification of the water column are seasonal and daily changes in solar radiation, wind and tidal mixing (Scott *et al.,* 2010). The tidal current within the site also causes an increase in nutrient availability through upwelling. This influences phytoplankton production in the site throughout the year, with a maximum chlorophyll biomass of >5 mg m^{-3} (Scott *et al.,* 2010) providing a food source for Offshore subtidal sand and gravel communities.

The site lies within the central North Sea in an area of relatively high human activity and anthropogenic influence. There are a large number of shipping routes through the site which may impact water quality (JNCC and MMO 2015; OSPAR, 2009b). Enrichment due to riverine inputs are thought to affect ecological function of sites in the North Sea (Wieking and Kröncke, 2005; van Leeuwen *et al.,* 2015). Atmospheric deposition in the North Sea has been highlighted as a major source of contamination of trace metals (cadmium, lead, copper and zinc; Injuk *et al.,* 1992).

While this information identifies possible sources of contamination, there is currently no information available to 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 Offshore subtidal sands and gravels. 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 determine the sediment contaminant levels within the site. Samples taken within the site at Montrose Bank and ~20km to the west of the site at the Arbroath sample station suggest the sediment is below background conditions for the majority of monitored contaminants and will have limited effects on marine life. However, evidence suggests levels of chlorobiphenyl-118 may be high enough to have adverse effects on marine organisms (CSEMP, 2014). The level of arsenic was also recorded as above background concentrations but the impact of this is unknown (CSEMP, 2014).

Exploration of North Sea oil and gas reserves has resulted in the accumulation 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). The levels of these sediment pollutants within the site are currently unknown. Oil and gas exploration operations no longer occur within the site, however remaining drill cuttings may present an unexplored pollution pathway at the site. Old well sites are located in the Montrose Bank section of the site.

There is no direct empirical evidence from the site to suggest Offshore subtidal sands and gravels are impacted by sediment contamination. **JNCC therefore advise a conserve objective** and that EQS standards should be adhered to so that sediment quality is maintained, to prevent impact to the feature and its associated biological communities. 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 Firth of Forth Banks Complex Nature Conservation MPA.

Attribute: Extent and distribution
Objective: Conserve *The feature is being exposed to damaging pressures associated with demersal trawling and dredge fishing and this may be impacting the feature's extent and distribution. Despite this,* ***JNCC advise 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 of the feature within the site

The known extent and distribution of Ocean quahog aggregations within the site 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.

Grab samples taken during the 2011 JNCC and Marine Scotland survey provide evidence of Ocean quahog aggregations throughout the site. Records came from the north-eastern Montrose Bank section of the site (where 14 individuals were sampled from seven out of 15 sample stations), the Wee Bankie and Scalp Bank section of the site (where four individuals were sampled from two out of five sample stations), and the Berwick Bank (where two individuals were found at one of four sample stations) (Pearce *et al.*, 2014). In 2000, Ocean quahog aggregations were recorded as being super-abundant on the SACFOR scale within the west of the Berwick Bank section (Dove Marine Laboratory, 2000).

Based on the known habitat preferences of ocean quahog (Witbaard and Bergman, 2003), >99% (~2,130 km^2) of the site is considered suitable for ocean quahog colonisation. The site protects a large area of relatively shallow Offshore subtidal sands and gravels in which ocean quahog are able to burrow and feed, and larvae are able to settle.

Vessel monitoring system (VMS) data from 2009 to 2016 indicate that the Ocean quahog aggregations within the site are likely to be exposed to demersal trawling and dredging, to which the feature is known to be sensitive. Demersal trawling is highest in the north of the Wee Bankie section of the site (including Scalp Bank), with an average of > 500 hours of demersal trawling activity recorded in the area over seven years (2009 -2015) and >100 hours in 2016. VMS data show that dredge fishing activity is also highest in the Wee Bankie section of the site (including Scalp Bank), with a maximum average of > 600 hours over 7 years (2009-2015). During 2016 a total of over 2500 hours of dredge fishing was recorded in this area. Ocean quahog aggregations are sensitive to demersal fishing gear that penetrates >5cm depth into the seabed, such as that used in the dredge fishing activity in the site (Klein and Witbaard, 1993). The feature is being exposed to damaging pressures associated with demersal trawling 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 aggregation extent and distribution, please see the Advice on Operations Workbook.

Attribute: Structure and function

Objective: Conserve

The feature is being exposed to damaging pressures associated with demersal trawling and dredge fishing and this may be impacting the feature's structure and function. Despite this, ***JNCC advise 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 setting of this objective would be improved by long-term monitoring information of Ocean quahog aggregation condition within 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 count / 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 quahogs 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 conserve the population within the site.

Structure of the feature within the site

Average density of the ocean quahog recorded across the site in 2011 was 0.02 individuals/km^2. This is considerably lower than documented averages from the northern North Sea (16,000 ind/km^2) (Witbaard, 1997; Witbaard and Bergman, 2003). However, the 2011 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). Both adults and juveniles were recorded during the 2011 survey, suggesting larval recruitment occurs in the site (Pearce *et al.*, 2014).

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). More data are required to develop a time series of ocean quahog population structure to identify any changes to the feature over time. As there are no time series data for Ocean quahog aggregations within the site, it is unclear whether the population in the site is declining, stable or increasing. The age structure, growth rate and reproductive viability of the population located within the site are also currently unknown.

Vessel monitoring system (VMS) data from 2009 to 2016 indicate that the Ocean quahog aggregations within the site are likely to be exposed to demersal trawling and dredge fishing. Ocean quahog aggregations are sensitive to demersal fishing gear that penetrates >5cm depth into the seabed, such as that used in the dredge fishing activity in the site (Klein and Witbaard, 1993). The feature is being exposed to damaging pressures associated with demersal fishing activity and this may be impacting the feature's structure. Despite this, **JNCC advise 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

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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 of the feature within the site

Whilst there is no direct evidence on the ecosystem services provided by Ocean quahog aggregations within the site, ocean quahog are filter feeders and remove plankton and detritus from the water column, playing a role in carbon cycling and nutrient regulation (Tyler-Walters and Sabatini, 2017). The longevity of ocean quahog also enables scientists to construct 'master chronologies' over tens or hundreds of years to study changes in climate and environmental change using the biogenic carbonates stored in the growth rings of ocean quahog (Schöne, 2013). These 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) and climate oscillations for modelling ocean-atmosphere interactions over 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).

VMS data from 2009 to 2016 indicate that the Ocean quahog aggregations within the site are likely to be exposed to demersal trawling and dredge fishing, to which the feature is known to be sensitive. Ocean quahog aggregations are sensitive to demersal fishing gear that penetrates >5cm depth into the seabed, such as that used in the dredge fishing activity in the site (Klein and Witbaard, 1993). The feature is being exposed to damaging pressures associated with demersal fishing activity and this may be impacting the feature's function. Despite this, **JNCC advise 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

For further information on activities capable of affecting Ocean quahog aggregations and their structure and function, please see the Advice on Operations Workbook.

Attribute: Supporting processes

Objective: Conserve

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. Supporting habitats are important in governing the extent and distribution of Ocean quahog aggregations and the species is highly sensitive to physical loss of habitat. It is therefore important to conserve the supporting Offshore subtidal sands and gravels habitat to provide the best chance of settlement by new recruits and to retain existing individuals. 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

A relatively strong southward flowing current, the Scottish Coastal Current, brings waters from the northern North Sea to the site. Movement of the water masses from the North-East Atlantic to central North Sea may help to carry new recruits (during their pelagic larval phase) into the area from populations around Iceland (Sündermann and Pohlmann, 2011).

The tidal regime within the site is semi-diurnal with a variable mean spring tide of between 4.5m to 4.8m (Seagreen Wind Energy Ltd, 2010). Tidal currents within the site flow parallel to the coast in a southerly or northerly direction, with a peak tidal velocity of 0.5m/s within the site (Seagreen Wind Energy Ltd, 2010; Seagreen Wind Energy Ltd, 2011). The Scottish Coastal Current exhibits spatial variation driven by winds and atmospheric pressure gradients, suggesting that the energy levels exacted on the Ocean quahog aggregations and their supporting habitat are not constant (SEA3, 2016).

The variable depth of the site suggests that it could be affected by storm events, as surges may cause increased sediment movement in the shallower areas of the site. However, the impact of storms on the Ocean quahog aggregations is unknown.

There is no evidence to suggest that the plugged and abandoned oil and gas wells in the site are impacting the hydrodynamic regime, however future developments that add further infrastructure to the site may result in a change in local turbulence and vertical mixing (Clark *et al.,* 2014).

As impacts to the hydrodynamic regime are currently minimal, Ocean quahog aggregations in this site are not thought to be affected by anthropogenic impacts on this sub-attribute. 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 which can be exerted by ongoing activities.

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 of the feature within the site

The known extent and distribution of and suitable habitat to support Ocean quahog aggregations within the site is available to view via the JNCC's Interactive MPA Mapper.

Based on what is known about the habitat preferences of ocean quahog (Witbaard and Bergman, 2003), >99% (~2,130 km^2) of the seabed habitats present within the site are considered suitable for ocean quahog colonisation (Sotheran and Crawford-Avis 2014a; Sotheran and Crawford-Avis 2014b). The supporting habitat within the site consists of Offshore subtidal sands and gravels as described in Table 1. This area of relatively shallow sediment is suitable habitat for ocean quahog to burrow and feed, and is also important for the species' life cycle by offering an area suitable for larval settlement, growth and spawning (Witbaard and Bergman, 2003; Tyler-Walters and Sabatini, 2017).

JNCC consider that there are currently no activities capable of affecting the natural extent and physical structure of habitat suitable to support Ocean quahog aggregations within the site. As such, **JNCC advise a conserve objective** is set. This is based on expert judgement; specifically, our understanding of the feature's sensitivity to pressures exerted by the activities present. Activities should look to minimise, as far as is practicable, a change in substrata that may result in a change to the sediment composition of Ocean quahog aggregations supporting habitat within the site.

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 the species can actively pump protons to drive increased calcification (Stemmer *et al.,* 2013; 2014). This suggests that although ocean quahog can buffer against the effects of short-term acidification, longer-term acidification may have energetic consequences and ultimately restrict growth and/or reproductive output.

Adult ocean quahog have a medium sensitivity to increases in water temperature. Evidence suggests that the optimal temperature for ocean quahog survival, spawning and recruitment is 6-16°C (Loosanoff, 1953; Merrill *et al.,* 1969; Golikov and Scarlato, 1973; Jones, 1981; Mann, 1989; Cargnelli *et al.,* 1999; Harding *et al.,* 2008). Temperature change can be local (associated with localised effects, such as warm-water effluents, are 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 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 evidence on the site's physicochemical properties is required. The dominant factors in the stratification of the water column are seasonal and daily changes in solar radiation, wind and tidal mixing (Scott *et al.,* 2010). The tidal current within the site causes an increase in nutrient availability through upwelling. This influences phytoplankton production in the site throughout the year, with a maximum chlorophyll biomass of >5 mg m^{-3} (Scott *et al.,* 2010) providing a food source for Ocean quahog aggregations within the site (Tyler-Walters and Sabatini, 2017).

The site lies within the central North Sea in an area of relatively high human activity and anthropogenic influence. There are a large number of shipping routes through the site which may impact water quality (JNCC and MMO 2015; OSPAR, 2009b). Enrichment due to riverine inputs are thought to affect ecological function of sites in the North Sea (Wieking and Kröncke, 2005; van Leeuwen *et al.,* 2015). Atmospheric deposition in the North Sea has been highlighted as a major source of contamination of trace metals (cadmium, lead, copper and zinc; Injuk *et al.,* 1992).

While this information identifies possible sources of contamination, there is currently no information available to 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.

There is limited information available to ascertain the sediment contaminant levels within the site. According to 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 suggests the sediment is 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). The level of Arsenic was also recorded as above background concentrations but the impact of this is unknown (CSEMP, 2014).

Exploration of North Sea oil and gas reserves has resulted in the accumulation 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). Levels of these sediment pollutants within the site are currently unknown. Oil and gas exploration operations no longer occur within the site, however remaining drill cuttings may present a possible pollution pathway within the site.

There is no direct empirical evidence from the site to suggest habitat supporting Ocean quahog aggregations are impacted by changes in water or sediment quality. **JNCC advise a conserve objective** and that activities must look to avoid, as far as is practicable, exceeding the EQS levels 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 processes, please see the Advice on Operations Workbook.

Table 3. Supplementary advice on the conservation objectives for Shelf banks and mounds in Firth of Forth Banks Complex Nature Conservation MPA.

Attribute: Extent and distribution
Objective: Conserve *As a large-scale geological feature, it is not considered that any activities currently taking place are capable of significantly affecting the extent and distribution of the shelf banks and mounds protected within this site. As such,* ***JNCC advise a conserve objective****.*
Explanatory notes In the context of a large-scale feature, extent and distribution refers to the area that the large-scale feature occupies within a site. **Site advice** The known extent and distribution of Shelf banks and mounds within the site are available to view via the JNCC's Interactive MPA Mapper. The Shelf banks and mounds large-scale feature extends across ~264 km^2 of the site and includes four bedform features: Wee Bankie and Scalp Bank in the west section of the site, Montrose Bank in the north-east and Berwick Bank in the south-east. A change in the prevailing hydrodynamic regime, which could occur as a result of large scale subsea infrastructure, could affect the extent and distribution of the area of the shelf banks and mounds protected within this site. However, due to the lack of available evidence of such an activity or impact, **JNCC advise a conserve objective**.
Attribute: Structure and function
Objective: Conserve *As a large-scale geological feature, it is not considered that any human activities are capable of significantly affecting the physical nature of the area of the shelf banks and mounds protected within this site. Moreover, there is no evidence to suggest that the functional role of the shelf banks and mounds has been impaired because of human activity. As such,* ***JNCC advise a conserve objective*** *for this attribute.*
Explanatory notes In the context of a large-scale feature, structure refers to the physical nature of the feature and the functional role it plays in supporting the wider health and biodiversity of Scotland's seas. **Site advice**

Physical nature

The site's four banks and mounds are formed by the action of strong currents on mobile sediment, causing the build-up of subtidal sands and gravels into distinct bedform features (Marine Scotland, 2016). The banks and mounds rise with a slope greater than 2% from the seafloor, with some sections of the feature reaching a peak of ~30m below sea level (Sotheran and Crawford-Avis, 2014a; Heriot-Watt University, 2012; Marine Scotland, 2016), compared to a depth of ~60-80m in the surrounding seabed. The strong currents present in the site influence the composition of the sediments. The mosaic of sediment types throughout the habitat is considered to be a result of the interaction between the banks and mounds and the tidal currents, causing varying levels of sediment deposition (JNCC, 2014). The banks and mounds are predominantly formed of circalittoral coarse sediment as a result of the tidal currents removing the smaller grains (Scott *et al.,* 2010; Sotheran and Crawford-Avis, 2014a; Sotheran and Crawford-Avis, 2014b).

As a large-scale geomorphological feature, it is not considered that any current human activities within the site are capable of significantly affecting the physical nature of the protected Shelf banks and mounds features. As such, **JNCC advise a conserve objective**.

Functional role

Functions provided by large-scale features can occur at a number of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC, 2011). Ecosystem services that may be the provided by the area of the Shelf banks and mounds protected within the site include:

- Biological productivity – There is evidence to suggest that two of the bank and mound features are of wider functional significance to the health and biodiversity of Scotland's seas: Wee Bankie for foraging seabirds (Daunt *et al.,* 2008; Camphuysen *et al.,* 2011) and grey seals (*Halichoerus grypus*) (McConnell *et al.,* 1999, Jones *et al*., 2015), and Berwick Bank for foraging grey seals (Prime and Hammond, 1990; McConnell *et al.,* 1999; Jones *et al.,* 2015). The banks and mounds, comprising of sand and gravel habitats, increase the turbulence of tidal currents, causing vertical mixing between nutrient-rich deep waters and shallower waters which increases primary productivity (Scott *et al.,* 2010). These conditions are suitable for sustaining a sandeel population, a key prey item for top predators in the North Sea food web (Scott *et al.,* 2010, Wright *et al*., 2000). The sandeels within the banks and mounds feature are thought to be of critical importance to foraging black-legged kittiwakes (*Rissa tridactyla*), northern gannet (*Morus bassanus*) and common guillemot (*Uria aalge*), as well as a food source for grey seal, which can access these prey over the shallow banks and mounds. Breeding success of black-legged kittiwake from the nearby Isle of May colony has been linked to the availability of sandeels in the site (Daunt *et al.,* 2008).

- Nutrition – Berwick Bank is a spawning ground for plaice, the larvae of which may be important for repopulating exploited stocks along the east coast of England (Lockwood and Lucassen, 1984). The bank and mound bedform features provide habitat for king scallops, which show higher growth rates in shallower waters and are more abundant in areas adjacent to strong currents where nutrient availability is greater (Mason, 1957; Mason, 1983). The feature also provides habitat for sandeels, which can be fished to produce fishmeal and fish oil. Other commercial fish species also benefit from the enhanced biological productivity described above.
- Climate regulation – sedimentary habitats which make up the banks and mounds feature provide a long-term carbon sink through bioturbation, living biomass and calcification of benthic organisms (Alonso *et al.,* 2012, Hattam *et al.,* 2015).

There is no evidence to suggest that the functional role of the Shelf banks and mounds has been impaired as a result of human activity. As such, **JNCC advise a conserve objective** for this feature.

Attribute: Supporting processes

Objective: Conserve

*The shelf banks and mounds are actively maintained by the prevailing hydrodynamic regime. JNCC do not believe there is any evidence to suggest that the prevailing hydrodynamic regime has been affected by human activities. As such, **JNCC advise a conserve objective**.*

Explanatory notes

In the context of large-scale features, supporting processes refers to the role that the hydrodynamic regime plays in maintaining the functional significance of the feature within a site.

Site advice

The Shelf banks and mounds are actively maintained by the prevailing hydrodynamic regime and is predominantly the result of tidal currents causing the build-up of subtidal sands and gravels into distinct bedform features (Heriot-Watt University, 2012). The interaction between this large-scale feature and the local tidal currents leads to the generation of internal waves, which continually replenish the Shelf banks and mounds feature (Scott *et al.,* 2010).

The tidal regime within the site is semi-diurnal with a variable mean spring tide of between 4.5m to 4.8m (Seagreen Wind Energy Ltd, 2010). Tidal currents within the site flow parallel to the coast in a southerly or northerly direction, with a peak tidal velocity of 0.5m/s within the site (Seagreen Wind Energy Ltd, 2010; Seagreen Wind Energy Ltd, 2011). Photos taken within the banks and mounds show the presence of sandwaves, indicating that the sediment surface is regularly mobilised by tidal currents (Allen *et al*., 2014). These strong tidal currents affect the feature's sediment composition by transporting smaller grains of sediment from the mounds and depositing these in surrounding, deeper areas (Scott *et al.,* 2010).

The relatively strong southward flowing current, the Scottish Coastal Current, brings waters from the northern North Sea to the site. The current exhibits spatial variation driven by winds and atmospheric pressure gradients, suggesting that the energy levels exacted on the banks and mounds are not constant (SEA3, 2016).

It is important to conserve the hydrodynamic regime within the site to ensure that these key processes remain unimpacted. JNCC do not have evidence to suggest that the prevailing hydrodynamic regime has been affected by human activities. As such, J**NCC advise a conserve objective.**

Table 4. Supplementary advice on the conservation objectives for the Wee Bankie Key Geodiversity Area in Firth of Forth Banks Complex Nature Conservation MPA.

Terminology

- *Geodiversity features* – a collective term for geological and geomorphological features.
- *Key Geodiversity Area* – a collective term for geodiversity features that in combination make up the key geodiversity interests of a site.
- *Relict* – a category of geodiversity features which have been formed by natural processes which are no longer taking place e.g. iceberg plough marks formed by glacial movement during the last ice age.
- *Active* – a category of geodiversity features which are formed and maintained by natural processes that are still taking place e.g. sand and sediment wave fields which are maintained by the prevailing hydrodynamic regime.

Overview of the protected geodiversity features of the site

The site protects relict geodiversity features comprising one of the Key Geodiversity Areas within Scotland's seas:

- **Wee Bankie –** comprising of relict glacial moraines which are interpreted as marking an ice limit of the Last Glacial Maximum.

There is no direct information on the condition of the protected geodiversity features within the site. Consequently, the conservation objectives for feature attributes have been set based on JNCC's understanding of the sensitivity of the protected geodiversity features to pressures associated with human activities to which the features are considered to be sensitive (based on Brooks, 2013). It is important to note that only physical pressures (such as abrasion to the seabed surface and the physical removal or deposition of material) are considered to pose a threat to the integrity of the relict protected geodiversity features of the site.

Attribute: Extent and distribution

Objective: Conserve

There are currently no activities taking place that are capable of significantly affecting the extent and distribution of the protected geodiversity feature of the site. It is not considered possible to recover the extent and distribution of the protected geodiversity feature through human intervention. As such, ***JNCC advise a conserve objective*** *for the protected geodiversity feature of the site. JNCC recommend that activities that result in the physical removal of material associated with the moraines are kept to a minimum.*

Explanatory notes

In the context of the protected geodiversity feature of the site, extent and distribution refers to area that this feature occupies within a site. Any significant loss of extent to relict geodiversity features may be more significant than for active geodiversity features because the processes that led to the formation of relict features are no longer taking place.

The extent and distribution of geodiversity features within the site is shown on the JNCC MPA Mapper.

Wee Bankie

The Wee Bankie Key Geodiversity Area is a series of relict glacial ridges composed of poorly sorted sediment located ~40 km east of the Firth of Forth and Firth of Tay. The moraines mark an ice limit at some stage during glacial retreat from the Last Glacial Maximum (Brooks *et al*., 2013). This feature encompasses the greater extent of the largest and westernmost section of the site (named Wee Bankie because of the feature's moraines) and then extends into the other sections of the complex, covering ~750 km^2 of the site in total.

The moraines have no resilience to physical pressures that may result in a loss to the feature's extent and distribution, such as physical extraction of material from the seabed (Brooks *et al*., 2013). Human activities have the potential to cause partial disruption to the feature's surface or stratigraphy, but as relict features they are unable to recover. JNCC consider that there are currently no activities taking place that may result in the physical removal of parts of the moraines within the site. As such, **JNCC advise a conserve objective** for this protected geodiversity feature.

Attribute: Structure and function

Objective: Conserve

*JNCC consider that there are currently no activities taking place that are capable of significantly affecting the structure and function of the protected geodiversity features of the site. As such, **JNCC advise a conserve objective**. JNCC recommend that activities which result in the sub-surface abrasion, penetration or physical removal of unconsolidated material from the moraines are kept to a minimum.*

Explanatory notes

In the context of the protected geodiversity features of the site, structure refers to the physical nature of protected geodiversity features and function as both the scientific importance of the feature in its own right, as well as the role it plays in supporting biological functioning.

Structure

Wee Bankie

The Wee Bankie moraines are a series of prominent submarine ridges formed of glacial till ~20m high relative to the surrounding seabed and found at a depth of 50-30m below sea level (Graham *et al.,* 2009). The ridges are steepest on their western edge, with a more gradual slope in the east. The mapped Wee Bankie moraines reach a width of ~20km across and ~70km in length.

As the moraines are a relict feature Brooks and colleagues (2013) conclude that they have no resilience to physical pressures that may result in impacts to the physical structure of this feature, such as extraction of material from the seabed or penetration or abrasion of the unconsolidated material which make up the moraines. JNCC consider that there are currently no activities taking place that may impact the physical structure of the moraines within the site. As such, **JNCC advise a conserve objective** for this protected geodiversity feature.

Function

<u>Wee Bankie</u>

Functions provided by geodiversity features can occur at a number of temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC, 2011). Ecosystem services that may be provided by the protected geodiversity features of the Wee Bankie Key Geodiversity Area include:

- Scientific study: the bedform features of the Wee Bankie Key Geodiversity Area form a series of prominent submarine ridges marking an ice limit at some point during the ice retreat of the British-Irish Ice Sheet, during the Last Glacial Maximum (Brooks *et al.,* 2013, Graham *et al*., 2009). The feature has an important role in furthering scientific understanding of deglacial history (Brooks *et al.,* 2013).
- Habitat provision: The moraines that form this Key Geodiversity Area are also considered to be of functional importance as the ridges form an integral part of the Offshore subtidal sands and gravels protected feature, supplying substrate that supports the sedimentary biological communities. The moraines also provide habitat for the Ocean quahog aggregations feature. Both the Offshore subtidal sands and gravels and Ocean quahog aggregations, supported by the moraines, provide ecosystem services in their own right. See Function under Offshore subtidal sands and gravels and Ocean quahog aggregations for further information.

JNCC consider that there are currently no activities taking place that are capable of significantly affecting the conservation status of the protected geodiversity features that comprise the Wee Bankie Key Geodiversity Area. As such, **JNCC advise a conserve objective** and recommend that activities which result in the sub-surface abrasion, penetration or physical removal of unconsolidated material from the moraines within the site are kept to a minimum.

Attribute: Supporting processes
Objective: Not set *The Wee Bankie Key Geodiversity Feature is a relict geological feature. As such, supporting processes are not relevant*.
<u>Explanatory notes</u> In the context of the protected geodiversity features of the site, supporting processes refers to the role that the hydrodynamic regime plays in maintaining the integrity of active protected geodiversity features within the site. **<u>Wee Bankie</u>** The Wee Bankie Key Geodiversity Area is a relict geological feature. As such, supporting processes are not relevant to the conservation status of the feature.

References

Allen, C., Axelsson, M. & Dewey, S., (2014), Analysis of seabed imagery from the 2011 survey of the Firth of Forth Banks Complex, the 2011 IBTS Q4 survey and additional deep-water sites from Marine Scotland Science surveys (2012), JNCC Report 471.

Alonso I., Weston K., Gregg R., & 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]

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. & Archambault, P. (2004). The Influence of Troughs and Crests of Ripple Marks on the Structure of Subtidal Benthic Assemblages Around Rocky Reefs. *Estuarine, Coastal and Shelf Science* 60: 781-790.

Best, M.A., Wither, A.W. and Coates, S. (2007). Dissolved oxygen as a physico-chemical supporting elements in the Water Framework Directive. *Marine Pollution Bulletin*, 55: 53-64 [online]. Available at: http://www.sciencedirect.com/science/article/pii/S0025326X06003171 [Accessed 20 September 2017].

Bett, B.J. (2012). Seafloor biotope analysis of the deep waters of the SEA4 region of Scotland's seas. JNCC Report No. 472. [online] Available at: http://jncc.defra.gov.uk/pdf/472_web.pdf [Accessed: 10 October 2015]

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

Breuer, E., Stevenson, A.G., Howe, J.A., Carroll, J. & 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. & 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.

Brooks, A.J., Kenyon, N.H., Leslie, A., Long., D., Gordon, J.E. (2013). Characterising Scotland's marine environment to define search locations for new Marine Protected Areas. Part 2: The identification of Key Geodiversity Areas in Scottish waters. Scottish Natural Heritage Commissioned Report No. 432.

Brooks, A.J., (2013). Assessing the sensitivity of geodiversity features in Scotland's seas to pressures associated with human activities. Scottish Natural Heritage Commissioned Report No. 590.

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

Camphuysen, K., Scott, B. and Wanless, S. (2011). Distribution and foraging interactions of seabirds and marine mammals in the North Sea: A metapopulation analysis [online]. Available at: http://www.abdn.ac.uk/staffpages/uploads/nhi635/ZSLpaper-kees.pdf [Accessed 20 September 2017].

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

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

Clark S., Schroeder F., Baschek B. (2014) The Influence of Large Offshore Wind Farms on the North Sea and Baltic Sea – a Comprehensive Literature Review. HZG Report 2014 – 6

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. JNCC Report No. 557 [online]. Available at: http://jncc.defra.gov.uk/PDF/Report%20557_web.pdf [Accessed 20 September 2017].

Coates, D.A., Alexander, D., Herbert, R.J.H. and Crowley, S.J. (2016). Conceptual ecological modelling of shallow sublittoral sand habitats to inform indicator selection. JNCC Report No. 585 [online]. Available at: http://jncc.defra.gov.uk/pdf/Report_585_web.pdf [Accessed 20 September 2017].

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]

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

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

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

Dove Marine Laboratory (2000) 1999 – 2001 Northumberland Coast (Berwick to Tynemouth) Marine Biodiversity Project.

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. & Van Der Woerd, H.J. (2004). A survey of total suspended matter in the southern North Sea based on 2001 SeaWiFS data. *EARSeL eProceeding* 3 (2): 166-178.

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

Environment Agency (EA) (2014). Water Framework Directive: Surface water classification status and objectives [Online]. Available at: http://www.geostore.com/environmentagency/WebStore?xml=environment-agency/xml/ogcDataDownload.xml [Accessed 20 March 2015].

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 17 October 2017].

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

Graham, A.G.C., Lonergan, L. and Stoker, M.S. (2009) Seafloor glacial features reveal the extent and decay of the last British Ice Sheet, east of Scotland. *Journal of Quaternary Science.*, 24, 117–138

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

Hattam, C., Atkins, J.P., Beaumont, N.J., Börger, T., Böhnke-Henrichs, A., Burdon, D., de Groot, R., Hoefnagel,E., Nunes, P., Piwowarczyk, J., Sastre, S. and Austen, M.C. 2015. Marine ecosystem services: Linking indicators to their classification. *Ecological Indicators*, 49: 61-75. DOI: http://dx.doi.org/10.1016/j.ecolind.2014.09.026.

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.

Heriot-Watt University (2012). Large-scale feature case studies. Heriot-Watt University, Edinburgh [online] Available at: http://www.gov.scot/resource/0038/00389524.doc [Accessed: 6th November 2017]

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

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

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

Joint Nature Conservation Committee (JNCC) (2004a). Common standards monitoring guidance for inshore sublittoral sediment habitats [online]. Available at: http://jncc.defra.gov.uk/PDF/CSM_marine_sublittoral_sediment.pdf [Accessed 20 September 2017].

Joint Nature Conservation Committee (JNCC) (2004b). Common standards monitoring guidance for littoral sediment habitats [online]. Available at: http://jncc.defra.gov.uk/PDF/CSM_marine_littoral_sediment.pdf [Accessed 20 September 2017].

Joint Nature Conservation Committee (JNCC) (2004c). Common standards monitoring guidance for littoral rock and inshore sublittoral rock habitats [online]. Available at: http://jncc.defra.gov.uk/pdf/CSM_archived200402s_marine_rock.pdf [Accessed 20 September 2017].

Joint Nature Conservation Committee (JNCC) (2004d). Marine advice non-native species [online]. Available at: http://jncc.defra.gov.uk/default.aspx?page=1532 [Accessed 20 August 2017].

Joint Nature Conservation Committee (JNCC) (2014). Firth of Forth Banks Complex MPA - Assessment Against the MPA Selection Guidelines v5.0 July 2014. Available at: http://jncc.defra.gov.uk/PDF/Firth_of_Forth_Banks_Complex_Application_of_the_MPA_Selection_Guidelines_v5.0.pdf [Accessed 22 January 2018]

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 broad-scale seabed habitat map for the UK, Available: http://jncc.defra.gov.uk/ukseamap [Accessed: 11 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.

Jones, E.L., McConnell, B.J., Smout, S., Hammond, P.S., Duck, C.D., Morris, C.D., Thompson, D., Russell, D.J.F., Vincent, C., Cronin, M., Sharples, R.J. & Matthiopoulos, J. 2015. Patterns of space use in sympatric marine colonial predators reveal scales of spatial partitioning. *Marine Ecology Progress Series.* 534, 235–249.

Klein, R. and Witbaard, R. 1993. The appearance of scars on the shell of Arctica islandica L. (mollusca, Bivalvia) and their relation to bottom trawl fishery. NIOZ-rapport, 1993(12). Nederlands Instituut voor Onderzoek der Zee: Den Burg. 28 p

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 Report No. 08/04.

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

Lockwood, S.L, and Lucassen, W. (1984). The recruitment of juvenile plaice (*Plueronectes platessa*) to their parent spawning stock. ICES Journal of Marine Science 41: 268-75.

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.
Marine Scotland Science (2012). Marine Protected Areas and sandeels (*Ammodytes marinus* & *A. tobianus*). Position paper for 4th MPA Workshop, Heriot-Watt University, 14-15 March 2012. Available at: http://www.scotland.gov.uk/Resource/0038/00389460.doc. [Accessed 22 January 2018]

Mason, J., (1957). The age and growth of the scallop, Pecten maximus (L.), in Manx waters. Journal of the Marine Biological Association of the United Kingdom, 36: 473-492.

Mason, J., (1983). Scallop and queen fisheries in the British Isles. Farnham: Fishing News Books.

Mazik, K., Strong, J., Little, S., Bhatia, N., Mander, L., Barnard, S. and Elliott, M. (2015). A review of the recovery potential and influencing factors of relevance to the management of habitats and species within Marine Protected Areas around Scotland. Scottish Natural Heritage Report No. 771 [online]. Available at: http://www.snh.org.uk/pdfs/publications/commissioned_reports/771.pdf [Accessed 20 September 2017].

Marine Scotland (2016). Large-scale features of functional significance [online] Available at: http://www.marine.gov.scot/information/large-scale-features-functional-significance [Accessed 9th November 2017]

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

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

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

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 (2009a). Agreement on coordinated environmental monitoring programme assessment criteria for the quality status report 2010. *Monitoring and Assessment Series*. OSPAR Agreement 2009-2002.

OSPAR Commission (2009b). Assessment of the impacts of shipping on the marine environment. *Monitoring and Assessment Series*. OSPAR Agreement 2009-2002.

OSPAR Commission (2009c). OSPAR Background for Ocean Quahog *Arctica islandica*. *Biodiversity series*. OSPAR Agreement 2009-2002.

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

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

Pearce, B., Grubb, L., Earnshaw, S., Pitts, J., Goodchild, R., (2014), Biotope Assignment of Grab Samples from Four Surveys Undertaken in 2011 Across Scotland's Seas (2012), JNCC Report 509

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.

Prime, J. H. and Hammond, P. S. 1990. The diet of grey seals from the southwestern North Sea assessed from analyses of hard parts found in faeces. *Journal of Applied Ecology*. 27. 435-447.

Ragnarsson S. Á., Thorarinsdóttir G.G., and Gunnarsson K. 2015 Short and long-term effects of hydraulic dredging on benthic communities and ocean quahog (*Arctica islandica*) populations. Marine Environmental Research 109, 113-123

Readman, J.A.J., (2016) [Flustra foliacea] and [Hydrallmania falcata] on tide-swept circalittoral mixed sediment. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [online]. Plymouth: Marine Biological Association of the United Kingdom. Available from: https://www.marlin.ac.uk/habitat/detail/74 [Accessed 06 February 2018]

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, [online]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/species/detail/2067 [Accessed 10 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: Linderboom, H.J. and de

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., 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., & 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.

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

Seagreen Wind Energy Limited (2010) Seagreen Phase 1 Scoping Report. Round 3: Firth of Forth [online] Available at: http://www.seagreenwindenergy.com/pdf/scoping-report.pdf [Accessed: 27 October 2017]

Seagreen Wind Energy Limited (2011) Seagreen Phases 2 & 3 Scoping Report. Round 3: Firth of Forth [online] Available at: http://www.seagreenwindenergy.com/assets/phase2-offshore/offshore-phase-2-report.pdf [Accessed: 27 October 2017]

Seagreen Wind Energy Limited (2017) [online] Available at: http://www.seagreenwindenergy.com/home.asp Last visited 14/09/2017 [Accessed: 27 October 2017]

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.

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.

Strategic Environmental Assessment (SEA) 3 (2016). UK Offshore Energy Strategic Environmental Assessment 3 (OESEA3). Available: https://www.gov.uk/government/consultations/uk-offshore-energy-strategic-environmental-assessment-3-oesea3 [Accessed: October 2017]

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.

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

Tillin, H.M., Hull, S.C., Tyler-Walters, H. (2010). Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network (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. & 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 Peterborough [online] Available at: http://jncc.defra.gov.uk/PDF/Report%20512-A_phase1_web.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.

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

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. (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.

Wright, P.J., Jensen, H. and Tuck, I. (2000). The influence of sediment type on the distribution of the lesser sandeel, *Ammodytes marinus*. Journal of Sea Research, 44: 243-56.

Zatsepin, V.I. and Filatova, Z.A. (1961). The bivalve mollusc *Cyprina islandica* (L). Its geographic distribution and role in the communities of benthic fauna. *Trans. Institute Oceanology Academy of Sciences USSR*, 46: 2-24.

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