Supplementary Advice on Conservation Objectives for South-West Deeps (West) Marine Conservation Zone

March 2018

JNCC

jncc.defra.gov.uk

Contents

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

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

The advice presented here describes the ecological characteristics or 'attributes' of the site's protected features: Subtidal coarse sediment, Subtidal sand, Subtidal mud, Subtidal mixed sediments, Fan mussel (*Atrina fragilis*) specified in the site's conservation objective. These attributes are: extent and distribution, structure and function and supporting processes.

Supplementary advice on the conservation objectives for the geomorphological feature: Celtic Sea Relict Sandbanks is not currently provided in this document. Further information regarding this feature can be found on the Site Information Centre or by contacting JNCC at OffshoreMPAs@jncc.gov.uk.

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

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

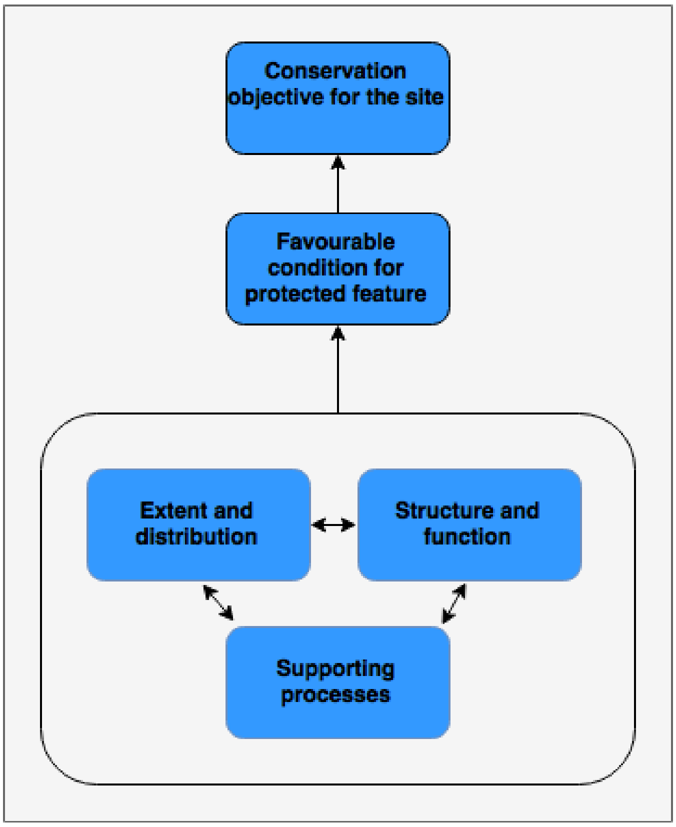

Figure 1. Conceptual diagram showing how a feature's attributes are interlinked and collectively describe favourable condition and contribute to the conservation objectives stated for the site.

In Table 1 below, the attributes for the broad-scale habitats (Subtidal coarse sediment, Subtidal sand, Subtidal mud and Subtidal mixed sediments) are listed and a description provided in explanatory notes. In Table 2 the attributes for the species FOCI Fan mussel (*Atrina fragilis*) are listed with descriptions in the explanatory notes. Please note the descriptions of Fan mussel attributes are considered DRAFT as information is currently under review by experts.

Please note our current understanding of whether the available evidence indicates that each attribute needs to be recovered or maintained is not provided. However, links to available evidence for the site are provided in the tables below and should you require further site-specific information on the attributes listed for the site's features, please contact JNCC at OffshoreMPAs@jncc.gov.uk.

Table 1: Supplementary advice on the conservation objectives for protected sedimentary broad-scale habitats (Subtidal coarse sediment, Subtidal sand, Subtidal mud and Subtidal mixed sediments) in South-West Deeps (West) MCZ

Attribute: Extent and distribution

Objective:

An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.

Explanatory notes

Extent refers to the total area in the site occupied by Subtidal sedimentary habitats and must include consideration of their distribution i.e. how spread out they are within a site. A reduction in extent has the potential to alter the biological and physical functioning of Subtidal sedimentary habitat types (Elliott *et al.,* 1998; Tillin and Tyler-Walters, 2014). The distribution of a habitat influences the component communities present, and can contribute to the health and resilience of the feature (JNCC, 2004). The extent of the Subtidal sedimentary habitats within the site must be conserved to their full known distribution.

Subtidal sedimentary habitats are defined by:

- ***Sediment composition*** (grain size and type) (e.g. Cooper *et al.,* 2011; Coates *et al.,* 2015; 2016; Coblentz *et al.,* 2015). Some species can inhabit all types of sediment, whereas others are restricted to specific types; and
- ***Biological assemblages*** - See JNCC's Marine Habitats Correlation Table for more detail about the range of biological communities (biotopes) that characterise Subtidal sedimentary habitats in the UK marine environment. In offshore environments, note that Subtidal sedimentary habitats are not typically dominated by algal communities.

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

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

- *A5.1 Subtidal coarse sediment* – Comprises of coarse sand, gravel, pebbles, shingle and cobbles. These sediments typically have low silt content and are characterised by robust fauna, including venerid bivalves (Connor *et al.,* 2004). The particle sizes of Subtidal coarse sediments are classed as more than 0.063 mm but predominantly contain grains sizes in excess of 2 mm (McBreen and Askew, 2011).
- *A5.2 Subtidal sand* – Comprises of clean medium to fine sands or non-cohesive slightly muddy sands. Such habitats are often subject to a degree of wave action or tidal currents which restrict the silt and clay content to less than 15%. This habitat is characterised by a range of taxa including polychaetes, bivalve molluscs and amphipods (Connor *et al.,* 2004). Subtidal sand is defined by the ratio of mud to sand being lower than 4:1, with particle sizes of less than 0.063 mm for mud and 0.063 mm to 2 mm for sand (McBreen and Askew, 2011).
- *A5.3 Subtidal mud* - Comprises of mud and cohesive sandy mud. This habitat is predominantly found in stable deeper/offshore areas where the reduced influence of wave action and/or tidal streams allow fine sediments to settle. These habitats are often dominated by polychaetes and echinoderms, such as *Amphiura* spp., sea-pens, such as the slender sea-pen (*Virgularia mirabilis*), and burrowing megafauna, such as the Norway lobster (*Nephrops norvegicus*) (Connor *et al.,* 2004), although polychaetes, sea spiders, molluscs, crustaceans and fish are also found. Bathymetry, current velocity, bottom water-mass distribution and particle size of the mud (clay, silty or sandy) have a significant influence on the distribution and composition of the seabed communities present. Subtidal mud is defined by a ratio of mud to sand being greater than 4:1, with particle sizes of less than 0.063 mm for mud and 0.063 mm to 2 mm for sand (McBreen and Askew, 2011). On the continental shelf, the Priority Marine Feature (PMF) Offshore deep-sea muds directly equates to the EUNIS habitat A5.3 Subtidal mud, but the PMF also covers deep-water examples that occur on or beyond the continental slope (Tyler-Walters *et al.,* 2016).
- *A5.4 Subtidal mixed sediments* – Comprises of mixed sediments found from extreme low water to deep, offshore circalittoral habitats. These habitats include a range of sediments, such as heterogeneous muddy gravelly sands and mosaics of cobbles and pebbles embedded in or lying upon sand, gravel or mud. Mixed sediments include mosaic habitats, such as superficial waves or ribbons of sand on a gravel bed or areas of lag deposits with cobbles/pebbles embedded in sand or mud and are less well defined, sometimes overlapping other habitat or biological subtypes. These habitats may support a wide range of infauna and epibionts, including polychaetes, bivalves, echinoderms, anemones, hydroids and bryozoans (Connor *et al.,* 2004). Subtidal mixed sediments are classed by a range sediment sizes, predominantly more than 0.063 mm, but mud may also be present (McBreen and Askew, 2011).

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

The designated broad-scale habitat features for this site are Subtidal coarse sediment, Subtidal sand, Subtidal mud and Subtidal mixed sediments. The extent and distribution of these features within the site is shown in the site map. For further site-specific information please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Structure and function

Objective:

An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.

Explanatory notes

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

Physical structure: Finer scale topography

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

Physical structure: Sediment composition

On the continental shelf, sediment composition is highly dependent on the prevailing hydrodynamic regime. Coarser sediments tend to dominate in high energy environments that are subject to strong prevailing currents. Conversely, finer sedimentary habitats are typically associated with lower energy environments. However, storm conditions can mobilise all sediment types, including the coarser fractions, most notably in shallower waters (Green *et al.,* 1995).

In deeper waters, bottom currents may impact sediment composition through erosional and depositional processes (Sayago-Gil *et al.,* 2010). The continental shelf edge and upper continental slope (>200 m) have been shown to be impacted by currents, influencing sediment composition by depositing finer particles in deeper waters (Hughes, 2014). Indeed, mud content can increase exponentially with depth as hydrodynamic influence is reduced (Bett, 2012).

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

Biological structure: Key and influential species

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

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

Biological structure: Characteristic communities

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

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

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

Similar to the biological structure of key and influential species, function 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).

Function

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

Ecosystem services that may be provided by Subtidal sedimentary habitats include:

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

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.

Structure and function of the feature within the site
For further site-specific information on the structure and function of the feature within the site, please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Supporting processes

Objective:

An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.

Explanatory notes

Subtidal sedimentary habitats and the communities they support rely on a range of natural processes to support function (ecological processes) and help any recovery from adverse impacts. For the site to fully deliver the conservation benefits set out in the statement on conservation benefits (hyperlink is provided in the box at the top of this document), the following natural supporting processes must remain largely unimpeded - Hydrodynamic regime and Water and sediment quality.

Hydrodynamic regime

Hydrodynamic regime refers to the speed and direction of currents, seabed shear stress and wave exposure. These mechanisms circulate food resources and propagules, as well as influence water properties by distributing dissolved oxygen, and facilitate gas exchange from the surface to the seabed (Chamberlain *et al.,* 2001; Biles *et al.,* 2003; Hiscock *et al.,* 2004; Dutertre *et al.,* 2012). Hydrodynamic regime also effects the movement, size and sorting of sediment particles. Shape and surface complexity within Subtidal sedimentary habitat types can be influenced by hydrographic processes, supporting the formation of topographic bedforms (see finer scale topography). Typically, the influence of hydrodynamic regime on Subtidal sedimentary habitats is less pronounced in deeper waters, although contour-following currents (e.g. on the continental slope) and occasional episodes of dynamic flows can occur (Gage, 2001).

Water and sediment quality

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

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

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

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

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

Water quality

The water quality properties that influence the communities living in or on Subtidal sedimentary habitats include salinity, pH, temperature, suspended particulate concentration, nutrient concentrations and dissolved oxygen. They can act alone or in combination to affect habitats and their communities in different ways, depending on species-specific tolerances. In fully offshore habitats, these parameters tend to be relatively more stable, particularly so for deeper waters, although there may be some natural seasonal variation. In deeper waters, dissolved oxygen levels are generally lower due to stratification of the water column and the isolation of bottom water masses (Greenwood *et al.,* 2010). Salinity also increases with depth, peaking about 50 m down, after which the salinity decreases with increasing depth to a minimum around 1000 m in North Atlantic waters (Talley, 2002).

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

Sediment quality

Various contaminants are known to affect the species that live in or on the surface of Subtidal sedimentary habitats. These include heavy metals like mercury, arsenic, zinc, nickel, chromium and cadmium, polyaromatic hydrocarbons, polychlorinated biphenyls, organotins (such as TBT) and pesticides (such as hexachlorobenzene). These metals and compounds can impact species sensitive to contaminants, degrading the community structure (e.g. heavy metals) and bioaccumulate within organisms thus entering the marine food chain (e.g. polychlorinated biphenyls) (OSPAR 2009; 2010; 2012). The biogeochemistry of mud habitats in particular is such that the effects of contaminants are greater (Sciberras *et al.,* 2016) leading in some cases to anoxic or intolerant conditions for several key and characterising species and resulting in a change to species composition. It is therefore important to ensure sediment quality is maintained by avoiding the introduction of contaminants and as a minimum ensure compliance with existing EQS as set out above, particularly in mud habitats.

Supporting processes for the feature within the site

For further site-specific information on the natural processes which support the feature within the site, please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Table 2: Draft Supplementary advice on the conservation objectives for Fan mussel (*Atrina fragilis*) in South-West Deeps (West) MCZ

Attribute: Extent and distribution
Objective: An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.
Explanatory notes Extent describes the occurrence of *Atrina fragilis* (herein referred to as Fan mussel), with distribution providing a more detailed overview of the species location(s) and pattern of occurrence within a site. The distribution of Fan mussels within a site is likely to consist of individuals found alone or in highly patchy small communities (Anon, 1999; ERCCIS, 2002; Hiscock *et al.,* 2005). It is important to conserve the full known extent and distribution of the Fan mussel population within a site, as well as the life history and environmental preferences of the species as this will have a strong influence on extent and distribution. Fan mussel is found predominantly off southern and western British coasts, as well as northern Scotland and offshore (Seaward, 1982; Hiscock *et al*., 2005). Although Fan mussel has never been recorded as abundant in the UK, the species is categorised as “nationally rare” since 1970 and “scarce” and “threatened” in UK waters (Solandt, 2003; Hiscock and Jones, 2004; Hiscock *et al*., 2005; JNCC, 2010). Due to the severe decline of Fan mussel populations in the UK and the relatively slow growth rates associated with the species (3-4 cm a year with an average life expectancy of twelve years), it is thought that the Fan mussel’s population extent and distribution within a site would be slow to recover from any loss (Anon, 1999; Solandt, 2003; Hiscock *et al*., 2005; Tyler-Walters *et al*., 2009). Scientific literature indicates that recovery of a population’s extent and distribution within a site is likely to be reliant on several factors: the degree of anthropogenic disturbance, an unpredictable supply of recruits from elsewhere (i.e. the Bay of Biscay and the Iberian Peninsula; Hiscock *et al.,* 2005), and the presence of suitable supporting habitat within the site (this include a range of sediment types from mud, sand and gravel sediments to clay substrates). Recovery would also be highly dependent on wider environmental parameters such as temperature. Further advice on these factors is provided under the structure and supporting processes attributes. ---

Extent and distribution of Fan mussel within the site

The extent and distribution of the feature within the site is shown in the site map. For further site-specific information please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Structure and function

Objective:

An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.

Explanatory notes

Structure

Structure refers to the densities and age classes of individuals from a population found within a site. The structure of Fan mussel populations is difficult to assess as although in the 19th century Fan mussel were a gregarious species in the UK often found in large populations (Jeffreys, 1863), more recent reports state that individuals are predominantly found alone or in highly patchy small communities (Anon, 1999; ERCCIS, 2002; Hiscock *et al.,* 2005). It is important that the number and age class of individuals within a site is conserved in the long-term to maintain the population.

The structure of Fan mussel populations tends to be highly skewed in UK waters, with populations containing mainly adults (Anon, 1999; ERCCIS, 2002; Hiscock *et al.,* 2005). This lack of juveniles has been attributed to the fact that UK waters act as a sink for Fan mussels, low fecundity, high larval mortality and the remoteness to other individuals (Marshall, 2002; Stirling, 2016). Despite low reproductive output, as the seas around the UK warm, it is expected that UK populations of Fan mussel may experience increased recruitment from the Iberian Peninsula resulting in a range extension (Hiscock *et al.* 2004; Hiscock, 2012). Recovery of the feature within a site is therefore likely to be increasingly reliant on an unpredictable supply of recruits from elsewhere and influenced by warming seas associated with climate change.

Fan mussels can grow up to 40 cm long at a growth rate of around 3 - 4 cm a year (Anon, 1999). This suggests that larger individuals are at least 12 years old (Solandt, 2003). As with many animals, the growth rate is fastest in young individuals (up to 3 years old), slowing in later years at the onset of sexual maturity (Richardson *et al.,* 1999). After damage, Fan mussels are able to regrow shell material at a rate of 1 cm a year (Yong and Thompson, 1976). However, this may be highly dependent on location (Solandt, 2003) and therefore shell length is not a reliable indicator of age for this species.

Recovery of Fan mussel populations to damage is hard to monitor and slow due to the relatively long-lived, slow-growing, low density, irregularly recruiting, high juvenile mortality and low fecundity of the species (Anon, 1999; Solandt, 2003; Hiscock *et al*., 2005; Tyler-Walters *et al*., 2009). For the UK, this is compounded by the fact that any recovery would also be expected to be dependent on a supply of recruits from elsewhere.

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 Fan mussel. These processes can occur at several temporal and spatial scales and help to maintain the provision of ecosystem services locally and to the wider marine environment (ETC,2011).

Ecosystem services that may be provided by a Fan mussel population include:

- Scientific study: The study of *Atrina* shells provides information about changes in sea temperatures in the mid-Piacenzian (c.3.3–3.0 Ma) (Valentine *et al.,* 2011);
- Regulatory processes: Providing a bentho-pelagic link by removing plankton and detritus from the water column;
- Ecosystem engineering: Fan mussels can provide habitats for benthic communities acting as a substrate for their settlement, increasing their diversity and providing safe areas from predators (Cummings *et al*., 1998; Fryganiotis *et al*., 2013). They can also promote the growth of species relevant to the fisheries sector. For example, juvenile Pectinids attached to *Atrina* shells (Hall-Spencer *et al*., 1999); and
- Climate change regulation: Fan mussels take up carbon from the environment during the process of shell growth (NRC, 2010).

Structure and function of the feature within the site

For further site-specific information on the structure and function of the feature within the site, please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

Attribute: Supporting processes

Objective:

An objective has not been set for this attribute. Links to available evidence are provided below. Please contact JNCC at OffshoreMPAs@jncc.gov.uk for further site-specific information on this attribute.

Explanatory notes

Fan mussel rely on a range of supporting natural processes to support function (ecological processes) and recovery from adverse impacts. Supporting processes can be physical, biological and chemical in nature (Alexander *et al.,* 2014). In the case of Fan mussel, it is unclear which of the supporting processes 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 larvae, 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). Consequently, the hydrodynamic regime is important for supporting Fan mussel feeding, growth and survival within a site.

Alterations to the natural movement of water and sediment within a site could affect the presence and distribution of Fan mussel, particularly given the reliance on larvae from the Bay of Biscay, France to re-stock populations in UK waters (Hiscock *et al.,* 2005). The natural movement of water and sediment within the site should therefore not be hindered.

Supporting habitat

The extent and distribution of supporting habitat plays an important role in determining the extent and distribution of the species. As a burrowing species, Fan mussel has been found in a range of sediments, from mud, sand and gravel sediments to clay substrates. The depth range occupied by the species is from mean low water spring to 400 m deep (Solandt, 2003), with higher densities found between 30 to 50 m (Fryganiotis *et al*., 2013). Fan mussel are thought to be highly sensitive to physical loss of habitat (Solandt, 2003; Hiscock and Jones, 2004; Hiscock et al., 2005; Tyler-Walters et al., 2009; Fryganiotis et al., 2013). It is therefore important to conserve the extent and distribution of supporting habitats within a site to provide the best chance of any potential settlement for new recruits and consequently conservation of its Fan mussel population.

Water and sediment quality

Fan mussel sensitivity to contaminants is poorly understood and consequently our confidence in sensitivity information is low. Fan mussel is not considered sensitive to contaminants at the Environmental Quality Standards (EQS) levels (Tyler-Walters and Sabatini, 2017). However, above EQS levels, some contaminants may impact the conservation status of Fan mussel depending on the nature of the contaminant (UKTAG, 2008; EA, 2014).

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

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

- Marine Environmental and Assessment National Database (MERMAN);
- 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).

Fan mussel is sensitive to changes in several water quality parameters. 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 water quality properties that influence Fan mussel conservation status include salinity, pH, temperature, suspended particulate concentration, nutrient concentrations and dissolved oxygen (Anon,1999; Hiscock and Jones, 2004 and Tyler-Walters and Sabatini, 2017). These parameters can act alone or in combination to affect Fan mussel 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 (Gray and Elliot, 2009).

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. Many uncertainties exist in predicting our future climate and the impacts on habitats and species (EC, 2013). It is therefore important to conserve the natural temperature regime of the water column as far as is practicable against wider environmental pressures.

Fan mussels are not considered sensitive to organic and inorganic pollutants (Tyler-Walters and Sabatini, 2017). JNCC advise that aqueous contaminants should be restricted to comply with water column annual average limits according to the amended EQS 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.

Supporting processes for the feature within the site
For further site-specific information on the natural processes which support the feature within the site, please see the Site Information Centre.

For information on activities capable of affecting the protected features of the site, please see the Advice on Operations workbook (hyperlink is provided in the box at the top of this document).

References

Alexander, D., Colcombe, A., Chambers, C. and Herbert, R.J.H. (2014). Conceptual Ecological Modelling of Shallow Sublittoral Coarse Sediment Habitats to Inform Indicator Selection. JNCC Report No. 520, Peterborough [online]. Available at: http://eprints.bournemouth.ac.uk/22354/1/Conceptual%20Model%20Shallow%20Sublittoral%20Coarse%20Sediment%202014.pdf [Accessed 20 September 2017].

Anonymous (1999). *Atrina fragilis* (a fan shell). Species Action Plan. In UK Biodiversity Group. Tranche 2 Action Plans. English Nature for the UK Biodiversity Group: Peterborough.

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

Best, M.A., Wither, A.W. and Coates, S. (2007). Dissolved oxygen as a physico-chemical supporting element 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. and Raffaelli, G. (2003). Flow modifies the effect of biodiversity on ecosystem functioning: an in-situ study of estuarine sediments. *Journal of Experimental Marine Biology and Ecology*, 285: 165-177.

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].

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.

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].

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

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

Cummings, V.J., Thrush, S.F., Hewitt, J.E. and Turner, S.J. (1998).The influence of the Pinnid bivalve *Atrina zelandica* on benthic macroinvertebrate communities in soft-sediment habitats. *Journal of Experimental Marine Biology and Ecology*, 228: 227–240.

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

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

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

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 2017].

European Commission (EC) (2013). Guidelines on climate change and Natura 2000: Dealing with the impact of climate change on the management of the Natura 2000 Network of areas of high biodiversity value. Technical Report 068 [online]. Available at: http://ec.europa.eu/environment/nature/climatechange/pdf/Guidance%20document.pdf [Accessed 4 December 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 [online]. Available at: https://circabc.europa.eu/sd/a/2c12cea2-f827-4bdb-bb56-3731c9fd8b40/Art17%20-%20Guidelines-final.pdf [Accessed 20 September 2017].

Environmental Records Centre of Cornwall and the Scilly Isles (2002). Available at: http://erccis.org.uk/ [Accessed 22 December 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].

Fryganiotis, K., Antoniadou, C. and Chintiroglou, C. (2013). Comparative distribution of the fan mussel *Atrina fragilis* (Bivalvia, Pinnidae) in protected and trawled areas of the north Aegean Sea (Thermaikos Gulf). *Mediterranean Marine Science*, 14: 119-124.

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

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

Green, M.O., Vincent, C.E., McCave, I.N., Dickson, R.R., Rees, J.M. and 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. and 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.

Hall-Spencer, J.M., Froglia, D., Atkinson, R.J.A. and Moore, P.G. (1999). The impact of Rapido trawling for scallops, *Pecten jacobaeus* (L.), on the benthos of the Gulf of Venice. *ICES Journal of Marine Science: Journal du Conseil*, 56 (1): 111-124.

Hiscock, K. and Jones, H. (2004). Testing criteria for assessing 'national importance' of marine species, biotopes (habitats) and landscapes. Report to Joint Nature Conservation Committee from the Marine Life Information Network (MarLIN). Plymouth: Marine Biological Association of the UK.

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.

Hiscock, K., Sewell, J. and Oakley, J. (2005). Marine Health Check. A report to gauge the health of the UK's sea-life. Godalming, WWF-UK.

Hiscock, K., Bayley, D., Pade, N., Lacey, C., Cox, E. and Enever, R. (2012). Prioritizing action for recovery and conservation of marine species: a case study based on species of conservation importance around England. *Aquatic conservation: marine and freshwater ecosystems.* 23: 88-110.
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.

Jeffreys, J.G. (1863). British Conchology, (vol. 2 – Marine Shells) London.

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

Joint Nature Conservation Committee (JNCC) (2010). UK priority species data collection *Atrina fragilis.* Joint Nature Conservation Committee, Peterborough [online]. Available at: http://jncc.defra.gov.uk/_speciespages/123.pdf [Accessed 23 March 2015].

Jones, E., McConnell, B., Sparling, C. and Matthiopoulos, J. (2013). Grey and harbour seal density maps. Sea Mammal Research Unit to Marine Scotland Report [online]. Available at: http://www.scotland.gov.uk/Resource/0041/00416981.pdf [Accessed 20 September 2017].

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.

Marshall D.J. (2002). In situ measures of spawning synchrony and fertilization success in an intertidal, free-spawning invertebrate. *Marine Ecology Progress Series*, 236: 113-119.

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].

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

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.

National Research Council (NRC) (2010). Ecosystem Concepts for Sustainable Bivalve Mariculture. Washington, DC: The National Academies Press.
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.

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

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

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

Richardson, C.A., Kennedy, H., Duarte, C.M., Kennedy, D.P. and Proud, S.V. (1999). Age and growth of the fan mussel (*Pinna nobilis*) from south east Spanish Mediterranean seagrass (*Posidonia oceanica*) meadows. *Marine Biology*, 133: 205-212.

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.

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

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.

Seaward, D.R. (1982). Sea area atlas of the marine molluscs of Britain and Ireland. London, Nature Conservancy Council.

Solandt, J.L. (2003). Fan Mussel (*Atrina fragilis*) current status. UK Biodiversity Group. Tranche 2 Action Plans, Maritime species and habitats. 5: 1-63.

Stirling, D., Boulcott, P., Scott, B.E. and Wright, P. (2016). Using verifies species distribution models to inform the conservation of a rare marine species. *Diversity and Distributions,* 22: 808-822.

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.

Tillin, H.M., Hull, S.C. and Tyler-Walters, H. (2010). Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network. Plymouth: Marine Biological Association of the UK. Defra Contract No. MB0102 Task 3A, Report No. 22 [online]. Available at: http://www.marlin.ac.uk/assets/pdf/MB0102_Task3-PublishedReport.pdf [Accessed 10 October 2017].

Tillin, H.M. and Tyler-Walters, H. (2014). Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities: Phase 2 Report – Literature review and sensitivity assessments for ecological groups for circalittoral and offshore Level 5 biotopes. JNCC Report No. 512B [online]. Available at: http://jncc.defra.gov.uk/PDF/Report%20512-A_phase1_web.pdf [Accessed 10 October 2017].

Tyler-Walters, H., Stuart, I.R., Marshall, C.E. and Hiscock, K. (2009). A method to assess the sensitivity of sedimentary communities to fishing activities. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 19: 285-300.

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

Tyler-Walters, H. and Wilding, C.M. (2017). *Atrina fragilis* Fan mussel. In: Tyler-Walters, H. and Hiscock, K. (eds). Marine Life Information Network: Biology and Sensitivity Key Information Reviews [online]. Available at: http://www.marlin.ac.uk/species/detail/1157 [Accessed 22 December 2017].

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

Valentine, A., Johnson, A.L.A., Leng, M.J., Sloane, H.J. and Balson, P.S. (2011). Isotopic evidence of cool winter conditions in the mid-Piacenzian (Pliocene) of the southern North Sea Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 309: 9-16.

Yong, C.M. and Thompson, T.E. (1976). Living Marine Molluscs. William Collins and Sons and Co.