Marine
Management
Organisation

Stage 3 Fishing Gear MPA Impacts Evidence: Bottom Towed Gear

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Contents

Executive Summary

This document collates and analyses the best available evidence on the impacts of bottom towed fishing gears on MPA features and will inform site level assessments of the impact of bottom towed gear on MPAs as part of Stage 3 of the MMO's work to manage fishing in MPAs.

Bottom towed gears have the potential to impact MPA features, therefore management of these fishing gears is likely required. For each MPA, a site level assessment considering the site conservation objectives, intensity of fishing activity taking place and exposure to natural disturbance will be completed to determine whether management will be required.

1 Introduction

The Marine Management Organisation (MMO) is the principal regulator for England's seas, including leading the assessment and management of fishing for marine protected areas (MPAs) offshore of 6 nautical miles (nm)[1].

This document forms part of MMO's Stage 3 work to achieve the government's aim of having appropriate fisheries management measures in place for all offshore MPAs in English waters by the end of 2024. It is one of a suite of documents which focus on the interaction of fishing gear on particular designated features, and it will support the delivery of site-level assessments.

This document describes the impact of bottom towed gear on protected habitats and species (i.e. designated features). It describes the potential for pressures and impacts caused by bottom towed gear on designated features within MPAs by gathering and analysing the available evidence for gear-feature interactions.

The Stage 3 Call for Evidence Introduction provides further background information and details of other documents produced.

1.1 Key definitions

A separate glossary in the Stage 3 Call for Evidence Introduction includes the important terms used in this document. Wherever possible these are taken from Natural England's Glossary of terms used within conservation advice packages (CAPs).

The following terms are particularly important when reading this document and are described further in Figure 1.

Designated Feature ('feature') - A species, habitat, geological or geomorphological entity for which an MPA is identified and managed.

Sensitivity – The sensitivity of a feature (species or habitat) is a measure that is dependent on the ability of the feature (species or habitat) to resist change and its ability (time taken) to recover from change.

Pressure - the mechanisms through which an activity has an effect on a feature.

Impact - the consequence of pressures (such as habitat degradation) where a change occurs that is different to that expected under natural conditions.

[1] Inshore fisheries and conservation authorities (IFCAs) are responsible for managing fishing within 6 nm.

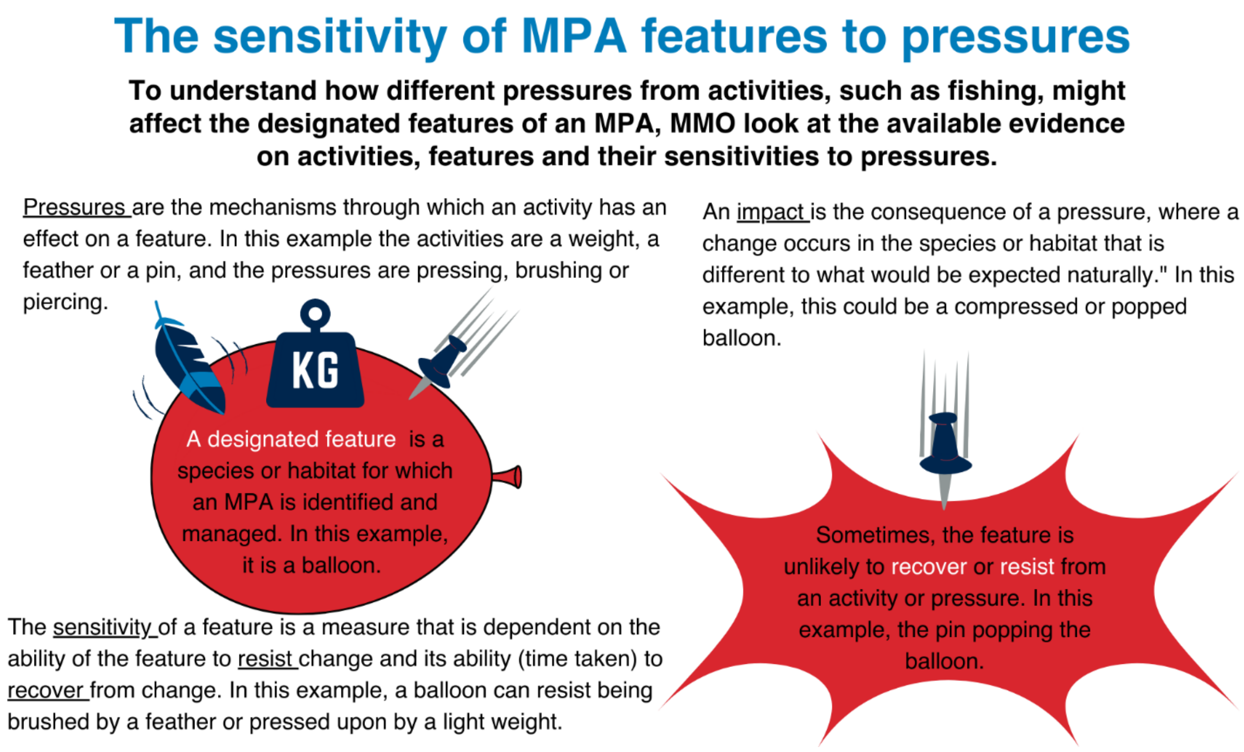

Figure 1. The sensitivity of MPA features to pressures.

1.2 Structure of this document

Section 2 describes the types of fishing gears considered in this document.

Section 3 lists the MPA features considered and references the evidence sources used in this document.

Sections 4 to 8 describe the available evidence of the pressures resulting from the fishing gears on different MPA features. Each section also describes evidence about the sensitivity of each feature to damage and how resilient it is (how quickly a feature can recover).

Annex 1 lists pressures which are common to all features. Any feature-specific pressures with insufficient evidence are listed in the relevant section.

2 Overview of gear group: bottom towed gear

This section describes the different types of fishing gear which are considered in this document under the broad group of ‘bottom towed gear’.

Bottom towed fishing gear means any trawls, seines, dredges or similar gear, including trawls towed on or very close to the seabed, which are actively moved in the water by one or more fishing vessels or by any other mechanised system and in which any part of the gear is designed and rigged to operate on, and be in contact with, the seabed.

In this document bottom towed gear includes the following fishing gear types:

- dredges: boat dredges, mechanized dredges
- demersal seines: Danish or anchor seines, pair seines, Scottish seines
- bottom trawls: otter trawls, beam trawls, nephrops trawls, pair trawls, twin trawls and semi-pelagic trawls.

Each has a different effect on the seabed, and analysis of the impact of these gears will take these differences into account.

Further information regarding different fishing gear types can be found at: http://www.fao.org/3/cb4966en/cb4966en.pdf

2.1 Description

When pulled across the seabed, various parts of a demersal towed gear can cause penetration, abrasion, or disturbance of the seabed surface substrate. Evidence of the impacts of towed gears varies depending on the gear type, particularly gear penetration depth (Sciberras et al., 2018).

The interaction of bottom towed gears, especially dredges, with the seabed and ambient water can result in regions of high velocity, high bed shear stress and possibly a fluidised bed (Sewell and Hiscock, 2005; O'Neill and Summerbell, 2011). This may contribute to entrainment of sediment around and behind the gear, which is then dispersed in a cloud, creating a suspension with a vertical profile that depends on the turbulence and the particle settling velocities (O'Neill and Summerbell, 2011). The sediment gradually settles as turbulence reduces. The degree of suspension and settlement of sediments varies between the gear types used and the type of substrate.

The quantity of suspended material and its spatial and temporal persistence will depend on factors associated with the gear (such as type/design, weight, towing speed), the sediment (particle size, composition, compactness) (Sewell et al., 2007), the intensity of the activity and the background hydrographic conditions (Kaiser et al., 2002; Dale et al., 2011; O'Neill and Summerbell, 2011). Prolonged exposure to the pressure may result in changes in sediment composition through suspension and transport of finer material.

Danish and Scottish seines have lighter ground gear than trawls. The area of seabed affected mainly depends on the length of the ropes used and the sea depth and is therefore much smaller than the area affected by trawling (Buhl-Mortensen et al., 2013). The biggest impact is from the ropes, when they are pulled together in the first phase of the operation. Since this kind of fishing is dependent on the ropes not getting caught on obstacles during the herding phase, there are clear limitations on the sediment types where it can be used. The potential to cause damage is probably much smaller than for bottom trawling, since there are no trawl doors, the ground gear is lighter, and the seine is not dragged long distances. However, the ropes may have a physical impact similar to that of the sweeps of a trawl (Buhl-Mortensen et al., 2013).

3 MPA features

This section identifies features which have been identified as potentially sensitive to bottom towed fishing gear. Table 1 references out to descriptions of the features from a recognised source. These sensitivities were derived using advice from the Joint Nature Conservation Committee (JNCC) and Natural England and review of the available scientific literature. Please see Annex 1 for a summary of the pressures of bottom towed gear on the features described in this document and their associated sensitivities.

Table 1. Feature Descriptions

Feature Name	Feature Description (website link)
Sea-pen and burrowing megafauna communities	JNCC: Seapens and burrowing megafauna in circalittoral fine mud MarLIN: Seapens and burrowing megafauna in circalittoral fine mud
Fan mussel	MarLIN: Fan mussel (*Atrina fragilis*)
Ocean quahog	MarLIN: Ocean quahog (*Arctica islandica*)
Rocky reef	EUNIS: Atlantic and Mediterranean moderate energy circalittoral rock EUNIS: Atlantic and Mediterranean high energy circalittoral rock EUNIS: Circalittoral rock and other hard substrata JNCC: Annex I reef JNCC: Circalittoral rock (and other hard substrata) JNCC: High energy circalittoral rock JNCC: Moderate energy circalittoral rock
Biogenic reef (*Sabellaria spp.*)	JNCC: Annex I reef JNCC: Reefs MarLIN: Ross worm (*Sabellaria spinulosa*) MarLIN: Honeycomb worm (*Sabellaria alveolata*) OSPAR Commission: *Sabellaria spinulosa* reefs
Annex I sandbanks[2] and MCZ sediment[3]	EUNIS: Subtidal coarse sediment EUNIS: Subtidal sand EUNIS: Subtidal mud EUNIS: Subtidal mixed sediment

[2] Annex I Sandbanks which are slightly covered by sea water all the time
[3] Marine conservation zone subtidal sediment habitats include: subtidal coarse sediment, subtidal sand, subtidal mixed sediments, subtidal mud.

Feature Name	Feature Description (website link)
	JNCC: Sandbanks which are slightly covered by sea water all the time

Annex 1 provides tables summarising which features are affected by different bottom towed gear types. Where a feature is potentially sensitive to bottom towed gear (based on its resilience to the pressure and ability to recover) the interaction is considered in sections 4 to 8 below. Each section lists the relevant pressures to which the features are sensitive. It also lists those pressures where insufficient evidence has been found to indicate whether it is sensitive/not sensitive.

4 Sea-pen and burrowing megafauna communities

This section brings together and analyses the available evidence on how bottom towed gear affects sea-pen and burrowing megafauna communities.

Sea-pen and burrowing megafauna communities have been identified by OSPAR as a habitat of key conservation importance as defined under Annex V of the 1992 OSPAR Convention (OSPAR, 1992; OSPAR Commission, 2010) and are protected in UK waters by various legislation. They are a designated feature of the following offshore marine conservation zones (MCZs): East of Haig Fras (JNCC, 2021a), Farnes East (JNCC, 2017), Greater Haig Fras (JNCC, 2018a), North West of Jones Bank (JNCC, 2018b) and West of Walney (JNCC, 2018e; Natural England and JNCC, 2018).

The habitat is defined using the OSPAR definition (OSPAR Commission, 2021): ‘Plains of fine mud, at water depths ranging from 15 to 200 m or more, which are heavily bioturbated by burrowing megafauna with burrows and mounds typically forming a prominent feature of the sediment surface. The habitat may include conspicuous populations of sea-pens, typically *Virgularia mirabilis* and *Pennatula phosphorea*. The burrowing crustaceans present may include *Nephrops norvegicus*, *Calocaris macandreae* or *Callianassa subterranea*. In the deeper fjordic lochs which are protected by an entrance sill, the tall seapen *Funiculina quadrangularis* may also be present. The burrowing activity of megafauna creates a complex habitat, providing deep oxygen penetration. This habitat occurs extensively in sheltered basins of fjords, sea lochs, voes and in deeper offshore waters such as the North Sea and Irish Sea basins.’

Although they occur in the same muddy habitats, sea-pen and burrowing megafauna communities are functionally and ecologically different and are not necessarily associated with one another (Hill et al., 2020). Sites with this feature may have an abundance of burrowing megafauna but lack sea-pens (Hill et al., 2020). It is possible that this may be due to environmental factors or because of human pressures. Some forms of sampling may fail to indicate the presence of sea-pens where they have been visually recorded via other methods, so it could be possible that sea-pens occur more frequently than research suggests (Hill et al., 2020). There is no single keystone species essential to the feature or the community (Hill et al., 2020), but burrowing megafauna are an essential element of the habitat.

The evidence base for all relevant gear interactions with this feature is not extensive and uncertainty exists around its sensitivity to fisheries impacts.

4.1 Overview of the sensitivity of sea-pen and burrowing megafauna communities to bottom towed gear

4.1.1 Sensitivity – resistance to damage

This feature is considered highly vulnerable to physical disturbance to the seabed or mechanical damage from demersal fishing gear because the gear has the potential to damage the feature's fragile components such as sea-pens, can change benthic community structure and function, and resuspend sediment particles (OSPAR Commission, 2010; Gonzalez-Mirelis and Buhl-Mortensen, 2015).

Dinmore et al. (2003) stated that large, slow-growing species such as sea-pens are particularly vulnerable to trawling. Sea-pens are more sensitive to removal by penetrative gear, as it can entirely remove animals from their burrows (Hill et al., 2020). The Marine Life Information Network (MarLIN) has therefore assessed resistance as 'Low' for all three sea-pen species commonly found in this feature (*V. mirabilis, F. quadrangularis* and *P. phosphorea*) (Hill et al., 2020). For definitions of resistance (tolerance), resilience (recovery) and sensitivity rankings from the Marine Evidence based Sensitivity Assessment (MarESA) (Tyler-Walters et al., 2018), see the glossary in the Stage 3 Call for Evidence Introduction.

Many species of sea-pens such as *V. mirabilis* and *P. phosphorea* can withdraw into tubes in the sediment (Hoare and Wilson, 1977; Ambroso et al., 2013). It has been hypothesised, therefore, that they may be able to avoid approaching demersal fishing gears (Hughes, 1998). It should be noted, however, that the penetration depths of demersal gears in mud habitats can vary from 3 to 6 cm (Gubbay and Knapman, 1999), and for otter trawl doors from ≤15 to 35 cm (Eigaard et al., 2016). Also, sea-pen behavioural observations have only noted that individuals can withdraw completely below the sediment surface without specifying depth or speed. It is also unclear whether this withdrawal could be triggered by approaching gear as this behaviour is not well understood (Ambroso et al., 2013). Their withdrawal has been described as rhythmic and unsynchronised (Langton et al., 1990). Numerous studies also hypothesise that their ability to withdraw makes measuring sea-pen abundance extremely difficult (Birkeland, 1974; Eno et al., 2001; Greathead et al., 2007, 2011). It should be noted that the sea-pen *F. quadrangularis* cannot withdraw into the sediment (Hill et al., 2020).

Some species of burrowing megafauna may be able to avoid demersal fishing gears by burrowing beneath the sediment surface. For example, *N. norvegicus* form burrows in the sediment of 20 to 30 cm depth (Aguzzi and Sardà, 2008). Despite this ability, there is still a successful targeted fishery. This is because *N. norvegicus* is a burrowing crustacean with behavioural adaptations to ambient light (Ball et al., 2000). Burrow emergence is highest at dawn and dusk in shallower grounds, and gets closer to midday in deeper waters (Chapman, 1980). Fishing effort is targeted to exploit this behaviour, increase catch rates, and minimise gear avoidance. Generally, larger, slow-growing burrowing megafauna are more vulnerable to demersal fishing gear than smaller individuals that are pushed aside with fluidised sediments rather than damaged (Dinmore et al., 2003).

A review on the response of benthic fauna to experimental demersal fishing found that a gear pass reduced benthic invertebrate abundance by 26% and species richness by 19%, indicating that many species are sensitive (Sciberras et al., 2018). The United Nations General Assembly (United Nations General Assembly, 2006) defines sea-pen and burrowing megafauna communities as sensitive habitats that 'are easily adversely affected by human activity and/or if affected are expected only to recover over a very long period, or not at all'. The Sciberras review demonstrated that reductions in abundance and species richness were highly dependent on specific gear type, habitat type and the site's history of fishing disturbance. More penetrative gears, such as hydraulic dredges, had a significantly larger impact than those that penetrate less. Habitats with a higher percentage content of mud saw greater reductions in community abundance than those with lower mud content, and abundance also decreased more in historically undisturbed areas compared to previously disturbed areas (Sciberras et al., 2018).

4.1.2 Recovery – rate of recovery

Recovery from damaging activities will depend on the intensity and frequency of the impact and the recruitment processes of a species. Literature on the recruitment processes of sea-pens remains limited. Hughes, (1998) suggested that they are characterised by patchy recruitment, slow growth and long lifespans. Greathead et al. (2007) also described sea-pens as having a patchy site distribution likely related to patchy larval settlement processes. Habitats formed by slow growing and long-lived specimens such as hydroids, corals (Troffe et al., 2005) or sea-pens are highly sensitive to pressures associated with fishing, suggesting that even with a reduced level of effort, fishing activity could cause considerable damage and prevent habitat recovery (Greathead et al., 2015).

Sites that are more intensely impacted (for example, through penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion) or frequently disturbed are likely to take longer to recover than those with less damaging pressures (for example, abrasion or disturbance of the substrate on the surface of the seabed) or less disturbance.

The recovery rates of burrowing megafauna such as *N. norvegicus* will also depend on the spatial scale of impact and the recruitment processes of the species. Time to sexual maturity for *N. norvegicus* is 2.5 to 3 years and larval stages spend about 50 days as plankton, allowing for high potential dispersal (Hill et al., 2020). Post-settled individuals show limited migration capacity (Rice and Chapman, 1971) however and are habitat limited due to their substrate requirements (Ungfors et al., 2013). This means that well-defined boundaries exist for *N. norvegicus* fisheries. The *N. norvegicus* component of the feature may therefore have a medium resilience to disturbance (likely recovering within 2 to 10 years, as defined by MarESA (Tyler-Walters et al., 2018)), depending on the scale of removal at each site (Hill et al., 2020).

Evidence from fishing grounds shows that populations of *N. norvegicus* can persist in areas where they are targeted for removal, suggesting a reasonable level of resilience against repeated disturbance. However, due to a lack of historical population data it is unclear how much of the population is removed and therefore how populations would recover if disturbance was completely removed (Hill et al., 2020).

Sciberras et al., (2018) found that sessile and low mobility benthic fauna with longer lifespans took longer to recover after demersal fishing (>3 years, categorised by MarESA as a medium recovery rate (Tyler-Walters et al., 2018)) than mobile species with shorter lifespans (<1 year, categorised by MarESA as a high recovery rate (Tyler-Walters et al., 2018)). This is partly because mobile groups like polychaetes have high intrinsic rates of growth, but could also be because gastropod, malacostracan and ophiuroid species are able to migrate quickly and colonise areas.

4.2 Level of literature, caveats and assumptions

There is limited literature available on fishing gear interactions with sea-pen and burrowing megafauna communities, and in the UK the research is primarily conducted in the Irish Sea. The majority of research available on active fishing gears considers the impact of demersal trawls and dredges. These are likely to have considerably greater impacts to this feature due to the increased abrasion and penetration these gears have when compared with demersal seines. In a comprehensive review of the impacts of fisheries on sediments and benthic fauna, no studies were found to document the physical impact of demersal seines (Buhl-Mortensen et al., 2013), however, the overriding principles are likely to be similar for demersal seines albeit to a lesser degree.

Sea-pen and burrowing megafauna communities tend to occur within sedimentary MCZ features. This is the case for all the MCZs listed in section 4. They typically inhabit mud biotopes that fall under EUNIS habitat A5.3: sublittoral mud (EEA, 2019c; Hill et al., 2020). Therefore, where feature-specific literature is unavailable, this review will refer to section 8, where the specific pathways through which bottom towed gear types may pressure Annex I sandbanks which are slightly covered by sea water all the time and MCZ subtidal sediment habitats are discussed.

4.3 The pressures of bottom towed gear on sea-pen and burrowing megafauna communities

As a result of bottom towed gear, this feature may be sensitive to the following pressures, so they are considered in this document:

- abrasion or disturbance of the substrate on the surface of the seabed
- penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
- removal of non-target species
- removal of target species (this is not classed as sensitive, but we have been advised by JNCC and Natural England that it may be relevant at the site level).

There is insufficient evidence available to determine whether this feature is sensitive to the following pressures as a result of the use of bottom towed gear:

- hydrocarbon and PAH contamination
- Introduction or spread of invasive non-indigenous species
- litter
- synthetic compound contamination
- transition elements and organo-metal contamination.

4.3.1 Abrasion or disturbance of the substrate on the surface of the seabed

Bottom trawls

Bottom trawling can cause chronic and widespread disturbance to the seabed in shallow shelf seas and could lead to changes in the trophic structure and function of benthic communities. Studies evaluating trawling disturbance on the biodiversity of mud dominated sediments revealed a reduced species diversity and a shift in trophic structure in the most exploited fishing areas (Jennings et al., 2001; Blanchard et al., 2004; Vergnon and Blanchard, 2006). Sewell and Hiscock, (2005) point out that areas which have been intensively trawled for several years still support profitable fisheries which would not be possible without ample benthic food. It has therefore been suggested that it is likely that the benthic community in these areas has shifted towards a dominance of highly productive, opportunistic species such as polychaetes (Jennings and Kaiser, 1998; Rijnsdorp et al., 1998). Such a shift in community structure could cause significant changes to the sea-pen and burrowing megafauna feature because the mud-dominated sediments where it normally occurs are predominately found in sheltered areas with reduced wave action, which tend to be dominated by slower growing species. This has important implications for the processing of primary production in shallow coastal areas and the wider functioning of the marine ecosystem.

The findings from various studies on the sensitivity of sea-pen and burrowing megafauna communities have been brought together in a review by Hughes, (1998). Hughes (1998) suggested that this feature exhibits a mosaic of patches of megafaunal communities depending on the level of disturbance. In trawled areas, it is likely that the density of *N. norvegicus* has been reduced but Hughes, (1998) determined that most stocks have the potential to recover even after heavy fishing pressure. *N. norvegicus* individuals are able to escape direct impact from surface abrasion by digging tubular burrows into the sediment of 20 to 30 cm depth (Aguzzi and Sardà, 2008). The openings of *N. norvegicus* burrows are likely to be damaged by abrasion. However, Marrs et al. (1998) reported that burrows were re-established within 2 days providing that the occupant had remained unharmed. The anthropogenic factors that may affect sea-pen distribution it is likely that physical disturbance from demersal fishing activities will have the greatest influence, especially for *F. quadrangularis* (Hughes, 1998).

An experimental study found that trawl caught *N. norvegicus* females were reported to have fewer eggs on average than creel caught females from the same area, it was postulated that eggs may be lost due to physical abrasion (Chapman and Ballantyne, 1980). The proportion of eggs lost to abrasion ranged from 11 to 22% in samples taken from the Clyde and West of Kintyre (Chapman and Ballantyne, 1980).

4.3.2 Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion

Bottom Trawls

Eigaard et al. (2016) conducted a review of literature to estimate the penetration depths of bottom towed gears on different sediments (see Table 4 of section 8). On muddy substrates otter trawl door penetration ranged between ≤15 and 35 cm (Eigaard et al., 2016). This variation in penetration depth was explained by differences in towing speed, size, weight, rigging of gear, and regional differences in fisheries tradition. Most notably, the maximum penetration depth of bottom towed gear on muddy sediments in UK waters was 15 cm by otter trawl doors. Experiments from the review where penetration exceeded 15 cm were from the Mediterranean or from a Norwegian fjord.

When fished over fine muddy sediments the otter trawl doors are sometimes fitted with metal shoes up to 30 cm wide which are designed to prevent the boards digging too far into the sediment (Jennings and Kaiser, 1998). Krost et al. (1990) estimated that otter boards penetrated soft mud to a depth of 15 cm in the Baltic Sea. This suggests that characterising megafauna, such as *N. norvegicus* could avoid being impacted by penetration, disturbance or abrasion below the surface of the seabed because their burrows tend to have a maximum depth of 20 to 30 cm. However, Howson and Davies (1991) found that the burrow density of *N. norvegicus* was lower in frequently trawled areas of Loch Fyne except in areas protected from trawling by submarine obstructions.

Bergman and Van Santbrink (2000) studied the direct mortality of benthic fauna caused by commercial trawling in the North Sea. The study found otter trawling in silty areas to cause lower mortality rates of burrowing species (for example, bivalves and crustaceans) than beam trawling. It was theorised that this was likely due to the sediment being disturbed to a lesser depth by the ground rope and bridles of the otter trawl gear than the beam trawl, although depths were not specified. In the review by Eigaard et al. (2016) the penetration depth of otter trawl sweeps and bridles was found to be 0 cm, and of the ground gear to be 0 to 10 cm, whilst the penetration depth of beam trawl shoes was ≤5 to 10 cm and tickler chains was ≤10 cm, indicating similar penetration depths between gears.

Johnson (2002) noted that chronic trawling resulted in a decreased abundance and biomass of sedentary macrofauna and decreased diversity. These conclusions were also found by Vergnon and Blanchard (2006) who noted that species diversity was lower in the areas most exploited by trawling. Jennings et al. (2001) and Kaiser (2014) found that chronic beam trawling (6.5 times per year) in an area of the North Sea characterised by muddy sand at 55 to 75 m depth led to significant declines in infaunal productivity and biomass. However, less frequent beam trawling (2.3 times per year) in an area of the North Sea characterised by sand at 40 to 65 m depth had no significant effect on infauna. This suggests that beam trawling over deeper, more stable habitats has longer term effects on benthic communities. Tuck et al. (1998) studied trawling efforts in a previously untrawled muddy area and changes were still apparent after 18 months. It may also suggest that beam trawling at frequencies of less than 3 times per year over shallower and more stable habitats, may not have adverse, long-term effects on benthic communities in sandy habitats (Jennings et al., 2001; Kaiser, 2014). Kaiser et al. (2006) also found negative, short-term impacts of beam trawling on benthic taxa in both muddy sand and sand habitats. It should be noted however that beam trawls are not the preferred gear to be used on mud-dominated substratum as they would sink (Kaiser et al., 2006).

Areas unfished for *N. norvegicus* were found to have a higher species diversity, numbers of individual organisms and biomass than fished areas: 49 species were recorded from unfished areas as opposed to 19 at fished sites (Ball et al., 2000). Large specimens of several molluscs and echinoderms were found to be present at unfished but not at fished sites.

Trawls used to catch *N. norvegicus* on muddy sediments may cause extensive damage to erect epifauna such as sea-pen and burrowing anemones (Sewell and Hiscock, 2005). Sea-pens are sensitive to mechanical damage by *Nephrops* trawling, in particular *F. quadrangularis* due to the brittle nature of its axial rod and inability to retract into the sediment (Greathead et al., 2007). Although *V. mirabilis* and *P. phosphorea* can withdraw into the sediment, they will not be able to avoid activities that penetrate into the sediment. Assuming their burrows are only deep enough to hold the entire animal (Greathead et al., 2007), then V. mirabilis burrows are up to 40 cm deep while *P. phosphorea* burrows are only up to 25 cm. *F. quadrangularis* can grow up to 150 cm in height above the sediment surface but cannot withdraw into a burrow. Some species of sea-pens have flexible axial rods, and are able to re-anchor in the sediment when dislodged (Malecha and

Stone, 2009), however the long-term success of injured or dislodged sea-pens can be relatively low because mobility can be limited and species-specific (Kenchington et al., 2011).

Dredging

In their global meta-analysis of experimental bottom fishing, Sciberras et al. (2018) found that dredges penetrate deeper into sediments in general than other types of bottom towed gear. However, when Pranovi et al. (2000) investigated the impact of rapido gear with a box dredge on a muddy inshore substrate, they reported that the gear only disturbed the upper 6 cm of sediment. A preliminary study by Giovanardi et al. (1998) also showed that in a muddy area, the rapido gear penetrated into the sediment and produced a furrow 5 to 7 cm deep. It should be noted, however, that rapido gear is currently only used in the Mediterranean.

In a global analysis of the response and recovery of benthic biota to fishing, the biota of soft-sediment habitats, in particular muddy sands, were particularly vulnerable, with predicted recovery times measured in years (Kaiser et al., 2006). Following dredging, predatory mobile species such as fish, crabs and starfish have been found to be attracted to the dredge tracks by carrion within one hour of dredging at densities up to 30 times greater than in areas outside the tracks (Maguire et al., 2002). The selective removal of sensitive species (for example, *Callianassa subterranea*) and proliferation of predators such as starfish or crabs may lead to shifts in burrowing megafauna community structure and permanent modification of the substratum in these dredge tracks (Veale et al., 2000).

Dredging and suction dredging penetrate to greater depths (for example, 3 to 10 cm into the seabed for scallop dredges (Stewart and Howarth, 2016)) than demersal trawling and are likely to remove sea-pens (Tuck et al., 1998). In a study by Hoare and Wilson (Hoare and Wilson, 1977), sea-pens removed by dredges were invariably damaged (Hoare and Wilson, 1977). Scallop dredging may significantly reduce the number of species, number of individuals and lower biomass of macrofauna (Pranovi et al., 2000). Indeed, the greatest amount of mortality is left on the seabed rather than occurring as bycatch (Jenkins et al., 2001).

4.3.3 Removal of target species

A major fishery exists for *N. norvegicus*, which is a characterising species of the sea-pen and burrowing megafauna communities feature (Hill et al., 2020). It is fished throughout most of the geographic range of the biotopes in which it occurs (Hill et al., 2020), and over 95% of the *N. norvegicus* caught in Europe are taken using targeted single or multi-rig trawlers or in mixed species fisheries (Ungfors et al., 2013). The physical effects of bottom towed gear on seabed communities are addressed in sections 4.3.1 and 4.3.2. This pressure addresses the direct removal or harvesting of biota. Ecological consequences of this include the sustainability of populations, impacting energy flows through food webs and the size and age composition within populations. Economic concerns include the sustainability of fish stocks, which can also be used as an indicator of population sustainability as much of the population data collected will be via fish stock assessments.

N. norvegicus are opportunistic feeders that primarily consume crustaceans, molluscs and to a lesser extent polychaetes and echinoderms (Parslow-Williams et al., 2001). They are preyed upon by numerous bottom-feeding white fish including cod, haddock, skate and dogfish (Hill et al., 2020). They also support a variety of non-commercial species (including *Lesueurigobius friesii, Cycliophoran Symbion pandora, Balanus crenatus, Triticella koreni, Electra pilosa, Eudendrium capillare, Sabella pavonine* and *Serpula vermicularis*) by providing habitat either within their burrows or on themselves (Sabatini and Hill, 2008). Unsustainable removal of *N. norvegicus* could therefore have an impact on the populations of these species.

Male *N. norvegicus* are consistently landed by trawls in larger numbers than females, although sex ratio does vary (Ungfors et al., 2013). This is likely because egg-bearing females are more prone to remain in their burrows for months at a time and in laboratory conditions, large males are less inclined to make burrows (Sabatini and Hill, 2008; Ungfors et al., 2013). Unsustainable removal could impact the size and age composition of *N. norvegicus* stocks.

In trawled areas, it is likely that the density of *N. norvegicus* has been reduced but literature suggests that most stocks have the potential to recover (Hughes, 1998) so JNCC's and Natural England's Advice on Operations has classed the feature as not sensitive to the ecological effects of this pressure (Annex 1). JNCC and Natural England have advised, however, that it should still be considered at this stage because the pressure could pose a risk at a site level. Currently, the abundance and distribution of these communities is mostly limited to the information on *N. norvegicus* from surveys contributing to ICES stock assessments. Overviews of the status of stocks for each MPA may be presented at the site level assessment stage as a proxy for population health.

4.3.4 Removal of non-target species

Bottom Trawls

Sea-pens are not targeted by commercial or recreational fisheries but may be damaged or removed as bycatch. Benthic trawls (for example, rock hopper ground gear, otter trawls) will remove and capture sea-pens with limited efficiency (Kenchington et al., 2011; Hill et al., 2020). Kenchington et al. (2011) estimated the gear efficiency of otter trawls for sea-pens (*Anthoptilum* and *Pennatula*) to be in the range of 3.7 to 8.2%, based on estimates of sea-pen biomass from (non-destructive) towed camera surveys. Gear efficiency relates true population size to fishing mortality expressed at catch per unit effort. Murillo et al. (2011) reported sea-pens (*pennatulaceans*) in 36% of 910 research vessel survey tows in the Northwest Atlantic.

However, the ability to withdraw mentioned in section 4.1.1 suggests that sea-pens may be able to avoid approaching demersal trawls and fishing gear. This was suggested as the explanation for the similarity in the densities of *V. mirabilis* in trawled and untrawled sites in Loch Fyne, and the lack of change in sea-pen density observed after experimental trawling (using modified rock hopper ground gear) over an 18 month period in Loch Gareloch (Howson and Davies, 1991; Hughes, 1998; Tuck et al., 1998).

A study by Murillo et al. (2016) in the Northwest Atlantic found that species richness of deep (> 500 m) mud communities (including the sea-pens *F. quadrangularis* and *Anthoptilum grandiflorum*) was negatively correlated with bottom trawling intensity. Buhl-Mortensen et al. (2016) reported similar findings in the southern Barents Sea, where 70 of the area’s 97 most common taxa (including *F. quadrangularis*) were negatively correlated with bottom trawling intensity. Greathead et al. (2011) hypothesised that the sea-pen *F. quadrangularis* was largely absent from Fladen fishing grounds in the northern North Sea, not only due to its patchy distribution but also because of the area’s fishing activities. Comparative studies by Engel and Kvitek (1998), and Hixon and Tissot (2007) also found significantly lower sea-pen density in areas of high trawling intensity, suggesting that sea-pens are unable to recover from persistent fishing pressure.

Loss of the sea-pens would change the biological character of the designated feature (Hill et al., 2020). Habitats dominated by large sessile fauna may be severely affected by trawling disturbance (Løkkeborg, 2005). The indirect impacts of bottom trawling have greater impacts to larger benthic species such as sea-pens that are particularly vulnerable to trawling disturbance, while smaller individuals and species suffer lower mortality rates (Dinmore et al., 2003). Trawling may reduce benthic community biomass and biodiversity, and shift the assemblage composition towards short-lived, smaller species due to taxonomic differences in direct mortality and recovery rates (Jennings et al., 2005; Tillin et al., 2006).

During field studies into the mortality of non-target epibenthic invertebrates and undersized flatfishes frequently caught in North Sea fisheries, the mortality of discarded species was measured and compared for different types of commercial beam trawls (12 m, 4 m, and 4 m with chain matrix) and for otter trawls (Lindeboom and de Groot 1998). It was found that 10% of *N. norvegicus* brought aboard by 4 m commercial beam trawls with a chain matrix were already dead (immediate discard mortality) (Lindeboom and de Groot 1998). From the high mortality of all invertebrate species studied (7 to 45%), the authors suggested that commercial bottom trawling alters benthic community composition (Lindeboom and de Groot 1998).

Removal of species has the potential to affect the spatial distribution of subtidal mud and sand communities, change the presence and abundance of typical species and change the species composition of component communities (NWIFCA, 2017). An organism's vulnerability to fishing activity depends on its physical characteristics (hard or soft bodied), its mobility (mobile or sessile) and its habitat (infaunal or epifaunal) (Mercaldo-Allen and Goldberg, 2011). Larger bodied, slow moving, fragile organisms are most vulnerable (Kaiser and Spencer, 1996). The effects of trawling can have different impacts upon organisms with different methods of feeding; otter trawling had the greatest impact on suspension feeders in mud and sand habitats (Kaiser et al., 2006).

Dredges

Determining the full effects of dredging remains difficult, as most fishing grounds have been exploited for decades, long before scientific study began (Stewart and Howarth, 2016). Some studies have found little change in the abundance and biodiversity between dredged and undredged sites (for example, O'Neill et al., 2013), whereas others report a significant reduction in infaunal biomass (for example, Kaiser et al., 2000). Pranovi et al. (2000) also found adverse effects to infaunal polychaetes and amphipods.

4.4 Variation in impacts

The sensitivity and recovery rates of habitats and species can vary depending on several factors including the fishing intensity (Hughes, 1998; Jennings et al., 2001; Kaiser, 2014); gear type (Buhl-Mortensen et al., 2013); sediment composition (Greathead et al., 2015); sediment stability (Kaiser et al., 1998); exposure to natural disturbance (Dernie et al., 2003); and the biological community structure (Sewell and Hiscock, 2005). Foden et al. (2010) used vessel monitoring system (VMS) data to estimate the distribution and intensity of benthic fishing in the UK and found that the recovery time of habitats was determined by gear width, gear penetration, fishing frequency and sediment grain size. Fishing intensity across the UK varied considerably between habitat types, being lowest in sand and highest in mud (Foden et al., 2010). In 2007, at an average fishing intensity for benthic gear types, mud habitats appeared to fully recover, whereas muddy sand habitats were fished at frequencies in excess of estimated recovery periods (Foden et al., 2010). It should be noted, however, that this review was unable to estimate recovery times for beam trawling or for scallop dredging in mud.

The comprehensive reviews by Collie et al. (2000) and Kaiser et al. (2006) showed how mortality imposed by the passage of a trawl is habitat specific and differs between benthic species groups and types of trawl gear. Collie et al2000) found that fauna in stable mud habitats were more adversely affected than those in coarse sediments. Kaiser and Spencer (1996) concluded that mortality effects from beam trawling may be related to hydrodynamic conditions and species ability to withstand disturbance.

Over a 60 year period, Bradshaw et al. (2002) found that the amount of change in the benthic community was related to how long a site had been fished, rather than actual fishing intensity. Mobile, robust and scavenging taxa had increased in abundance, while slow-moving or sessile, fragile taxa had decreased.

Recovery rates depend on recruitment of new individuals, growth of surviving biota, and active immigration from adjacent habitat. Most existing estimates of recovery rates come from experimental studies, with changes in abundance recorded before and after experimental trawling (Collie et al., 2000; Kaiser et al., 2006). The various characterising species of the sea-pen and burrowing megafauna community will also have different biological characteristics and recruitment rates. Sea-pens likely have patchy recruitment, slow growth and long lifespans (Hughes, 1998). *N. norvegicus* takes 2.5 to 3 years to reach sexual maturity and larval stages spend about 50 days as plankton, allowing for high potential dispersal (Hill et al., 2020).

General studies have found that long-living, sessile and suspension feeding organisms, such as sea-pens, show the greatest declines in response to a given type and frequency of trawl disturbance, while opportunistic species, for example, short-living polychaetes, are less affected (Kaiser et al., 2002).

Kaiser et al. (1998) assessed changes which had taken place to megafaunal benthic communities from two different habitats (one with stable sediments and a rich fauna; the other with mobile sediment and a relatively impoverished fauna), six months after beam trawling had taken place. Immediately after fishing, the stable sediment community was significantly altered: the abundance of some species had decreased (for example, the sea mouse *Aphrodita aculeata*), while others had apparently increased (for example, the hermit crab *Pagurus bernhardus*), although there was considerable variation between samples. This suggested the effects of trawling were not uniform. For the mobile sediment, no effects of trawling were apparent. After six months, the effects of any trawling disturbance, on either habitat, were no longer evident. This suggests that communities inhabiting more stable, mud-dominated, sediments are more heavily impacted by trawling.

The feature ‘sea-pen and burrowing megafauna communities’ can be comprised of the following biotopes: sea-pen and burrowing megafauna in circalittoral fine mud (and its sub-biotope: sea-pens, including *Funiculina quadrangularis*, and burrowing megafauna in undisturbed circalittoral fine mud); burrowing megafauna *Maxmuelleria lankesteri* in circalittoral mud; *Brissopsis lyrifera* and *Amphiura chiajei* in circalittoral mud; and *Atrina fragilis* and echinoderms on circalittoral mud. These biotopes all have slightly different characterising species and therefore different sensitivities to various pressures. These variations will be addressed during site level assessments.

4.5 Summary of the effects of bottom towed gear on sea-pen and burrowing megafauna communities

Bottom towed gears have the potential to impact sea-pen and burrowing megafauna communities, therefore management of these fishing gears is likely required for MPAs designated for this feature. For each MPA, a site level assessment considering the site conservation objectives, intensity of fishing activity taking place and exposure to natural disturbance will be needed to determine whether management will be required.

The site level assessment will assess fishing activities for their impact upon protected habitats and species (in this case, the relevant biotopes for sea-pen and burrowing megafauna communities). Specifically, this assessment will consider the potential for these activities to hinder the conservation objectives of the MCZ. The data used in the assessment will include VMS data, as well as feature habitat data from JNCC and Natural England. Where the assessment concludes that the current level of management is not sufficient to protect the designated features of the site, recommended management options will be provided. MMO has regard to the best available evidence and through consultation with relevant advisors, stakeholders, and the public, will conclude which management option is implemented.

Due to the evidence of impacts from bottom towed gear on this feature, management should consider prohibition of bottom towed gears in specified areas of MPAs where this feature occurs.

In recognition of the potential pressures of bottom towed fishing gear (particularly trawling and scallop dredging) upon designated features and their supporting habitats, the Southern IFCA is currently undergoing the process of introducing permanent bottom towed fishing gear closure areas to protect sea-pen and burrowing megafauna communities and subtidal muds in the Bembridge MCZ.

5 Fan mussel

This section brings together and analyses the available evidence on how bottom towed gear affects fan mussels.

Fan mussel (*Atrina fragilis,* family: *Pinnidae*) is a designated feature of the following MCZs: East of Haig Fras (JNCC, 2021a), South of Isles of Scilly (JNCC, 2021d) and South West Deeps (West) (JNCC, 2018d).

Fan mussel is distributed throughout UK continental shelf waters (Tyler-Walters and Wilding, 2022), particularly in deep waters around the Shetland Isles and Orkney, the west coast of Scotland, possibly the north-east of Scotland, the south coast of England (particularly around Cornwall), the Channel Isles, Pembrokeshire and Northern Ireland (Solandt, 2003; Tyler-Walters and Wilding, 2022).

In the UK, fan mussel is often found as solitary individuals, but can also occur as small groups or patches of individuals forming small beds (Tyler-Walters and Wilding, 2022). This species is generally found in mud, sandy mud and fine gravel habitats, particularly in full salinity sheltered areas with weak to moderately strong tidal flows (Tyler-Walters and Wilding, 2022). Their distribution has been linked to several environmental variables including depth, seabed topography, current speed, and percentage of mud and gravel (Stirling, 2016).

5.1 Overview of the sensitivity of fan mussel to bottom towed gear

5.1.1 Sensitivity – resistance to damage

Fan mussel has thin and brittle shells (Tyler-Walters and Wilding, 2022), making them very fragile and sensitive to physical and mechanical damage. Fishing gears can consequently damage the portions of the shell that protrude into the water column and, if the fishing gears (such as scallop dredges) penetrate the seabed, such gears can also damage the portions of shell embedded in the sediment (Fryganiotis et al., 2013; Stirling, 2016). Fan mussel may be able to adapt to such damage by withdrawing into the remaining undamaged shell whilst the damaged shell is repaired at a rate of approximately 1 cm per year (Solandt, 2003). Post-larval pinnids have small shells (1 to 2 cm) that are easily damaged and weakly attached to the substrate (Stirling, 2016). Being partly buried in the sediment, fan mussel is also sensitive to being dislodged and removed from the substrate (Stirling, 2016). Individuals are unable to re-burrow themselves following a disturbance incident (Hiscock and Jones, 2004). Whole populations may be removed if sediment is removed to a depth of 30 cm (Tyler-Walters and Wilding, 2022).

5.1.2 Recovery – rate of recovery

Fan mussel recoverability may be limited by their life history characteristics (Tyler-Walters and Wilding, 2017) . Long lifespans, slow growth, low gamete production and sporadic recruitment reduces their ability to recover from damage, displacement, or mortality (Hiscock and Jones, 2004; UK Biodiversity Group, 1999). There is however still a major lack of information on fan mussel life history which adds to the degree of caution that needs to be taken when assessing the recoverability of the species as a whole.

Larval dispersal may be limited or irregular (Tyler-Walters and Wilding, 2022) and larvae mortality is likely to be high (Stirling, 2016) possibly due to an infrequency of suitable conditions (UK Biodiversity Group, 1999). Fan mussel recruitment is likely poorer and more variable than other bivalve species (UK Biodiversity Group, 1999), however recruitment levels may be higher at locations with inlets and embayments where larvae are entrapped. With patchy, low-density populations, fertilisation is also likely to be inefficient (Tyler-Walters and Wilding, 2022).

Pinnids have fast shell growth rates relative to other bivalves (Stirling, 2016); however, growth rates are likely slower for sexually mature individuals, which must put energetic resources into gonad development rather than shell accretion. Shell growth rates will also vary with location, water temperature, and availability of food supply (Solandt, 2003; Tyler-Walters and Wilding, 2022). An under-recording of the species in deep waters suggests that the species may be more prevalent in deeper waters than previously realised, and thus deep-waters may provide a potential reservoir for recruitment; however, there is no evidence to support this (Tyler-Walters and Wilding, 2022).

Slow recovery rates may be a contributing factor to the decline of fan mussel in UK inshore waters over the last hundred years (Solandt, 2003; Tyler-Walters and Wilding, 2022). In summary, the recruitment and recovery of fan mussel is likely to be prolonged and may take up to 25 years in the UK where populations are sparsely distributed (Tyler-Walters and Wilding, 2022). The species is categorized as having low resilience to any loss of population or 'very low' resilience to severe declines in population abundance (Tyler-Walters and Wilding, 2022).

5.2 Level of literature, caveats and assumptions

Biological and distribution data for fan mussel is generally limited (Fryganiotis et al., 2013; Stirling, 2016), however information about suitable habitats is available so assumptions can be made about potential impacts to this species in certain areas. There is limited evidence regarding fishing impacts specific to fan mussel and therefore evidence from other species within the Pinnidae family has been cautiously considered in some cases. It should however be noted that there is no true proxy species for fan mussel and that species considered in the Pinnidae family occur in different a climate to England.

The majority of evidence on the impacts of bottom towed fishing gear to fan mussel is regarding dredging and demersal trawling, with no evidence on demersal seine and semi-pelagic gear. It is assumed that demersal seines and semi-pelagic gear does not penetrate deep enough into sediment to remove individuals, but some damage may occur through abrasion (Eigaard et al., 2016).

5.3 The pressures of bottom towed gear on fan mussel

As a result of bottom towed gear, this feature may be sensitive to the following pressures, so they are considered in this document:

- abrasion or disturbance of the substrate on the surface of the seabed
- penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
- smothering and siltation rate changes
- removal of non-target species

There is insufficient evidence available to determine whether this feature is sensitive to the following pressures as a result of the use of bottom towed gear:

- hydrocarbon and PAH contamination
- introduction or spread of invasive non-indigenous species
- introduction of microbial pathogens
- litter
- organic enrichment
- synthetic compound contamination
- transition elements and organo-metal contamination

5.3.1 Abrasion or disturbance of the substrate on the surface of the seabed and penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion

Demersal and semi-pelagic trawls, dredges and demersal seines

These pressures are grouped together to avoid repetition, due to the similar nature of their impacts on the species. Fan mussel typically live in the sublittoral fringe, in subtidal mud, sandy mud or gravel habitats (Tyler-Walters and Wilding, 2022). The specific pathways through which bottom towed gear types may cause abrasion and penetration pressures above or below the surface on Annex I sandbanks which are slightly covered by sea water all the time and MCZ subtidal sediment habitats are discussed within section 8.

Up to 70% of the shell lengths of fan mussel can be buried below the surface of sediments, with the posterior portion projecting above, making fan mussel sensitive to gear types which interact with the seabed, particularly dredges (UK Biodiversity Group, 1999). Despite fan mussel being able to withdraw into their shells and repair damage to the posterior edge of the shell, they cannot survive being uprooted from the seabed (UK Biodiversity Group, 1999). These impacts are discussed further within section 5.3.2.

5.3.2 Removal of non-target species

Fragile infaunal species which live on or within the surface sediments (such as bivalves, holothurians, gastropods) are particularly sensitive to damage or disturbance (Kaiser and Spencer, 1996). If removed from the sediment, for example by bottom towed gear, *Atrina sp.* are unable to re-burrow into the substrate. Despite being able to burrow vertically they cannot right themselves if removed from the sediment and laid on their sides (Yonge, 1953 cited in Tyler-Walters and Wilding, 2017).

Fan mussel has a fragile shell which is thought to be easily damaged by anchor impact or trampling (Tyler-Walters and Wilding, 2022), suggesting bottom towed gear may have similar impacts. Conversely, the mantle and ctenidia of fan mussel can be withdrawn into the shell and a damaged edge of the shell repairs quickly (Solandt, 2003; Yonge, 1953 cited in Tyler-Walters and Wilding, 2017). This could potentially reduce the sensitivity of the species to damage from bottom towed gear, although there is likely to be a considerable biological cost of repairing the shell, especially if the shell is repeatedly damaged.

Fan mussel is known to be negatively affected by the use of benthic fishing gear as it can dislodge or remove individuals, cause damage to emergent portions of the shell and potentially cause mortality (Fryganiotis et al., 2013, Stirling, 2016). Furthermore, fan mussel is a slow growing, erect epifauna with slow recoverability and is assessed to have high sensitivity to bottom towed mobile gear (Tyler-Walters et al., 2009).

Fan mussel is likely to have a ‘very low’ resilience and ‘high’ sensitivity to removal by a fishery that does not target it, and a ‘low’ resilience and ‘medium’ sensitivity to abrasion pressures (Tyler-Walters and Wilding, 2022).

Demersal trawls and dredges

Fan mussel was thought to have been more common in scallop areas in the early 1900s compared to the present (Tyler-Walters and Wilding, 2022). This suggests scallop dredging and trawling may have an impact on the abundance of this species. Most recent fan mussel specimens have been found in areas adjacent to dredged scallop beds or in areas seldom dredged (UK Biodiversity Group, 1999). Anecdotal evidence reports fragments of fan mussel shells being collected by scallop trawlers and large individuals being caught in the Celtic Sea in the 1970s (Solandt, 2003; Tyler-Walters and Wilding, 2022). Fan mussel is reported to incur damage from scallop trawling through the fishing and sorting process (Hall-Spencer et al., 1999; Pranovi et al., 2001 cited in Tyler-Walters and Wilding, 2017). Although it is not a gear type commonly used in English waters, rapido trawls for scallops in the Gulf of Venice were recorded to remove organisms from the top 2 cm of the sediment, with fan mussel removed and speared by trawl teeth, leading to an 87% reduction in fan mussel abundance (Hall-Spencer et al., 1999).

At a site off the coast of Northern Ireland where fan mussel was previously found, evidence of dredging was reported which may link to the absence of the species in subsequent surveys (Goodwin and Picton, 2011). Similarly, a fan mussel population off Glengad Head, Ireland, which was not subjected to dredging before 1975, is thought to have been destroyed by dredging, with live specimens and shells being found in scallop dredges (UK Biodiversity Group, 1999).

A study in the Adriatic Sea reported a much lower density of fan mussel in trawled areas, at approximately 0.03 individuals/km compared to approximately 5.5 individuals/km in an area where bottom trawling had been prohibited for 25 years (Fryganiotis et al., 2013). Anecdotal evidence from divers also suggests the presence of fan mussel in areas where trawling and dredging cannot take place, for example, where there are areas of high currents, steep sloping seabed or narrow and deep stretches of water (Solandt, 2003 cited in Mazik et al., 2015).

Demersal seines and semi-pelagic gear

No evidence is available for the impacts of demersal seines and semi-pelagic trawls towards fan mussel via removal of non-target species. The lack of records of fan mussel catches for these gear types suggests that they do not typically penetrate deep enough into the sediment to remove individuals (Eigaard et al., 2016). However, it cannot be assumed that demersal seines and semi-pelagic gear do not cause any damage to fan mussel as these gear types are towed on or close to the seabed.

5.3.3 Smothering and siltation rate changes

Demersal and semi-pelagic trawls, dredges and demersal seines

Fan mussel typically lives in the sublittoral fringe, in subtidal mud, sandy mud or gravel habitats (Tyler-Walters and Wilding, 2022). The specific pathways through which bottom towed gear types may cause changes in suspended solids or siltation rate changes are discussed in section 8.

The seabed type will determine the amount of fine material re-suspended by fishing gear: those with higher mud fractions will generate more than those which are naturally ‘cleaner’. There is limited evidence on impacts of siltation rate changes on fan mussel. In general, sediment plumes resulting from bottom towed gear will reduce light levels reaching the substrate, release nutrients and possible pollutants into the water column, and increase the total suspended sediment load (Jones, 1992). Deposition of suspended sediments may cause smothering of feeding and respiratory organs of sessile benthos (Jones, 1992; Kaiser et al., 2002).

Species within the family Pinnidae, like fan mussel, are adapted to sedimentary lifestyles and have ciliated waste canals to remove sediment from the mantle cavity (Yonge, 1953 cited in Tyler-Walters and Wilding, 2017). One third to one half of a fan mussel can protrude above the sediment surface (up to 10 to 15 cm for adults) which means that adult individuals may not be affected by smothering of up to 5 cm of fine sediment (Tyler-Walters and Wilding, 2022). However, small or juvenile individuals may be smothered by this amount of sediment and cases of higher sediment loads (i.e. 30 cm) are also likely to smother adult individuals (Tyler-Walters and Wilding, 2022). Additionally, increased siltation results in a higher metabolic demand, leading to a likely decrease in growth and reproductive capacity (Yonge, 1953 cited in Tyler-Walters and Wilding, 2017).

Pinna sp. are known to be absent from areas of severe sediments disturbance where only siphonate, infaunal bivalves occur (Butler et al., 1993). It is likely that *Atrina* species are well adapted to sedimentary habitats and occasional resuspension of sediments due to storms (Tyler-Walters and Wilding, 2022). Short term (i.e. 3 days) increases in suspended sediment are likely to result in a loss of condition but not mortality, however, increases in turbidity, for example from ‘clear’ to ‘intermediate’ (100 to 300 $mg.L^{-1}$) or turbid (>300 $mg.L^{-1}$) for a period of a year may be detrimental to this species (Tyler-Walters and Wilding, 2022).

Fan mussel are assessed to have ‘low’ resilience and ‘medium’ sensitivity to smothering and siltation rate changes (Tyler-Walters and Wilding, 2022). The impact of this pressure will depend on the intensity of bottom towed gear use and the proximity to fan mussel.

5.4 Variation in impacts

The potential impacts of bottom towed gear on benthic species such as fan mussel may vary with fishing activity, including gear type, the presence of different gear components, fishing intensity and the history of prior fishing (Hiddink et al., 2006; Lambert et al., 2017; Sciberras et al., 2018; Rijnsdorp et al., 2020). Given that fan mussel are unable to re-burrow once removed from the sediment (Tyler-Walters and Wilding, 2022), penetration depth, which can vary with gear type (Sciberras et al., 2018), may be a key factor influencing mortality. Sand and gravel habitats with long-lived bivalves were found to be more sensitive to high and medium levels of bottom towed gear fishing activity compared to low intensity or single passes (Eno et al., 2013).

A range of environmental variables may also influence the potential impacts of bottom towed fishing on fan mussel. Sensitivity of species and trawling impacts may depend on levels of natural disturbance and sediment mobility (Hiddink et al., 2006; Hall et al., 2008), as habitats with higher tidal velocity are usually associated with benthic communities with faster recovery rates, potentially making species in dynamic environments more resilient to fishing impacts (Lambert et al., 2014; Sciberras et al., 2018).

Fan mussel has been reported to occur in areas with weak to moderately strong currents and may be exposed to peak current speeds >1 $m.s^{-1}$ (Stirling, 2016). The distribution of fan mussel is linked to several environmental parameters (including depth and substrate type), which may in turn influence spatial overlap between the species and different fisheries (Stirling, 2016). The potential impacts of bottom towed gear may also vary with seabed topography as fan mussel may have refuge from fishing impacts in areas where the seabed is complex, as such topography precludes bottom towed fishing if the risk of losing gear is unacceptably high (Stirling, 2016). Growth rates of fan mussel (and thus potentially recovery from abrasion impacts) could also vary with location, temperature, and food supply (Solandt, 2003; Tyler-Walters and Wilding, 2022).

The ecology and life history of fan mussel may also influence potential impacts from bottom towed gear. As a sessile benthic species (Stirling, 2016), the spatial overlap between fishing activity and the distribution and abundance of fan mussel populations will clearly influence pathways for impact. The life history stage could influence recoverability. Growth rates for juveniles are much faster than for sexually mature individuals, which must put energetic resources into gonad development rather than shell accretion (Solandt, 2003; Tyler-Walters and Wilding, 2022); consequently, adults may have more limited recoverability from abrasion or damage to shells. Juveniles can also be smothered by a lower amount of sediment than adults (Tyler-Walters and Wilding, 2022). Recoverability from disturbance or population mortality will also be influenced by population density, with sparser populations having lower fertilisation efficiency (Tyler-Walters and Wilding, 2022).

Despite the potential variation in impacts set out above, all direct evidence shows that fan mussel is highly sensitive to the physical impacts of bottom towed gear.

5.5 Summary of the effects of bottom towed gear on fan mussel

Bottom towed gears have the potential to impact fan mussel, therefore management of these fishing gears is likely required for MPAs designated for this feature. For each MPA, a site level assessment considering the fishing activities taking place and site conservation objectives will be needed to determine whether management will be required.

The site level assessment will assess fishing activities for their impact upon protected habitats and species. Specifically, this assessment considers the potential for these activities to hinder the conservation objectives of the MCZ. The data used in the assessment will include vessel monitoring system (VMS) data, as well as feature habitat data from Natural England and JNCC. Where the assessment concludes that the current level of management is not sufficient to protect the designated features of the site, recommended management options will be provided. MMO has regard to the best available evidence and through consultation with relevant advisors, stakeholders, and the public, will conclude which management option is implemented.

Due to the evidence of impacts from bottom towed gear on this feature, site level management may consider prohibition of bottom towed gears in specified areas of MPAs where this feature occurs.

6 Ocean quahog

This section brings together and analyses the available evidence on how bottom towed gear affects ocean quahog.

Ocean quahog (*Arctica islandica*) is a long-lived bivalve mollusc found throughout the continental shelf area of English waters, as well as offshore. Ocean quahog is a designated feature of the following MCZs: North East of Farnes Deep (JNCC, 2018c), Fulmar (JNCC, 2021b), Holderness Offshore (JNCC, 2021c) and Farnes East (JNCC, 2017).

Ocean quahog is designated as a species of conservation importance in English and Welsh waters and has been recorded from the Baltic, Iceland, the Faroe Islands and throughout the continental shelf of the North Atlantic (Witbaard and Bergman, 2003). The depths at which it can be found range from the low intertidal zone at 4 to 480 m, but most commonly between 10 to 280 m (Holmes et al., 2003). Ocean quahog is known to occur in waters with salinity of 16 to 40 practical salinity units and temperatures of 6 °C to 16 °C, although experiments have recorded tolerance of up to 20 °C for a limited period of time (Oeschger and Storey, 1993; OSPAR, 2009; Tyler-Walters and Sabatini, 2017). The last remaining extant species of the family Arctidae (Morton, 2011), ocean quahog is considered the longest living non-colonial animal and is capable of living for centuries.

Commercial fisheries for ocean quahog operate off the coasts of Iceland and the United States, however no commercial fisheries exist for ocean quahog in Europe (Ridgway et al., 2012).

6.1 Overview of the sensitivity of ocean quahog to bottom towed gear

6.1.1 Sensitivity – resistance to damage

A long generation time of approximately 83 years (Hennen, 2015), slow growth rate in adults, variable age and size at maturity, and unpredictable recruitment success (owing to variable environmental factors, a long planktonic larval stage and low rates of juvenile survival), mean that ocean quahog is particularly sensitive to pressures exerted by fishing activity (OSPAR Commission, 2009). Additionally, population structure can be skewed, with some areas being dominated by adults and others by juveniles (AquaSense, 2001).

MarLIN has assessed the species as having varying resilience depending on location and amount of mortality. If a population has experienced significant mortality, then a precautionary resistance of ‘Very Low’ is recorded, as recovery is likely to take more than ten years, or potentially in excess of 25 years (for example in the North Sea; Witbaard and Bergman, 2003). If a population has only suffered some mortality, then the species is assessed as having a resilience of ‘Medium’ as recovery may be possible from low levels of continuous recruitment (Tyler-Walters and Sabatini, 2017). For definitions of resistance (tolerance), resilience (recovery) and sensitivity rankings from the MarESA (Tyler-Walters et al., 2018), see the glossary in the Stage 3 Call for Evidence Introduction.

There is significant evidence of the impacts of bottom trawling on ocean quahog in the North Sea, with benthic surveys indicating a reduction in distribution of the species between 1902 and 1986 and a reduction in species abundance between 1972 and 1980 and then between 1990 and 1994 (Rumohr et al., 1998). Gilkinson et al. (1998) noted that a key factor in determining sensitivity of bivalves to bottom trawling activity is burial depth, combined with size. Bivalves close to the sediment surface that are buried deep enough to establish stability within the sediment are reported to be more likely to break when they come into contact with otter trawls as they are less likely to be excavated to the surface without damage. However, bivalves that are excavated to the surface by bottom towed gear activity become increasingly exposed to indirect mortality via predation (Ragnarsson et al., 2015).

The recruitment of ocean quahog is linked to water temperature, with increasing temperatures being attributed to the cause of low recruitment success in North Sea populations (Witbaard and Bergman, 2003). With increasing warming of oceans, southerly populations of ocean quahog may experience recruitment failure which could result in range contraction of the species and therefore a change in the sensitivity of the species to fishing activity.

6.1.2 Recovery – rate of recovery

Recovery from damaging activities will depend on the intensity and frequency of the impact and the recruitment processes of a species. There is limited research that has examined the recovery of ocean quahog; however, it is thought that their recovery may be limited by their life history characteristics of having long lifespans, slow growth rates and taking 5 to 15 years to reach maturity (Tyler-Walters and Sabatini, 2017).

It has been reported that reductions in adult ocean quahog density over fished grounds can negatively affect recovery via less effective recruitment (Witbaard and Bergman, 2003). The minimum required density of ocean quahog for reproductive success is not currently known (Hennen, 2015) therefore precautionary management approaches may be required in order to ensure that ocean quahog density does not fall below the level required to sustain the population via sexual reproduction. As ocean quahog populations are potentially reproductively isolated from each other (Holmes et al., 2003) recovery after bottom towed gear fishing may vary at a population level. A low and constant rate of recruitment may be sufficient for ocean quahog populations to recover from low to moderate disturbance; however, it may be difficult for ocean quahog to recover from a sustained high level of fishing (Tyler-Walters and Sabatini, 2017).

It has been suggested that UK waters may be a sink of new ocean quahog recruits from Iceland, with long periods without successful recruitment in between larval settlement events (Witbaard and Bergman, 2003). Larvae are thought to be brought down the east coast of the UK and into the mid and southern North Sea by slower moving waters inside gyres that allow settlement to happen. The recovery of ocean quahog populations at a site is likely to depend on an outside source of larvae that arrives infrequently and unpredictably. The recovery of the species is also highly dependent on larger scale environmental pressures such as climate change (JNCC, 2018g).

6.2 Level of literature, caveats and assumptions

Most of the evidence regarding impacts to ocean quahog is for demersal trawling and targeted hydraulic dredging, with limited evidence for the impacts of dredges (for example scallop dredges) and demersal seines and no evidence on semi-pelagic gear.

Similarly, semi-pelagic gear is thought to have a lower impact on the benthos than other types of bottom towed gear, due to the trawl doors being lifted off the seabed and the net having light contact with the seabed (Grieve et al., 2014). However, due to a lack of literature the impacts from this gear type on ocean quahog is unknown.

Where feature-specific literature is unavailable, this review will refer to section 8, where the specific pathways through which bottom towed gear types may pressure Annex I sandbanks which are slightly covered by sea water all the time and MCZ subtidal sediment habitats are discussed.

6.3 The pressures of bottom towed gear on ocean quahog

As a result of bottom towed gear, this feature may be sensitive to the following pressures, so they are considered in this document:

- abrasion/ disturbance of the substrate on the surface of the seabed
- penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
- removal of non-target species

There is insufficient evidence available to determine whether this feature is sensitive to the following pressures as a result of the use of bottom towed gear:

- hydrocarbon and PAH contamination
- introduction or spread of invasive non-indigenous species
- litter
- synthetic compound contamination
- transition elements and organo-metal contamination

6.3.1 Abrasion or disturbance of the substrate on the surface of the seabed, penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion and removal of non-target species

These pressures are grouped together to avoid repetition, due to the similar nature of their impacts on ocean quahog. The specific pathways through which bottom towed gear types may cause abrasion or disturbance of the substrate on the surface of the seabed on Annex I sandbanks which are slightly covered by sea water all the time and MCZ subtidal sediment habitats are discussed in section 8.4.1.

When pulled across the seabed, various parts of a demersal towed gear can cause penetration, abrasion, or disturbance of the seabed surface substrate. Evidence of the impacts of towed gears varies depending on the gear type, particularly gear penetration depth (Sciberras et al., 2018).

Ocean quahog live buried in up to 14 cm of sediment with its siphons protruding from the sediment surface (Strahl et al., 2011), so it can be damaged by the passing of bottom trawl fishing gear (Klein and Witbaard, 1993). Ocean quahog is therefore exposed to both the pressures of surface abrasion and penetration of the sediment (Tyler-Walters and Sabatini, 2017).

Despite the thick, heavy shell of ocean quahog, it is vulnerable to physical abrasion caused by bottom towed gear such as hydraulic dredging, which may result in mortality. Studies suggest that 11% mortality is enough to remove a large proportion of adult populations of ocean quahog in the southern North Sea within 25 years (Witbaard and Bergman, 2003).

Beam trawls, otter trawls and dredges

Ocean quahog is highly sensitive to pressures caused by trawling and dredging (JNCC, 2021e). In areas of high trawling intensity, a higher proportion of damaged shells are found relative to areas of low fishing intensity (Witbaard and Klein, 1994). A study of the effects of bottom trawling on ocean quahog in the North Sea reported that damage and scars on individual shells were mainly found on the posterior ventral side, the side that is oriented towards the sediment surface and therefore the most exposed to contact with fishing gears (Klein and Witbaard, 1993). The study also highlighted that most damaged shells were found in areas with significant fishing activity.

Witbaard and Klein (1994) observed annual growth rings of ocean quahog and were able to determine the years in which they had sustained damage. Their long-term analysis of ocean quahog shell scars in the North Sea shows an increase in the number of damaged ocean quahog over time which corresponds to the trends in changes of the North Sea beam trawl fleet total engine capacity. The damage shown in growth rings suggests that some pressure from demersal trawling can be tolerated.

In a study looking at the catch composition and survival rates of benthic species caught by a beam trawl, Fonds (1991) estimated the mortality of ocean quahog caught in beam trawls to range from 74% to 90%. Shells were damaged both while fishing and onboard the fishing vessel. The number of damaged ocean quahog caught increases when tickler chains are used (74% of ocean quahog damaged with tickler chains, 27% damaged without tickler chains). The single passage of a beam trawl caused direct mortality of 5% to 22% of the initial densities of ocean quahog in the trawl track (Bergman and Van Santbrink, 2000). Bergman et al. (1998) found that ocean quahog caught in otter and beam trawls had high levels of direct discard mortality, at 90% of ocean quahog caught, the highest discard mortality rate of all invertebrate species observed in their study.

Scavengers have been shown to feed on damaged bivalves following the passage of a beam trawl (Kaiser and Spencer, 1994, 1996). Predation of damaged ocean quahog by cod (*Gadus morhua*) was found to occur after the passage of an otter trawl (Arntz and Weber, 1970) and by dab (*Limanda limanda*) after the passage of a beam trawl (Kaiser and Spencer, 1994, 1996; Bergman et al., 1998). Rumohr et al. (1998) compared historic epifaunal data collected during ICES routine cruises in the North Sea from 1902 to 1912, with epifauna data from the ICES Benthos survey of 1986. They showed that between the years 1902-1912, ocean quahog was present at 45% of sampled stations, whereas they were present at only 20 to 30% of stations in the 1986 survey. Ocean quahog was found to be absent from shallower sampling stations (30 to 50 m). Rumohr et al. (1998) noted a general decline in the presence of bivalves, whereas scavengers and predators occurred more frequently in the 1986 survey. The authors attribute this change to the impacts of fishing through discards, bycatch and damage to various species, which produces additional food sources for opportunistic scavengers. Another study by Witbaard (1997) found a significant decline in abundance of ocean quahog between 1972 and 1980 and between 1990 and 1994 in the southern North Sea.

Whilst it is clear that the use of bottom towed gear can negatively impact ocean quahog, literature describing how impacts vary depending on the size of the individual is mixed. Rumohr and Krost (1991) reported that large ocean quahog specimens (> 35 mm) are more susceptible to damage by bottom towed fishing gear than smaller specimens and posited that this is because the ratio of shell thickness to shell size decreases as the quahog grows larger. This is evidenced by the size distribution of ocean quahog found in areas of Kiel Bay in the Baltic Sea that had been frequented by bottom trawlers, as the upper size classes were reduced in these areas.

However, there are also studies which conclude that juvenile ocean quahog are more vulnerable than adults. Klein and Witbaard (1993) reported that shell strength increases with size, so smaller ocean quahog have thinner, weaker shells. Witbaard and Klein (1994) investigated the effects of beam trawling on ocean quahog age-frequency distribution. They found few juvenile ocean quahog in an area of high beam trawl activity, while spat and fully grown individuals were found in higher numbers. This is due to juvenile ocean quahog having comparatively thinner, weaker shells and living shallower in the sediment than adults. Juveniles are therefore more vulnerable to damage by bottom towed gear as they are more likely to come into contact with and be damaged by the gear (Klein and Witbaard, 1993, Witbaard and Klein, 1994).

Differing conclusions in respect to the relationship between shell size and shell strength may be a result of differing experimental methodology or variations in the type of bottom towed gear assessed. Similarly, ocean quahog's sensitivity to damage from bottom towed fishing pressures may vary depending on the kind of gear in use.

Intensive bottom trawling is believed to have a major effect on skewed size class distribution of ocean quahog in the oyster ground, North Sea, where recruitment to larger size classes was diminished, likely due to direct mortality due to physical damage induced by trawls, although natural processes could also contribute (Witbaard and Bergman, 2003). Size distribution of ocean quahog in areas with high trawling activity show fewer large individuals (Rumohr and Krost, 1991).

Rumohr and Krost (1991) fixed a dredge at the bottom edge of otter doors, which sampled the benthic fauna in the track of the otter doors. Trawling-induced damage sustained to ocean quahog was size dependent, with large individuals suffering more damage than smaller ones. Rumohr and Krost (1991) found that 50% of individuals with a shell length greater than 35 mm were damaged (size at sexual maturity 3.6 cm to 4.9 cm). The results of this study suggest otter board damage to have the opposite size distribution to beam trawl damage in the study by Witbaard and Klein (1994). However, the sampling method employed by Rumohr and Krost (1991), notably the use of a dredge to collect benthic fauna samples behind the otter boards, could be the cause of at least some damage sustained and affect its size distribution. Further to this, the differences in damage size distribution is likely due to differential interactions with the seabed between these two gears, with otter boards possibly digging out ocean quahog, as well as differences in sampling methods (Rumohr and Krost, 1991).

Otter boards penetrate the seabed deeper than beam trawls (Eigaard et al., 2016), possibly allowing the gear to reach deeper buried adults than beam trawls. A study of benthic macrofaunal communities’ sensitivities to trawling using their biological traits showed that large-bodied fauna (≥ 4 mm) were more sensitive to trawling than smaller organisms, with long-lived, sessile, deep-living species most affected (McLaverty et al., 2021).

Garcia et al. (2006) investigated effects of scallop dredging on benthic communities off western Iceland using bycatch data from scallop stock assessment surveys and commercial scallop fishery effort data. Their results showed that ocean quahog was the 11th most prevalent species in the bycatch in terms of biomass and was present in 11% of tows.

Dredges penetrate mud to a similar depth as beam trawls (Eigaard et al., 2016), so it can be assumed that they will affect the same proportion of an ocean quahog population buried in mud (all individuals buried to a depth of around 10 cm will be affected). However, damage and mortality rates are likely to vary due to differences in how the gear interacts with the seabed and ocean quahog. In sand, dredges penetrate deeper than beam trawls and otter trawl doors (Eigaard et al., 2016), therefore potentially affecting a greater proportion of ocean quahog buried in sand.

There is limited evidence on the impacts of dredges on ocean quahog as a non-target species. There is however extensive literature on the impacts of the hydraulic dredging fisheries targeting ocean quahog, though these fisheries are thought to cause significantly more damage and mortality than dredge fisheries not targeting ocean quahog, as they actively target ocean quahog deep in the seabed.

Ocean quahog has been targeted commercially in fisheries in Iceland and in the USA, however, there currently is no UK fishery. Both the US and Icelandic fishery use the same type of commercial hydraulic clam dredge (Thorarinsdóttir et al., 2010). The bivalves are dislodged by water jets placed in front of the dredge blade. Once dislodged, the bivalves are swept over the blade and into the dredge. As the dredge is moved along, it digs a track around 10 cm deep (Thorarinsdóttir et al., 2010).

Ocean quahog appears to be highly sensitive to targeted hydraulic dredging. Ragnarsson et al. (2015) looked at the short- and long-term effects of dredging on ocean quahog and non-target species in Iceland. The authors found that although the initial effects of dredging on the benthic community were significant, all taxa recovered to their original abundance within a year of the dredge passage, with the exception of ocean quahog. The hydraulic dredge used in this study to catch ocean quahog was highly efficient, with a catch rate of 82% of ocean quahog biomass within the dredge track, with an additional indirect mortality within the dredge tracks of 11% ocean quahog biomass due to shell damage and predation. The recovery of ocean quahog was very slow within the dredge tracks with the authors concluding that full recovery could take decades. The authors also conclude, although it is difficult to accurately predict recovery of ocean quahog in dredged areas, long term fishing closures are necessary for ocean quahog stocks to recover in heavily dredged areas.

Ragnarsson et al. (2015) reported a 93% decrease in the abundance of ocean quahog after hydraulic dredging off the coast of north-eastern Iceland. Although other species present recovered relatively quickly, ocean quahog had only recovered to 26% of the biomass present within the control areas five years after dredging had concluded.

Demersal seines and semi-pelagic gear

The ground gear of demersal seines is reported to penetrate the top 1.8 cm of sediment (Grieve et al., 2014), whereas ocean quahog is generally found buried in 0-

14 cm of sediment (Tyler-Walters and Sabatini, 2017). Observations in the North Sea found that demersal seining caught between 1–5 ocean quahog per hour (van der Reijden et al., 2014; Verkempynck and van der Reijden, 2015 cited in Waardenburg, 2017). It is unlikely that demersal seining has a significant negative impact on ocean quahog considering the levels of bycatch observed and the penetration depth of gear, however the use of the gear can still cause damage to individuals and populations.

There is no evidence available for the impacts of semi-pelagic trawls towards ocean quahog via removal, damage or mortality of species. It cannot be assumed that semi-pelagic gear do not cause any damage to ocean quahog as these gear types are towed on or close to the seabed.

6.4 Variation in impacts

The potential impacts of bottom towed gear on benthic species such as ocean quahog can vary with fishing activity, gear type, the presence of different gear components, fishing intensity and prior fishing history (Hiddink et al., 2006; Lambert et al., 2017; Sciberras et al., 2018; Rijnsdorp et al., 2020). A global meta-analysis of benthic fauna response to bottom fishing attributed variability around levels of community depletion to gear type, penetration depth of gear and habitat and taxonomic effects, however much of the variation between studies was unexplained (Sciberras et al., 2018).

A range of environmental variables may also influence the potential impacts of bottom towed fishing on ocean quahog. Sensitivity of species and trawling impacts may depend on levels of natural disturbance, sediment type, stability and mobility (Kaiser et al., 1998; Hiddink et al., 2006; Hall et al., 2008). Both experimental and comparative studies have found lower impacts of fishing in dynamic and high energy environments (Sciberras et al., 2018). Areas with a higher tidal velocity potentially have faster recovery rates, meaning benthic communities in more dynamic environments are potentially more resilient to fishing impacts (Lambert et al., 2014; Sciberras et al., 2018).

The comprehensive reviews by Collie et al. (2000) and Kaiser et al. (2006) showed how mortality imposed by the passage of a trawl is habitat specific and differs between benthic species groups and types of trawl gear. Kaiser and Spencer (1996) concluded that mortality effects from beam trawling may be related to hydrodynamic conditions and species ability to withstand disturbance.

Growth rates of ocean quahog (and thus potentially recovery from abrasion impacts) also vary with location, temperature, and food supply (Tyler-Walters and Sabatini, 2017). It should be noted that ocean quahog is a very slow-growing organism even when growth rates are at the higher end of the spectrum (average 1.5 mm per year; Cargnelli et al. (1999). The age dynamics of a population of ocean quahog may affect their sensitivity to bottom towed gear, as shell strength and burial depth in the sediment varies with age. Some studies suggest larger, older individuals to be more susceptible to damage due to a comparatively lower ratio of shell thickness to shell size than juveniles (Rumohr and Krost, 1991). Whereas other studies suggest the shells of older individuals to typically be thicker and therefore provide a higher level of protection (Hawkins and Angus, 1986).

6.5 Summary of the effects of bottom towed gear on ocean quahog

With regards to the discussion above, bottom towed gears have the potential to impact ocean quahog, therefore management of these fishing gears is likely required for MPAs designated for this feature. For each MPA, a site level assessment considering the site conservation objectives, intensity of fishing activity taking place and exposure to natural disturbance will be needed to determine whether management will be required.

The site level assessment will assess fishing activities for their impact upon protected habitats and species. Specifically, this assessment considers the potential for these activities to hinder the conservation objectives of the MCZ. The data used in the assessment will include vessel monitoring system (VMS) data, as well as feature habitat data from JNCC and Natural England. Where the assessment concludes that the current level of management is not sufficient to protect the designated features of the site, recommended management options will be provided. MMO has regard to the best available evidence and through consultation with relevant advisors, stakeholders, and the public, will conclude which management option is implemented.

Due to the evidence of impacts from bottom towed gear on this feature, site level management should consider prohibition of bottom towed gears in specified areas of MPAs where this feature occurs.

7 Biogenic (*Sabellaria spp*.) and rocky reef

Bottom towed gear interactions with biogenic reef (*Sabellaria spp*.) and rocky reef have not been included in this review as they have already been addressed in the Stage 2 assessment. Stage 2 assessed the impacts of fishing using bottom towed gears on rock, rocky and biogenic reef in 13 MPAs. These features were chosen for Stage 2 as they are some of the most sensitive to the impacts of bottom towed gears.

8 Annex I sandbanks which are slightly covered by sea water all the time and MCZ subtidal sediment habitats

This section brings together and analyses the available evidence on how bottom towed gear affects Annex I sandbanks which are slightly covered by sea water all the time and marine conservation zone subtidal sediment habitats (hereafter referred to as sandbanks and sediments).

Sandbanks which are slightly covered by sea water all the time (hereafter referred to as sandbanks) are an Annex I habitat listed in Council Directive 92/43/EEC (the Habitats Directive). They are a designated feature of the special areas of conservation (SACs) listed in Table 2. Sandbanks can be further classified into EUNIS habitat types. With the exception of subtidal mud, which is not found upon sandbanks, these EUNIS habitats correspond with MCZ subtidal sediment broadscale habitats. MCZ subtidal sediment habitats are designated features of the MCZs listed in Table 2.

Table 2. MPAs containing designated features of Annex I sandbanks or relevant MCZ broadscale habitats.

Bioregion	Relevant MPA	Relevant Features				
		Annex I sandbanks which are slightly covered by sea water all the time	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal sand	Subtidal mud
Eastern Channel	Albert Field MCZ		x	x		
	Bassurelle Sandbank SAC	x				
	East of Start Point MCZ				x	
	Foreland MCZ		x		x	
	Goodwin Sands MCZ		x		x	
	Inner Bank MCZ		x	x	x	
	Offshore Brighton MCZ		x	x		
	Offshore Overfalls MCZ		x	x	x	
	West of Wight-Barfleur MCZ		x	x		
Irish Sea	Fylde MCZ				x	x
	Shell Flat and Lune Deep SAC	x				
	West of Copeland MCZ		x	x	x	
	West of Walney MCZ				x	x
Northern North Sea	Farnes East MCZ		x	x	x	x
	Fulmar MCZ			x	x	x
	North East of Farnes Deep MCZ		x	x	x	x
	Swallow Sand MCZ		x		x	
Southern North Sea	Haisborough, Hammond and Winterton SAC	x				
	Holderness Offshore MCZ		x	x	x	
	Kentish Knock (East) MCZ		x	x	x	

Bioregion	Relevant MPA	Relevant Features				
		Annex I sandbanks which are slightly covered by sea water all the time	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal sand	Subtidal mud
	Margate and Long Sands SAC	x				
	Markham's Triangle MCZ		x	x	x	x
	North Norfolk Sandbanks and Saturn Reef SAC	x				
	Orford Inshore MCZ			x		
Western Channel and Celtic Sea	Cape Bank MCZ		x			
	East of Haig Fras MCZ		x	x	x	x
	Greater Haig Fras MCZ		x	x	x	x
	Hartland Point to Tintagel MCZ		x		x	
	North East of Haig Fras MCZ		x		x	x
	North West of Jones Bank MCZ		x	x	x	x
	North West of Lundy MCZ		x			
	South of Celtic Deep MCZ		x	x	x	
	South of the Isles of Scilly MCZ		x	x	x	
	South West Approaches to Bristol Channel MCZ		x		x	
	South West Deeps (East) MCZ		x		x	
	South West Deeps (West) MCZ		x	x	x	x
	Western Channel MCZ		x		x	

8.1 Feature summaries

8.1.1 Sandbanks and MCZ subtidal sediments

Sandbanks

Sandbanks consist of sandy sediments that are permanently covered by shallow sea water, typically at depths of less than 20 m below chart datum. The habitat comprises distinct banks which may arise from horizontal or sloping plains of sandy sediment.

The diversity and types of community associated with this habitat are determined particularly by sediment type together with a variety of other physical, chemical and hydrographic factors.

Within the UK's offshore waters, sediments can be categorised into a number of EUNIS habitat types as follows:

Subtidal coarse sediment

Coarse sediments include coarse sand, gravel, pebbles, shingle and cobbles which are often unstable due to tidal currents and/or wave action. These habitats are generally found on the open coast or in tide-swept channels of marine inlets. They typically have a low silt content and a lack of a significant seaweed component. They are characterised by a robust fauna including venerid bivalves (EEA, 2019a).

Subtidal sand

Subtidal sands consist of clean medium to fine sands or non-cohesive slightly muddy sands which are most commonly found on open coasts, offshore or in estuaries and marine inlets. 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 amphipod crustacea (EEA, 2019b).

Subtidal mud

Subtidal mud and cohesive sandy mud are found in marine areas extending from the extreme lower shore to offshore, circalittoral habitats. Unlike the subtidal sand, coarse and mixed sediments, subtidal mud does not occur on sandbanks. This biotope is predominantly found in sheltered harbours, sea lochs, bays, marine inlets and estuaries and stable deeper/offshore areas where the reduced influence of wave action and/or tidal streams allow fine sediments to settle. Such habitats are often dominated by polychaetes and echinoderms, in particular brittlestars (such as *Amphiura* spp.). Estuarine muds tend to be characterised by infaunal polychaetes and oligochaetes. Sea-pen (such as *V. mirabilis*) and burrowing megafauna (including *N. norvegicus*) communities are common in deeper muds and are also an MCZ habitat of conservation importance (HOCI). This specific HOCI has been assessed separately, see section 4 (EEA, 2019c).

Subtidal mixed sediments

Subtidal mixed sediments are found from the extreme low water mark to deep offshore circalittoral habitats. These habitats incorporate a range of sediments including heterogeneous muddy gravelly sands and mosaics of cobbles and pebbles embedded in or lying upon sand, gravel or mud. There is a degree of confusion with regards to nomenclature within this complex as many habitats could be defined as containing mixed sediments, in part depending on the scale of the survey and the sampling method employed. The British Geological Survey trigon (see: Figure 5 in McBree et al., 2011) can be used to define truly mixed or heterogeneous sites with surficial sediments which are a mixture of mud, gravel and sand. However, another 'form' of mixed sediment includes 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 these are less well defined and may overlap into other habitat or biological subtypes. These habitats may support a wide range of infauna and epibiota including polychaetes, bivalves, echinoderms, anemones, hydroids and Bryozoa. Mixed sediments with biogenic reefs or macrophyte dominated communities are classified separately. Subtidal biogenic reefs were assessed separately in the Stage 2 assessment. No MPAs currently being assessed by MMO are designated to protect subtidal macrophyte-dominated sediments however they do represent supporting habitats for marine birds within special protection areas (SPAs) (EEA, 2019d, 2019e, 2019f).

8.1.2 Supporting habitats

As well as being designated MPA habitats requiring protection in their own right, subtidal sediments act as important supporting habitats for other MPA designated features. These include MCZ species such as sea-pens and burrowing megafauna, fan mussel and ocean quahog. The dedicated review sections provide further detail on the specific supporting habitat(s) for each protected feature (sections 4 to 6).

With regard to MCZ features, supporting sedimentary habitats can provide the substrate for the benthic communities to grow and thrive, supporting ecological processes and the wider food web. The potential impact of fishing gears on the supporting substrate is discussed within this sandbank and subtidal sediment review. The potential impact of fishing gears on the MCZ features themselves is discussed in their dedicated sections.

8.2 Overview of the sensitivity of sandbanks and sediments to bottom towed gear

8.2.1 Sensitivity – resistance to damage

Sandbanks and subtidal sediments are less sensitive and likely to recover more quickly from fishing activity impacts than more fragile habitats such as biogenic reefs, however fishing activity still has the potential to negatively impact these habitats and hinder the conservation objectives of the sites in which they are protected, particularly with regard to the structure and function of the biological communities present. This is especially true in intensively fished areas which are likely to be maintained in a permanently altered state, inhabited by fauna adapted to frequent physical disturbance due to the inability of the habitat to sufficiently recover before the next passing of bottom towed gear (Collie et al., 2000).

Sensitivity of sandbanks and subtidal sediments to, and their recovery from, fishing activity will depend on several factors including the sediment type, presence of particularly sensitive species, exposure to natural disturbance (Natural England, 2022), as well as recruitment of new individuals (Collie et al., 2000), growth of surviving biota, and active immigration from adjacent habitat (Brey, 1999).

8.2.2 Recovery – rate of recovery

Clean sand communities are likely to recover from disturbance most quickly (Collie et al., 2000), whereas communities from gravel (subtidal coarse sediment) and muddy sand habitats tend to have the slowest physical and biological recovery rates (Dernie et al., 2003; Kaiser et al., 2006; Foden et al., 2010). When considered in terms of MCZ subtidal sediment habitats, muddy sand and clean sand habitats would both fall under the subtidal sand classification which highlights the complexity of understanding the impacts of fishing impacts on sedimentary habitats. Little evidence is available regarding the sensitivity and recovery of subtidal mixed sediments but in general terms the more physically stable habitats are, such as subtidal mud and coarse sediments like gravel, the longer recovery is likely to take (Collie et al., 2000).

8.3 Level of literature, caveats and assumptions

This review is based on information sourced from peer-reviewed scientific journals and research reports, the majority of which relate to UK waters. However, some research comes from studies undertaken elsewhere. A summary of the available literature is provided, and where evidence is conflicting, and our understanding of how bottom towed gear impacts vary with habitat type remains incomplete, this has been highlighted.

During the review of evidence, it has not always been possible to identify the precise gear being used, or the particular sediment type the gear is being used over, to be able to characterise the particular impact that results. Additionally, there can be limited information on how the biological impacts of pressures may vary with specific bottom towed gear types. As such evidence is described under more general headings such as bottom towed gear or sandy sediments.

Most current available evidence for impacts of trawling on subtidal sediment focuses on subtidal sand, with few studies considering impacts on subtidal mixed or coarse sediments.

To analyse the biological community within sediments, the majority of studies use sieves with a mesh size of 1.0 mm or greater. As such, impacts of bottom towed gear on the sub 1.0 mm biological community, known as meiofauna, are poorly understood. It has been argued, particularly regarding sand habitats, that the sub 1.0 mm community represents a large proportion of the biomass within the sediment as well as an important food source for large invertebrates and fish (Schückel et al., 2013). It is believed the action of the numerous and diverse species within the sub 1.0 mm size class may drive many important ecological processes (Natural England specialist, 2022, pers. comms.). As such, many studies considering the impact of bottom towed gears on sediment habitats may underestimate the effects on total biomass (Natural England specialist, 2022, pers. comms.). However, due to their small size, meiofauna may be resistant to disturbance by trawling because they are likely to be resuspended rather than killed by trawls and because their short generation times would allow them to withstand elevated mortality (Schratzberger et al., 2002).

The literature search has found limited evidence of the impacts of light otter trawling on subtidal sand or mud. This review therefore reflects the paucity of available evidence, and metrics given do not necessarily reflect the impacts across the whole fishery.

8.4 The pressures of bottom towed gear on sandbanks and sediments

As a result of bottom towed gears, these features may be sensitive to the following pressures, so they are considered in this document:

- abrasion or disturbance of the substrate on the surface of the seabed*
- penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion*
- removal of target species
- removal of non-target species
- changes in suspended solids (water clarity)$^{\Delta}$
- changes in smothering and siltation rates$^{\Delta}$.

Pressures marked with matching superscript symbols (* and $^{\Delta}$) have been consolidated in this review to avoid repetition, due to the similar nature of their impacts on sandbank and sediment habitats.

There is insufficient evidence available to determine whether this feature is sensitive to the following pressures as a result of the use of bottom towed gear:

- hydrocarbon and PAH contamination
- introduction of light
- litter
- Synthetic compound contamination

- Transition elements and organo-metal contamination

8.4.1 Abrasion, penetration or disturbance of the substrate on the surface of the seabed

Abrasion and penetration pressures associated with bottom towed gears can have both biological and physical impacts. The physical impacts include the creation of furrows and berms in the sediment from the trawl doors associated with bottom otter trawls (Rosenberg et al., 2003; Løkkeborg, 2005; Polet and Depestele, 2010; Grieve et al., 2014); flattening of bottom features such as ripples and irregular topography by beam trawls (Kaiser and Spencer, 1996) and demersal seines; and the homogenization of sediments by dredges, eliminating natural features such as ripples, bioturbation mounds and faunal tubes (Collie et al., 2000; Kaiser et al., 2002; Løkkeborg, 2005; Sewell and Hiscock, 2005; Beukers-Stewart and Beukers-Stewart, 2009; Craven et al., 2013).

Depending on the gear type, sediment type and degree of natural disturbance, such impacts can remain from days to months or even years (Lindeboom and de Groot, 1998; Fonteyne, 2000; Palanques et al., 2001; Grieve et al., 2014; Bruns et al., 2020; Bradshaw et al., 2021). However, physical impacts are unlikely to significantly impact the large-scale topography of sandbank and sediment features, the smaller scale physical impacts to topographic features such as ribbons and waves present in the sediments are unlikely to have a significant negative affect on the habitat. Of more concern are the impacts to the biological structure of sediment habitats which is discussed in more detail below.

Demersal trawls (including semi-pelagic gear) and dredges may impact the biological communities found in sandbank and sediment features through damage and mortality of fauna and flora on the seabed via surface and subsurface abrasion and penetration. This is due to collision and crushing as animals pass under the gear and/or the initial encounter with the gear. Uprooting may also occur, but this is likely to result in the removal of fauna via the gear and is therefore covered in section 8.4.4. Benthic megafauna on the seabed that are encountered by dredges have similar (or even higher) levels of damage as those organisms landed on the deck as bycatch with capture efficiencies ranging from 2.6 to 25.0% for the ten megafauna species studied by Jenkins et al., 2001 (see section 8.4.4).

Demersal towed gear disturbs the seabed by dragging the fishing gear over the seabed to catch bottom-dwelling fish and benthic invertebrates. This disturbance can modify benthic habitats and lead to direct and indirect mortality for non-target infaunal species (van Denderen et al., 2015) such as bristleworms (*Spiophanes bombyx*), bivalves (*Tellina fibula*), polychaetes (*Magelona filiformis*) and amphipods (*Bathyporeia* spp.), which are typically found in sandy sediments (Eggleton et al., 2016). Similarly, epifauna such as endobenthic bivalves (*Mactra stultorum*, *Donax vittatus*, *Arctica islandica* and Ensis species), masked crab (*Corystes cassivelaunus*), sea potato (*Echinocardium cordatum*) and more common species belonging to the groups Asteroidea, Cnidaria, Bryozoa and Paguridae can be impacted from trawls (Van Moorsel, 2011; Eggleton et al., 2016).

Demersal trawling has occurred over sandbanks for decades (Plumeridge and Roberts, 2017). It has been suggested that intensive fishing in some areas, particularly the industrialisation of the North Sea steam trawl fleet, may have caused severe damage to sandbank macrofauna communities from the 1920s to the 1950s (Plumeridge and Roberts, 2017) with patches of the bivalves, *Spisula subtruncata* and *Mactra stultorum*, disappearing almost completely in some areas. These are yet to re-establish, likely due to fishing activity (Kröncke, 2011) and have instead been replaced by smaller, faster growing bivalves (Kröncke, 2011; Plumeridge and Roberts, 2017).

Trawling removes the most sensitive species while allowing resilient organisms to remain (Hiddink et al., 2017). Therefore, historic and continued trawling activity is likely to contribute to a shift in the biological community from larger long-lived species to one dominated by smaller, short-lived, opportunistic species, which may be more resilient than long-lived species to trawling activity (Schratzberger et al., 2002; Queirós et al., 2006; Josefson et al., 2018; Rijnsdorp et al., 2018). Such species are not only more likely to be resuspended rather than be killed during trawling, due to their size (Josefson et al., 2018), but can also reproduce quickly when trawling ceases. Tuck et al. (1998) found that cirratulid polychaetes, *Cheatozone setosa* and *Caulleriella zetlandica*, and the spionid polychaete, *Pseudopolydora paucibranchiata*, are highly opportunistic and able to consistently increase their numbers in association with, or immediately following, disturbance. Species such as the hermit crab, *Paguristes oculatus*, which similarly exhibit this behaviour are largely scavengers, or otherwise groups that are able to effectively utilise the increased food availability offered by disturbed sediment (Pranovi et al., 2000).

The reduced density of larger-bodied bioturbators through demersal trawling can have a substantial impact on sediment-water fluxes of nutrients which could have major effects on ecosystem function. It is likely that demersal trawling activities are interfering with natural ecosystem production processes and may result in reduced biological yield at different trophic levels, including fish (Olsgard et al., 2008).

Large bioturbating species which are vulnerable to demersal trawling activity (for example *Brissopsis lyrifera* (heart urchin); *Amphiura chiajei* (brittle star); *Aphrodita aculeata* 'sea mouse'; *Nephtys caeca* (polychaete) increase the depth of oxygen penetration into the sediment, leading to an increased ability of benthic systems to process organic material with benefits to associated fauna in terms of maintaining levels of diversity (Widdicombe et al., 2004).

Tuck et al. (1998) conducted bottom trawling one day per month for 16 months in a fine muddy habitat. Biological surveys were completed after 5, 10, and 16 months of trawling and then after 6, 12, and 18 months of recovery in trawled and un-trawled reference areas. Results showed that experimental trawling disturbance had clear long-term effects on the topography of the seabed (detailed above under physical impacts) and the infaunal community at the site (Tuck et al., 1998). While physical impacts were almost indistinguishable after 18 months of recovery, community impacts persisted (Tuck et al., 1998). This evidence suggests that even infrequent trawling may be sufficient to maintain a community in an altered state (Tuck et al., 1998). It should be noted however that the study conducted by Tuck et al. (1998) took place in a highly sheltered location and involved intense trawling activity. The MPAs relevant to this sandbank and sediment literature review are generally subject to greater natural disturbance and likely lower trawling intensities. Therefore, the results obtained by Tuck et al. (1998) may not be representative of impacts to mud habitats within the MPAs being assessed.

Multi rig, bottom otter trawls and semi-pelagic trawls

The most significant impact of otter trawls is on the biological community (Rijnsdorp et al., 2020). Direct mortality due to otter trawling is considerable but has been found to be lower than that caused by beam trawling for a number of burrowing species (Bergman and Van Santbrink, 2000). While otter trawls have a lesser impact on the biological community than other gears such as beam trawls or scallop dredges (Collie et al., 2000; Hiddink et al., 2017), in terms of number of vessels, the otter trawl fleet is considerably larger than other demersal trawl fleets and therefore likely to have a larger impact compared with other demersal trawls such as beam trawls and fly shooting (also known as Scottish seining (Rijnsdorp et al., 2020).

Otter trawls have been found to remove an average of around 6% of faunal biomass per pass (Hiddink et al., 2017) with the first trawl pass having the most significant impact (Hiddink et al., 2006). Large sessile fauna (for example erect sponges, fan corals, hydroids, erect bryozoans) are particularly susceptible to damage, with otter trawling in coarse sediments resulting in considerably reduced abundances of these fauna (Humborstad et al., 2004; Rijnsdorp et al., 2018). Such erect fauna play an important role in biological communities with recruitment and reproductive success of species such as scallops heavily influenced by availability of suitable settlement habitat (Brand, 2006; Beukers-Stewart and Beukers-Stewart, 2009); for example, scallop spat are shown to attach primarily to three dimensional structures such as upright taxa including macroalgae, bryozoans, hydroids and live and dead maerl (Paul, 1981; Minchin, 1992; Bradshaw et al., 2001; Kamenos et al., 2004).

In a laboratory experiment, Gilkinson et al. (1998) demonstrated that smaller body-sized fauna (10 to 15 mm bivalves) are less susceptible to physical damage, as they are pushed aside by the pressure wave generated by the passing trawl, yet displacement was apparent for all bivalves. While the majority of infauna is capable of reburying following the displacement (Tillin, 2022), it could increase susceptibility to predation if unable to rebury sufficiently quickly (Gilkinson et al., 1998).

Otter trawling can therefore reduce biomass, species richness and diversity, as well as change the community structure in fished verses unfished areas (Ball et al., 2000; Kaiser et al., 2002). However, this may vary with habitat type as shown by a meta-analysis by (Kaiser et al., 2006) which found an initial impact from otter trawling on benthic communities in muddy sand and mud habitats but not sand habitats, although they did note some evidence of a small, delayed effect suggesting initial impacts may not capture the full extent of impacts to the biological community.

As well as sessile fauna, other benthic taxa can still be negatively impacted by otter trawls. Benthic taxa buried in soft sediments can be dislodged; hard substrates with their attached fauna can be removed entirely by the trawl or moved to a less favourable position (Auster et al., 1996; Thrush and Dayton, 2002; Buhl-Mortensen et al., 2013) and damage to biogenic structures or material, such as dead shells, may result in a reduction in the substrate available for surface-dwelling species (Collie et al., 2000; Kaiser et al., 2006).

Beam trawls

Beam trawl ground gear (the shoes, tickler chains or chain mat) is known to crush or dislodge epifauna on the seabed (Revill and Jennings, 2005) with declines in suspension feeders (De Juan et al., 2007), epifauna (Buhl-Mortensen et al., 2016), annual faunal production (Hermsen et al., 2003), biomass, species richness, species diversity, and habitat complexity (Collie et al., 1997; Thrush and Dayton, 2002) all being attributed to beam trawling.

Slow-growing or fragile macrofaunal species living in the upper layer of sandy sediments, such as certain bivalves (for example *Spisula* sp.), echinoderms (for example *Echinocardium cordatum*), holothurians, gastropods, tube-forming polychaetes (*Terebellidae* spp.) and newly settled juvenile infauna are particularly vulnerable to damage or disturbance, including frequent beam and otter trawling activities and have declined in abundance in areas over time (Bergman and Hup, 1992; Kaiser and Spencer, 1996; Jennings et al., 2001; Tiano et al., 2020). Bergman and Van Santbrink (2000) found mortalities up to 52% for echinoderms, up to 39% for crustaceans and gastropods, and up to 64% for bivalves after a single beam trawl sweep, although mortalities were lower where trawls used chain mats compared to those using tickler chains. Bergman and Hup (1992) found significant declines (40 to 65%) in starfish, small crustaceans, heart urchins, and tube-dwelling polychaete worms after beam trawling. The impact appeared to be greatest on concentrations of small-sized individuals, possibly because larger animals live deeper in the sediment or have better escape possibilities. This latter study contradicts others, however, which suggest larger longer-lived taxa show higher mortalities in response to beam trawling, compared to smaller, short-lived species (Bergman and Van Santbrink, 2000; Løkkeborg, 2005; Rijnsdorp et al., 2016) leading to declines in abundance of up to 50% for nine of the most common taxa in stable sand and gravelly areas (Kaiser and Spencer, 1996; Løkkeborg, 2005).

Following a beam trawl pass, damaged animals rapidly attract scavengers (Sewell and Hiscock, 2005). Highly mobile scavengers, such as fish and crabs, quickly arrive at beam trawl tracks within minutes to hours, dispersing once feeding has taken place (Kaiser and Spencer, 1996). Whelks (*Buccinum undatum*) have been shown to survive beam trawling and are capable of exploiting a wide variety of prey, feeding on damaged and moribund animals in trawled areas (Evans et al., 1996). Fish such as gurnard, whiting and dogfish, and the sea urchin, *Strongylocentrotus pallidus*, are also known to aggregate over beam trawl tracks to feed (Kaiser and Spencer, 1994). If not directly killed by the passing of a trawl, these species may be damaged and more likely to fall prey to mobile scavengers (Auster et al., 1996; Bradshaw et al., 2001; Shephard et al., 2009; Coleman et al., 2013; Craven et al., 2013).

The vast majority of studies have considered short term impacts of fishing activities with studies of beam trawling no exception. In a meta-analysis of fishing impacts, Kaiser et al. (2006) found 53 data points available for impacts 0 to 1 day post beam trawling and just 8 data points available for two to 50 plus days post beam trawling. Evidence concerning the long-term effects of beam trawling is mixed with some studies identifying rapid recoveries (Kaiser et al., 2006) while others identifying reductions in species abundance over a five year period (Jennings et al., 2001) and widespread changes to benthic assemblages and habitats due to chronic fishing activities over 10 years (Kaiser et al., 2000).

Dredges

During scallop dredging the greatest amount of mortality results in individuals left on the seabed rather than occurring as bycatch (Jenkins et al., 2001). This supplementation of the diet of predators such as starfish or crabs from carrion left in the dredge tracks (as noted by Veale et al. (2000)) and the removal of upright species may lead to shifts in benthic community structure to one dominated by small, encrusting, opportunistic, fast-growing species (Bradshaw et al., 2001). Bradshaw et al. (2002) discovered over a 60 year period, mobile, robust and scavenging taxa increased in abundance, while slow-moving or sessile, fragile taxa decreased and this change in the benthic community was related to how long a site had been fished, rather than actual fishing intensity.

Kaiser et al. (2000) found communities within areas closed to scallop dredging, beam and otter trawling were dominated by higher biomass and emergent fauna, increasing habitat complexity. In contrast, areas fished by these towed gears were dominated by smaller-bodied fauna and scavenging taxa. Large infaunal species, such as the burrowing heart urchin (*Echinocardium cordatum*), razor shells (*Ensis* spp.) and burrowing sandeels (Ammodytes), are frequently destroyed by dredging operations (Eleftheriou and Robertson, 1992). Blyth et al. (2004) found similar results with benthic communities in areas only permitting static gear activity having greater biomass to those where towed gear fishing (trawls and dredges) occurred. Additionally, benthic communities in seasonally trawled sites were similar to openly trawled sites indicating the six-month closure of towed gear is insufficient for the benthic community to recover. However, Blyth et al. (2004) did note sediment type varied across the study sites which may also have impacted the species present (see section 8.5.3).

Typically, stable mixed sediment seabeds (cobble, pebble, gravel, shell debris, sand and mud mixtures) are dominated by faunal turfs consisting largely of erect hydroids (for example *Nemertesia* spp., *Obelia* spp., *Abietinaria abietina*) and erect bryozoans (for example *Flustra foliacea*, *Bugula* spp., *Alcyonidium diaphanum*), all of which are particularly vulnerable to scallop dredging which can reduce the complexity of benthic habitats by flattening substrates and removing these structurally complex species (Eleftheriou and Robertson, 1992; Bradshaw et al., 2000; Sewell and Hiscock, 2005; Stewart and Howarth, 2016). These species form emergent structures that provide important settlement substrates for many other species, including scallop spat (Bradshaw et al., 2001; Lambert et al., 2011). The abundance of species within such faunal turfs has been found to be reduced by 56 to 96% by dredging (Kaiser et al., 2006).

Dredging in muddy sediments can cause high mortality and removal rates of benthic macrofauna. Morys et al. (2021) reported a total removal of organisms from their experimental dredging. While it was caveated that the small mesh sizes used in the study may have led to a greater rate of capture for smaller bodied organisms than from industry standard nets, the study posited that these species would still be displaced by towed gears with larger mesh sizes, either passing through or from disturbance via the associated pressure wave. The study hypothesises that if dredging causes reduction or complete removal of macrofauna such as oligochaetes and *Limecola balthica*, their consumption of oxygen and bioturbation would result in lower levels of stimulation for benthic biogeochemical processes, thus negatively impacting the sediment as a habitat.

Demersal seines

Where sessile or attached epifauna are present, demersal seines have the potential to disturb or damage epifauna when the ropes of a seine net are closed up in order to herd demersal fish (van der Reijden et al., 2014; Bureau Waardenburg, 2017).

Biotopes containing attached or sessile epifauna are considered sensitive to abrasion due to the disturbance and damage to these non-target species (MBIEG, 2020).

8.4.2 Changes in suspended solids (water clarity) and changes in smothering and siltation rates

Bottom towed gear impacts associated with these pressures are likely to be similar in nature and therefore the information below is relevant to all gears. The degree of suspension and therefore the likely degree of impact varies between gear types and sediment type and therefore gear specific suspension rates, where known, have been provided in the relevant sections below. There is limited information on how the biological impacts of smothering and siltation will vary depending on gear type. However, it is likely that the extent of impact will vary in line with the degree of resuspension, the larger the amount of entrainment of sediment, the greater the impact to vulnerable biological communities.

Contact of bottom towed gears with the seabed and ambient water mixes together the top layer of sediment and may contribute to entrainment of fine sediments in particular around and behind the gear (Lucchetti and Sala, 2012; Rijnsdorp et al., 2021). These are then dispersed in a cloud in the water column, creating a suspension with a vertical profile that depends on the turbulence and the particle settling velocities (O’Neill and Summerbell, 2011; Lucchetti and Sala, 2012). The sediment gradually settles as turbulence reduces. Suspension and settlement of sediments varies between the gear types used, sediment grain size and the degree of sediment compaction. More compacted substrates with higher mud fractions generate more sediment resuspension than those which are naturally ‘cleaner’ (Kaiser et al., 2002). Plumes caused by demersal trawls can persist from several hours (Martín et al., 2014) to several days (Palanques et al., 2001) after fishing activity has ceased. Particle size will determine the speed of settlement and therefore smaller, slower settling particles may be transported further away by prevailing currents and as a result trawling will influence the sorting of sediments in trawled areas (Brown et al., 2005). As an example, Linders et al. (2018) concluded that after bottom trawling, sand is typically transported 10 to 100 m when in suspension.

The upper layers of marine sediments act as an important site for carbon storage (Luisetti et al., 2019) and nitrogen cycling (Van De Velde et al., 2018). Disturbance of these layers will disrupt such processes significantly (Van De Velde et al., 2018). Through the removal of surficial sediments, trawling increases erosion, grain-size sorting, mixing and can result in organic carbon impoverishment (Mayer et al., 1991; Watling et al., 2001; Sánchez et al., 2009; Martín et al., 2014) as well as both the fining (Trimmer et al., 2005) and coarsening (Palanques et al., 2014; Mengual et al., 2016) of the sediment. However, this can again vary with sediment type, with trawling increasing surface concentrations of organic matter in muddy sediments (Pusceddu et al., 2005; Palanques et al., 2014; Sciberras et al., 2016), but only slight effects reported in sandy sediments (Trimmer et al., 2005; Hale et al., 2017; Tiano et al., 2019). For example, measuring changes in sediment characteristics using the RoxAnn seabed classification system, Fonteyne (2000) found that the most marked resuspension by gear activity occurred in areas of finer sand, but that these suspended particles settled again in only a few hours.

Re-suspension and mixing of sediment, as well as mortality of infauna by trawling, will affect the natural conditions of the ecosystem (Morys et al., 2021) altering biogeochemical processes within soft sediment habitats, releasing dissolved nutrients, organic matter and contaminants, exposing anoxic sediments, increasing biological oxygen demand, and resuspending phytoplankton cysts and copepod eggs (O'Neill and Summerbell, 2011); the consequences of which can lead to immediate declines in benthic community metabolism (Tiano et al., 2019). In muddy sediments, as few as three disturbances annually are enough to keep conditions in a transient biogeochemical state, with regularly trawled areas never reaching a steady condition (Van De Velde et al., 2018). These changes have broader implications such as alterations to the nitrogen cycle (Ferguson et al., 2020; De Borger et al., 2021); lowered nutritional value of organic matter for suspension and bottom feeders (Watling et al., 2001); decreased phytoplankton growth (Karlson, 1989; L'Helguen et al., 1996); and changes in the remineralisation of organic materials leading to reduction in the burial of organic carbon (Van De Velde et al., 2018).

Resuspended sediment and the resulting increase in turbidity may be a risk to organisms that are vulnerable to increased levels of sediment particles in the water column and creates the potential for impacts via smothering (Gubbay and Knapman, 1999; Linders et al., 2018). Changes in suspended sediment in the water column may have a range of biological effects on different species within the habitat; affecting their ability to feed or breathe. A prolonged increase in suspended particulates for instance can have several implications, such as affecting fish health and clogging filtering organs of suspension feeding animals (Elliott. et al., 1998).

The impact of smothering and siltation on species is variable. Tillin and Tyler-Walters (2014) found that sedentary, filter or suspension feeders, such as bivalves, had low resistance to smothering, whereas mobile epifauna, mobile predators and scavengers appear highly resilient and resistant. Similarly, erect, large, longer-lived epifaunal species with some flexibility had high resilience and for soft-bodied or flexible epifaunal species, increased turbidity (to a point) could even be beneficial under certain conditions (Tillin and Tyler-Walters, 2014).

Therefore, impacts on the biological communities of sandbank and sediment features from smothering and siltation is variable dependent on the species present. The most sensitive group of species are very small to medium sized suspension and/or deposit feeding bivalves. Overall, this ecological group is not predicted to be sensitive to acute changes in turbidity. However, this may change if subjected to a chronic, sustained change.

Sandeels spend large parts of their life buried within seabed sediments and the structure and function of the sediment habitat plays an important role in determining the distribution and presence of these species (JNCC, 2018f). Changes in suspended solids and smothering and siltation may impact sandeels through the infilling of sandeel burrows and changes to the sediment composition (as detailed above) due to sandeel preference for settling and burrowing in coarse sediments with little silt (Wright et al., 2000; Holland et al., 2005).

In some sites, sandeels are representative species of the 'characteristic community' (includes representative communities such as those covering large areas, and notable communities, such as nationally or locally rare or scarce, or known to be particularly sensitive) of sediment habitats. Site level assessments will be required to determine the role of sandeels in particular sediment habitats and whether their presence or absence affects the habitat’s condition. It will then be decided whether management of bottom towed gears, for the benefit of the local sandeel population, is appropriate.

At certain levels of intensity this pressure has the potential to impact on the species of a site however the communities that live in sandbank and sediment habitats will be adapted to some level of sedimentation in accordance with rates of natural disturbance and therefore as described above in relation to sandeels, site level assessments will be required to determine whether management of bottom towed gears is appropriate.

Multi-rig, bottom otter trawls and semi-pelagic trawls

Experiments using otter trawls demonstrated that sediments can be suspended up to 80 cm above the seabed, cause a sediment concentration increase behind the gear of up to 0.43 cm^3 per litre and an estimated 41.3 kg of sediment can be suspended by all otter trawl components (ground gear and trawl doors) per metre when towed over sandy substrates (O’Neill and Summerbell, 2011).

Investigations by Bradshaw et al. (2021) found that a single trawling event by an otter trawl on muddy sediment resulted in dissolved concentrations of particle-reactive elements near the seafloor decreasing immediately after trawling, a short-term release (hours) of dissolved substances in the vicinity of the track and suspension of approximately 9.5 tonnes of sediment, including tens to hundreds of kilograms of associated particulate elements, per kilometre of track. The sediment plume in the near-bottom water was transported more than 1 km away over the following three to four days (Bradshaw et al., 2021). This is in line with the findings of Palanques et al. (2001) who recorded elevated levels of re-suspended fine mud sediment for up to 5 days after their trawl disturbance event.

Detailed information for semi-pelagic and multi-rig gears is not currently available, however, the absence of otter doors in multi-rig trawls and the doors not contacting the seabed in semi-pelagic trawls, is likely to reduce resuspension of sediment when compared to bottom otter trawls (Rijnsdorp et al., 2017).

Beam trawls

No specific evidence regarding the entrainment of sediment has been identified for beam trawls, however the passing of a beam trawl, as per other bottom towed gears, will cause sediment to be re-suspended (Grieve et al., 2014).

Dredges

Scallop dredges have been shown to entrain sandy sediments up to 30 m behind the gear (O’Neill et al., 2008). The dredge teeth rake through, loosen, and break up the top layer of sediment. A study on sandy sediment grounds in Scotland demonstrated that the turbulent wake of scallop dredges entrains up to 0.85 kg per metre of plume about 20 m behind the dredge, which is the equivalent of a 1 mm layer of sediment per unit of swept width (O'Neill et al., 2013). This means a typical scallop dredger fishing eight dredges off each side would put about 13.6 kg of sediment into the water column per metre of seabed towed depending on the sediment's particle size distribution and the local hydrography (O'Neill et al., 2008).

Demersal seines

Due to the lighter gear components, demersal seines are likely to entrain less sediment into the water column than other demersal towed gears. While the potential impacts of entrainment of sediment and smothering on the biological communities will be similar to other gears, they are likely to be to a lesser degree from demersal seines.

8.4.3 Removal of target species

Bottom towed gears target demersal marine species. With the exception of sandeels within certain sandbanks and sediment habitats, these do not tend to be representative species of the 'characteristic community' (includes representative communities such as those covering large areas, and notable communities, such as nationally or locally rare or scarce, or known to be particularly sensitive).

Multi-rig, bottom otter trawls and semi-pelagic trawls

Sandeels are most commonly targeted by bottom otter and semi-pelagic trawls. The role of sandeels in sediment habitats and whether their presence or absence affects habitat condition is unclear. Target species removal is therefore likely to be a lesser concern than the removal/damage/mortality of non-target species, however site level assessments, particularly regarding sand eels, will be required to confirm these assumptions.

8.4.4 Removal of non-target species

As noted previously, demersal trawls and dredges may impact the biological communities of sandbank and sediment habitats through damage and mortality. The majority of this will occur on the seafloor caused by abrasion and penetration pressures (covered in section 8.4.1), however the uprooting and removal of non-target species through bycatch will further contribute to impacts on the biological community of bottom towed gears.

The mortality of non-target species caught by demersal gear such as beam trawls varies. One study found that beam trawl mortality ranges from 0 to 31% for hermit crab, whelks and starfish, 23 to 67% for crabs and to 26 to 88% for bivalves such as *Arctica islandica* (Lindeboom and de Groot, 1998) while others (de Groot and Lindeboom, 1994) found high mortalities (70 to 100%) for undersized, discarded fish, 50% or less for most crabs and molluscs and less than 10% for starfish.

Fragile species such as the soft coral (for example dead man's fingers *Alcyonium digitatum*) are particularly vulnerable as they are highly sensitive to removal and displacement (Jager et al., 2018). *Alcyonium digitatum* is permanently attached to the substratum and once displaced does not have the ability to re-establish its attachment (Jager et al., 2018).

Trawling can cause declines in benthic biota irrespective of habitat type (Hiddink et al., 2017) and can have large negative effects on the biomass and production of benthic communities across shallow, soft sediment areas (Hiddink et al., 2006). Jennings and Kaiser (1998) noted that within heavily fished areas, the removal of large epibenthic organisms can lead to long-term reductions in structural complexity and declines in the abundance of fishes associated with the epibenthic community.

Multi rig, bottom otter and semi-pelagic trawls

In otter trawls, the reduced penetration of ground-ropes compared with other gears results in otter trawl bycatch consisting mainly of demersal fish and epifaunal invertebrates as opposed to infauna (Creutzberg et al., 1987). This can include the removal of hard substrates along with their attached fauna (Auster et al., 1996; Thrush and Dayton, 2002; Buhl-Mortensen et al., 2013).

As detailed previously, semi-pelagic gears are towed on or very close to the seabed. As such, removal of species is likely to be similar to that of otter trawls with regard to epifauna and reduced with regard to infauna owing to the similar abrasion but reduced penetration respectively. However little evidence is available to quantify the remaining impact.

Beam trawls

Analysis of non-target species bycatch data from a historic beam trawl fishery suggests that such fisheries have had a considerable impact on the abundance of several by-catch species (Philippart, 1998). Beam trawling catches a large range of bottom-living species and is not a well-targeted fishery, often with poor selectivity and the potential to catch a wide variety of non-target bycatch (Seafish, 2022). Beam trawls tend to catch much more bycatch than scallop dredges (Kaiser and Spencer, 1996) and can have negative effects on non-target species and benthic communities, resulting in declines in productivity and biomass with high mortality rates recorded for various benthic organisms (Bergman and Hup, 1992; Løkkeborg, 2005; Sewell et al., 2007; Smith, 2020).

Changes in benthic community structure are known to occur following beam trawling (through a combination of damage/mortality via abrasion/penetration pressure and removal of non-target species) but the effects can be variable (Jennings and Kaiser, 1998; Lindeboom and de Groot, 1998). Tiano et al. (2020) found that beam trawling simplifies the benthic food web. In line with Johnson (2002), Tiano et al. (2020) observed reduced numbers of epifaunal organisms and shallow burrowers, with macrofaunal density of surface-dwelling organisms lowered by up to 74%.

A substantial amount of research in recent years has focused on increasing species selectivity in beam trawls to reduce unwanted bycatch. Revill and Jennings (2005) found that by incorporating benthic release panels into beam trawl nets, invertebrate bycatches were reduced by 75 to 80% and that more than 90% of the animals released survived. However, Bergman and Van Santbrink (2000) found that, when considering fishing with beam trawls, the greatest amount of mortality is left on the seabed rather than occurring as bycatch and will include fauna directly killed or damaged by the passing of a trawl and increasing the likelihood of falling prey to mobile scavengers (Bradshaw et al., 2001; Shephard et al., 2009; Craven et al., 2013).

Dredges

The epifauna and infauna assemblages of both stable and dynamic fine sands are known to be susceptible to direct physical disturbance from dredges which penetrate and disturb the sediment (Roberts et al., 2010). A meta-analysis by (Kaiser et al., 2006) indicated that both deposit- and suspension-feeders were consistently vulnerable to scallop dredging across gravel, sand and mud habitats.

Dredges can cause large amounts of bycatch for a range of non-commercially targeted species, the majority of which is discarded, damaged, dying or dead (Howarth and Stewart, 2014) which includes captured and non-captured undersized scallops. Fatal damage from the passing of a scallop dredge ranges from 2% to more than 20% of undersize scallops, depending on the fishing grounds (Beukers-Stewart and Beukers-Stewart, 2009). Non-fatal damage can also occur with 7% (this includes individuals above and below minimum conservation reference size and both caught as bycatch and left on the seabed) of scallops being damaged by the trawl (Jenkins et al., 2001). Despite undersize scallops being discarded and potentially not receiving fatal damage, they have an increased likelihood of predation due to reduced predator escape responses following discard and localised increases in predators and scavengers following trawls (Bradshaw et al., 2001; Shephard et al., 2009; Craven et al., 2013). Dredging can therefore cause indirect and direct mortality of undersized scallops as a result of fatal and non-fatal damage. This may reduce the survival or productivity of juvenile scallops before they have had a chance to breed or recruit to the fishery (Beukers-Stewart and Beukers-Stewart, 2009).

Hinz et al. (2012) found that for every scallop captured by a Newhaven dredge, four individuals of bycatch were also caught. An assessment of the 10 most common bycatch species in the Irish Sea scallop fishery found that approximately 20 to 30% of individuals suffered fatal damage after dredge capture (Shephard et al., 2009).

Overall, species diversity and richness, the total number of species and the number of individuals, are found to decrease significantly with increased fishing effort (Veale et al., 2000) through a combination of abrasion/penetration pressures and removal of non-target species.

Hinz et al. (2012) studied the environmental impact of different types of queen scallop fishing gears, including dredges. Results showed that traditional scallop dredges contained larger amounts of non-target species such as invertebrates than other gear types such as otter trawls and clear negative impacts were found for the brittlestar, *Ophiura* (Hinz et al., 2012). Species such as brittlestars, as well as other benthic invertebrates, are known to be key members of sandbank and sediment biological communities.

In regularly disturbed habitats, recovery rates for macrofauna are slow and range from <1 to 8 years (Kaiser et al., 2006; Hiddink et al., 2017), depending on species and sediment type (Hale et al., 2017). Recovery for slow-growing species, such as soft corals are much longer (up to 8 years) than biota with shorter lifespans such as polychaetes (<1 year) (Kaiser et al., 2006; Hinz et al., 2011).

Demersal seines

As detailed previously, demersal seines tend to be considered less damaging to seabed habitats due to the reduced abrasion and penetration associated with the gear when compared with other bottom towed gears (Eigaard et al., 2016).

However, demersal seines have the potential to disturb, damage and remove sessile and mobile epifauna when the ropes of a seine net are closed up in order to herd demersal fish (van der Reijden et al., 2014; Bureau Waardenburg, 2017).

Observations in the North Sea show that seining caught 19 of the typical sandbank species across the anthozoa, crustacea, echinoderm, mollusca and fish groups (van der Reijden et al., 2014; Bureau Waardenburg, 2017). All fish species excluding *Raja clavata* were target species and all other species were bycatch. Bycatch included long-lived species: *Alcyonium digitatum* (10 to 28 years), *Arctica islandica* (100and years), *Pagurus bernhardus* (6 to 10 years), *Buccinum undatum* (11 to 20 years) and *Neptunea antiqua* (21 to 100 years) (van der Reijden et al., 2014; Bureau Waardenburg, 2017). The occurrence in bycatch as well as the sensitivity of *A. islandica* and *B. undatum* to seining is also shown in further studies from the North Sea (Wijnhoven et al., 2013; Rijnsdorp, 2015; Verschueren, 2015). Long-lived species have life history traits such as slow growth, late maturity and low fecundity. This results in slow recovery rates and high vulnerability to fishing disturbance. As a result, demersal seining may affect the structure and function of the benthic communities associated with sandbanks.

8.5 Variation in impacts

When pulled across the seabed, various parts of a demersal towed gear can cause penetration, abrasion, or disturbance of the seabed surface substrate. Evidence suggests bottom towed gear impacts vary depending on gear type, with attributes such as penetration depth having a strong influence on the level of impact (Sciberras et al., 2018). Eigaard et al. (2016) summarised penetration depths of bottom towed gears from the literature, this has been reproduced for reference in Table 4.

The degree of disturbance from fishing is dependent on three main factors: the type of fishing gear deployed, the intensity of the fishing activity, and the sensitivity of the habitat. If a pressure or impact occurs too frequently for a habitat to recover, the biomass and productivity of the benthic community declines (Foden et al., 2010).

Table 4. Penetration depths (cm) of key gear components estimated from literature plus impact index condensed across sediment types (surface level impact, subsurface level impact, and maximum penetration depth in parenthesis). Recreated from (Eigaard et al., 2016)[4].

Gear types	Gear components	Coarse sediment	Sand	Mud	Mixed sediments	Indexed component impacts (maximum depth in brackets in cm)
Otter Trawl	Sweeps and bridles		0–2	0		Surface (<2)
	Sweep chains		0–2	2–5		Subsurface (≤5)
	Tickler chains	2–5	2–5		2–5	Subsurface (≤5)
	Trawl doors	5–10	0–10	≤15–35	10	Subsurface (≤35)
	Multi-rig clump		3–15	10–15		Subsurface (≤15)
	Groundgear		0–2	0–10	1–8	
Demersal Seine	Seine ropes*					Surface (<2)
	Groundgear*					
Beam trawl	Shoes	≤5–10	≤5–10	≤5–10	≤5–10	Subsurface (≤10)
	Tickler chains	≤3–10	≤3–10	≤10	≤3	Subsurface (≤10)
	Groundgear		1–8		0	
Dredge	Groundgear		1–15	6		

[4] See Eigaard et al. (2016) for a more comprehensive review of the studies contributing to this table.

The sensitivity and recovery rate of a sandbank or sediment habitat can also vary depending on several factors including the fishing intensity and gear type (Sciberras et al., 2018); exposure to natural disturbance and sediment mobility (Hall et al., 2008); the underlying sediment type and biological community present (Bradshaw et al., 2001; Lambert et al., 2017).

While sensitivity to bottom towed gear impacts could vary with sediment type, bottom towed gears can reduce the epifauna abundance in both sand and gravel habitats, and therefore such generalisations do not consider taxa-specific vulnerabilities to bottom towed gears (Lambert et al., 2017) and the intensity and extent of bottom towed gear activity that is sustainable, even in more resilient habitats, remains unclear (Stewart and Howarth, 2016).

The majority of data available considers the impact of demersal trawls and dredges. These will have considerably greater impacts to the sandbank biological community due to the increased abrasion and penetration these gears have when compared with demersal seines. However, the overriding principles are likely to be similar for demersal seines albeit to a lesser degree.

8.5.1 Fishing intensity

The intensity and regularity of bottom towed gear activity can affect the degree of impact on sediment habitats as well as their recovery. The first pass of a trawl has the largest initial impact on biomass and production of sediments (Hiddink et al., 2006) whereas in areas of high trawling intensity, further increasing trawling intensity can have smaller additional effects on biomass and production (Hiddink et al., 2006). Given that there are few areas of sediment habitats that are unimpacted by bottom trawling (or other anthropogenic impacts) (OSPAR, 2017) and the first pass of a trawl causing the greatest damage, many studies are likely analysing already impacted seabeds making understanding of the impacts of fishing intensity complex. Sandbanks and sediment habitats in the UK have been subject to human exploitation since before the 16th century, yet our understanding of these habitats and how fishing may impact them has developed only recently (Plumeridge and Roberts, 2017). As such, there is the potential for underestimating the alteration of these ecosystems due to shifting baseline syndrome (Plumeridge and Roberts, 2017).

Species which are the first to be removed by trawling are those that are most sensitive with repetitive trawling, leading to a shift in the composition of benthos towards smaller-bodied, mobile, robust and shorter-lived species (Kaiser et al., 2000; Bradshaw et al., 2002; Tillin et al., 2006; De Juan et al., 2007; Rijnsdorp et al., 2018). The removal of large epibenthic organisms from heavily fished areas can lead to long-term reductions in structural complexity and declines in the abundance of fishes associated with the epibenthic community (Jennings and Kaiser, 1998).

Jennings et al. (2001) analysed the variations in impacts of different trawling intensities in the central North Sea. Chronic trawling (on average 6.5 times per year) was linked to significant declines in infaunal productivity and biomass, whereas less frequent beam trawling (on average 2.3 times per year) had no significant effect on infauna. This suggests that trawling at frequencies of less than three times per year may not have adverse, long-term effects on benthic communities in sandy habitats (Jennings et al., 2001; Kaiser, 2014). However, they did note their results should not be interpreted as evidence that low levels of trawling disturbance have no effect on benthic community structure (Jennings et al., 2001). All their study sites were trawled to differing degrees and all sites have been fished for decades (if not centuries) so significant differences between their study sites and unfished sites may still be apparent as previously unfished sites are often the most vulnerable to fishing effects (Jennings and Kaiser, 1998).

Ball et al. (2000) found that unfished areas were found to have higher species diversity and numbers of individual organisms and biomass than fished areas, with large specimens of echinoderm and mollusc species present at unfished sites and absent from fished sites. Sewell and Hiscock (2005) noted that areas which have been intensively trawled for several years still support profitable fisheries which would not be possible without ample benthic food. It has therefore been suggested that the previously mentioned trawling induced a shift in the benthic community in sandbank or sediment habitats to a dominance of opportunistic species such as polychaetes remains highly productive (Gislason, 1994; Jennings and Kaiser, 1998; Rijnsdorp et al., 1998; Kröncke, 2011).

While some authors have argued that physical disturbance, such as that caused by bottom towed gears, simply speeds up a release of sediment solutes that would otherwise have occurred more slowly through diffusion or bioturbation (Sloth et al., 1996; Blackburn, 1997), others argue that alterations to sediment stability and structure, sediment redox conditions, and benthic communities (especially bioturbators) may lead to chronic longer-term changes in sediment biogeochemistry (Duplisea et al., 2001) and sediment-water fluxes (Bradshaw et al., 2021). Disturbance at a frequency greater than the timescale needed for re-equilibration of sediment biogeochemical gradients may result in these sediments always being in a transient state (Duplisea et al., 2001; Van De Velde et al., 2018; Bradshaw et al., 2021).

The recovery rate of faunal assemblages can also depend on the intensity and or frequency of the fishing disturbance (Hall et al., 2008) with intertidal sediment habitats exhibiting faster recovery rates to low intensity disturbance (less than 100 days) than high intensity disturbance (over 200 days) (Dernie et al., 2003). While the findings of this study are useful, it should be noted that this study was performed at a scale which does not specifically relate to bottom towed gears in subtidal habitats and is more relevant to intertidal bait-digging, hand collection of cockles and hydraulic dredging.

Through a meta-analysis of various studies, Collie et al. (2000) found similar recovery rates to Dernie et al. (2003) with the fauna of sandy seabeds recovering in approximately 100 days and tolerating two to three trawl passes per year. However, Jennings et al. (2001) noted that that such rates of recovery for mobile species are assumedly largely due to immigration, since life histories of benthic species (Brey, 1999) suggests regeneration of the population would not occur on this time scale. The effects of repeated trawling over large areas, as occurs in real fisheries, may therefore have collective effects that small experimental recovery studies are unlikely to detect.

8.5.2 Natural disturbance

Areas of high natural disturbance (strong currents, tides or storm events) may be less sensitive to bottom towed gear activity and able to recover more quickly (Bergman and Van Santbrink, 2000; Løkkeborg, 2005; Beukers-Stewart and Beukers-Stewart, 2009; Bolam et al., 2014; Grieve et al., 2014; Lambert et al., 2014) due to such areas having low initial species biomass (Hiddink et al., 2006; Sciberras et al., 2013) resulting from naturally occurring sediment erosion, re-suspension of organic matter and impaired settlement of new recruits. Areas with low natural disturbance and low sediment mobility are likely more sensitive to bottom towed gear activity and more prone to physical damage (Bergman and Van Santbrink, 2000; Bolam et al., 2014; Tillin and Tyler-Walters, 2014) due to the more developed, fragile and less mobile epifauna and infauna present in such sediments (Hall et al., 2008; Lambert et al., 2014). Several studies have associated a reduced or lack of observed trawling impact to higher levels of natural disturbance due to the adaptation of benthic fauna to the greater intensity and or frequency of disturbance events (Queirós et al., 2006; van Denderen et al., 2015)

Kaiser et al. (1998) assessed changes which had taken place to megafaunal benthic communities from two different habitats (one with stable sediments and a rich fauna; the other with mobile sediment and a relatively impoverished fauna) following beam trawling. For the mobile sediment, no effects of trawling were apparent, whereas in the stable sediment, immediately after fishing, the biological community was significantly altered with reduced abundance of some species and increased abundance of others (Kaiser et al., 1998). The authors noted it could take up to six months for all signs of the trawling disturbance to disappear (Kaiser et al., 1998).

In a comparative study of the effects of scallop dredging between a seasonally fished and a permanently closed area, Sciberras et al. (2013) found that abundance of scallops and epibenthic community composition were the same in both sites. Alongside potential seasonal fluctuations in species abundance, the study posited that relatively high level of natural disturbance in the study area could obscure the effect of fishing on benthic communities (Sciberras et al., 2013).

It should be noted however that while potential impacts of natural disturbance and fishing disturbance may be comparable with regard to disturbance or mortality, pressures deriving from natural and fishing disturbance are not directly comparable (Johnson et al., 2017). Fishing results in pressures not associated with natural disturbance such as crushing and damage to infauna resulting from penetration into the sediment (ABPmer and Ichthys Marine, 2015). Therefore, the direct impacts of trawled fishing gear may not directly relate to the impacts of sediment mobilisation caused through natural disturbance, and it would be wrong to preclude negative impacts due to fishing disturbance in areas of high natural disturbance (Diesing et al., 2013). Additionally, natural disturbance and fishing activity do not occur in isolation from each other. Fishing activity in naturally disturbed environments will increase the disturbance levels/frequency above which may naturally occur so effects may be cumulative. Also, disturbance from the two sources are likely to peak at different times of year with storm events more likely to occur over winter (Johnson et al., 2017) which may not be the case for fishing activity. As a result, fishing activity has the potential to extend the longevity of disturbance events throughout the year and potentially prevent the recovery of habitats which may normally occur outside of storm seasons (Johnson et al., 2017). There is also recent evidence suggesting that habitats are able to recover more quickly from storm disturbance than that of bottom towed gears and prohibition of bottom towed gears enhances habitat resilience allowing faster recovery from storm disturbance than a comparable habitat open to bottom towed gear activities (Sheehan et al., 2021). While this study is mainly concerned with rock and reef habitats, coarse sediments are present in the study area and the principle of increased ecological resilience through reducing anthropogenic disturbance may similarly apply to sedimentary habitats. Indeed, the authors of the above study highlight the potential role protection of soft sediment habitats from human disturbance, within and around MPAs, in improving the resilience of MPAs to all forms of disturbance (Sheehan et al., 2021).

Natural biological disturbance may also be generated by benthic megafauna, such as lobsters and fish. Simpson and Watling (2006) reported seasonal trawling produced at least short-term changes in macrofaunal community structure but did not seem to result in any long-term cumulative changes. The authors surmised that resilience to trawling disturbance could be attributed to high levels of biological disturbance generated by benthic megafauna (Simpson and Watling, 2006). By burrowing, pit-digging, and possibly foraging, animals such as fish and lobsters rework sediments to a depth of almost 20 cm, creating a natural level of disturbance that appears to maintain macrofaunal communities in a constant state of change, so potentially minimising trawling impacts (Simpson and Watling, 2006).

Fishing disturbance may not be the only pressure changing the benthic community structure of sandbank and sediment habitats. Hydroclimatic changes may also be having an effect (Kröncke and Reiss, 2007). Recorded decreases in species numbers and increased numbers of small polychaetes could also be due to changes in the North Atlantic Oscillation system, which in-turn is driving increased sea surface temperature and changes in food availability and sediment structure (Kröncke and Reiss, 2007). The presence of climate-driven factors does not exclude the possibility that fishing also contributes to community changes, with continuous fishing potentially preventing the re-establishment of once-dominant bivalve communities (Kröncke, 2011).

8.5.3 Sediment type / Species presence

Evidence regarding the different sensitivities of sediment habitats, individually and within sandbanks, to bottom towed gear activity is provided below however it should be noted that such generalisations do not consider taxa-specific vulnerabilities, whereby some species (for example soft corals) may suffer significant and enduring effects (Lambert et al., 2017; Jager et al., 2018).

Subtidal coarse sediment

Communities in gravel habitats are generally considered to be particularly sensitive to bottom towed gear activity (Collie et al., 2000; Hermsen et al., 2003; Bolam et al., 2017; Rijnsdorp et al., 2018), as such habitats contain large proportions of long-lived and more sessile epifauna (Bolam et al., 2017; Rijnsdorp et al., 2018) which are easily damaged or removed by the pass of bottom towed gears leading to reduced diversity, abundance and occurrences (Freese et al., 1999; Hinz et al., 2011; Pikesley et al., 2021). Collie et al. (1997) found that, compared with disturbed sites, subtidal coarse sediments undisturbed by bottom towed fishing gears were characterised by an abundance of bushy epifaunal taxa (bryozoans, hydroids, worm tubes) providing complex habitat for shrimp, polychaetes, brittle stars, mussels and small fish and as such had higher numbers of organisms, biomass, species richness and species diversity. Veale et al. (2000) obtained similar results with significant reductions in species diversity, richness, total species number and number of individuals with increasing fishing effort. This also translated to productivity with the production of most major individual taxa decreasing significantly with increased fishing effort.

Similarly, there is evidence to suggest the recovery of subtidal coarse sediments to disturbance may be longer than softer sediments, with studies demonstrating fragile species such as *A. digitatum*, showing no discernible recovery after four months of trawling had taken place (Lambert et al., 2017) and trawling tracks from scallop dredges persisting for up to ten months in coarse sediment unlike in sand where no discernible dredge tracks were visible (Lambert et al., 2015).

Evidence regarding the impact of bottom towed gears on subtidal coarse sediments however is not conclusive. Kaiser et al. (2006) found no detectable impact from otter trawling on sand and gravel communities and Lambert et al. (2017) found the benthic community structure, biomass and abundance of coarse sediments, at the population level, to be resilient to fishing, and able to be fished up to six times before changes mimicking that of natural variation occurred. These studies align with the sensitivity study conducted by (Rayment, 2001) which found some coarse sediment biotopes to have intermediate intolerance to abrasion, physical disturbance and displacement, with a high recoverability rate.

These contradictions suggest other variables outside of sediment type are likely to affect the level of impact such as the size and weight of the gear, the area fished and depth (Collie et al., 2000; Kaiser et al., 2002).

No longer-term studies are currently available regarding the impact of bottom towed gears on subtidal coarse sediments. This was highlighted by Lambert et al. (2017) as a limitation to their study, with the chronic impact of fishing needing continuous monitoring to ensure the taxa-specific changes they observed after four months do not result in long-term trends that could affect the population structure.

Subtidal sand

This habitat is characterised by clean, medium to fine sands, or non-cohesive slightly muddy sands, supporting a range of taxa including polychaetes, bivalve molluscs and amphipod crustacea (EEA, 2019b). There is limited information on the impacts of bottom towed gear on subtidal sand. Kaiser et al. (2006) observed an immediate 70% and 35% reduction of benthic fauna in subtidal sand and muddy sand respectively following beam trawling. However, this appeared to be short lived. Recovery times for benthic biota in sandy habitats to beam trawling do appear variable however, with studies reporting biota abundance recovering within 7 to 236 days of a trawling event (Kaiser et al., 1998, 2006; Foden et al., 2010). Collie et al. (2000) noted that recovery from disturbance occurred most rapidly in sand in comparison to other habitat types.

Clean sand and 'well sorted' sediments generally appear to have greater resilience to and recovery from, fishing disturbance (Collie et al., 2000; Dernie et al., 2003; Kaiser et al., 2006; Bolam et al., 2014; Handley et al., 2014; Lambert et al., 2015). The 'robust' species that characterise fine sands have the potential for relatively rapid habitat restoration and recolonisation (Hall et al., 2008), particularly in areas experiencing high levels of natural disturbance, likely through both active and passive migration of fauna (Roberts et al., 2010). For instance, Kaiser et al. (2006) observed an immediate 70% reduction of benthic fauna on subtidal sand following beam trawling. However, this appeared to be short lived with no change detectable two to seven days after the fishing event. Relatively rapid recolonisation is most likely a result of active and passive migration of adult organisms into disturbed areas (Mclusky et al., 1983) since life histories of benthic species (Brey, 1999) suggest regeneration of the population would not occur on this time scale. The effects of repeated trawling over large areas, as occurs in real fisheries, may therefore have collective effects that small experimental recovery studies are unlikely to detect.

However, larger, slow-growing fauna can also form part of sandy sediment communities; the recovery time for these species, such as *Mya truncate*, *Mya arenari*a and *Arctica islandica* are likely to be much longer (Beukema, 1995; Witbaard and Bergman, 2003; Roberts et al., 2010). Foden et al. (2010) reviewed available literature for recovery times of seabed habitats and compared these with bottom towed gear activity and found that in some areas, habitats such as muddy sand and sand and gravel are trawled too frequently for the habitat to recover.

As the mud fraction of sand increases (for example muddy sand vs coarse sand) recovery times also increase (Dernie et al., 2003) with meta-analysis by Collie et al. (2000) revealing that muddy sand habitats had the slowest rate of community restoration following fishing disturbances in soft sediment habitats. Negative effects on population were also found by (Collie et al., 2000) to be most significant in muddy sand and gravel habitats. Similarly, tracks of beam trawls become more noticeable as the mud fraction of the sand increases (Margetts and Bridger, 1971; de Groot, 1984); however, traces of such tracks soon disappear in most cases due to the action of waves and tides.

Subtidal mud

Subtidal mud habitats generally feature widespread, small scale, low relief topographic features such as ripples (Kaiser et al., 2002; Grieve et al., 2014). Habitat complexity is further enhanced through bioturbation creating mounds, burrows and polychaete tubes (Nilsson and Rosenberg, 2003; Grieve et al., 2014). Sediment penetration from otter boards creates furrows with much greater topographic relief than is normally present in these habitats, whilst abrasion flattens out small-scale topography, reducing the habitat complexity (Kaiser et al., 2002; Nilsson and Rosenberg, 2003; Polet and Depestele, 2010; Grieve et al., 2014). Penetration depths of demersal gears in mud habitats are considerably deeper than in sandy habitats 30 to 60 mm versus 10 mm respectively (Gubbay and Knapman, 1999). This results in a smooth seafloor interspersed infrequently with high relief features created by the furrows (Kaiser et al., 2002) which can remain for years in sheltered areas (Lindeboom and de Groot, 1998; Palanques et al., 2001).

In muddy sediments, disturbance leads to larger changes in the biogeochemistry, due to the greater role of macrofauna-mediated processes, compared to sand, where hydrodynamics mediate the redox system (Sciberras et al., 2013). Sediment biogeochemistry (the capacity of the sediment to recycle organic matter to bioavailable nutrients) is an important process in coastal seas as primary production is heavily dependent on the nutrients regenerated in the sediment (Soetaert and Middelburg, 2009; Provoost et al., 2013). Nutrients, other chemical substances and pollutants may also be released by trawling events (Eigaard et al., 2016). De Borger et al. (2021) found that denitrification from trawling was reduced by 69% in a fine sandy sediment, whereas nitrogen removal nearly doubled in a highly eutrophic mud. The shallow-penetrating gear studied had a slightly smaller effect on benthic denitrification than the deeper-penetrating gear, but there were no statistically different results between gear types for all other parameters (De Borger et al., 2021). This suggested that even relatively low penetration depths from bottom fishing gears generated significant biogeochemical alterations.

As noted previously, sediment biogeochemistry in consistently disturbed sediments may remain in a transient state, leaving them permanently recovering from a disturbance event (Van De Velde et al., 2018; Bradshaw et al., 2021; Morys et al., 2021). However, few long-term studies of trawling impacts have been completed in muddy sediments. Those which have been completed found highly variable recovery times from days (Sanchez et al., 2000; Kaiser et al., 2006) to months (Sparks-McConkey and Watling, 2001; Simpson and Watling, 2006; Smith et al., 2007) or years (Tuck et al., 1998) and contrasting impacts on the benthic community. The differences in recovery times are likely a result of the degree of natural disturbance and the intensity of fishing activity with Tuck et al. (1998) studying intense trawling activity in a sheltered sea loch that had been closed to fishing for 25 years, versus Simpson and Watling (2006) studying areas of the Gulf of Maine open to shrimp trawling for three months of every year. The MPAs relevant to this review are subject to greater natural disturbance and likely lower trawling intensities. Therefore, the results obtained by Tuck et al. (1998) may not be representative of impacts to mud habitats within the relevant MPAs.

Due to the low exposure to natural disturbance and high levels of sediment deposition that tend to be associated with subtidal muddy habitats, they often support high densities of infaunal communities and erect epifauna such as sea pens and burrowing anemones (Ball et al., 2000; Hall et al., 2008) which are susceptible to trawl disturbance (Ball et al., 2000; Kaiser et al., 2002; Sewell and Hiscock, 2005; Queirós et al., 2006) with evidence for trawling reducing densities of the tall sea pen, *Funiculina quadrangularis*, and its symbiotic brittle star, *Asteronyx loveni*, (Adey, 2007) and 5 to 50% direct mortality to many invertebrate species, increasing to 68% for some bivalve species from a single passage of a beam or otter trawl (Bergman and Van Santbrink, 2000). This can lead to reduced benthic habitat quality (Rosenberg et al., 2003).

This disturbance can have ecological impacts such as reduced biomass, diversity and species richness, changes in community structure (Tuck et al., 1998; Sparks-McConkey and Watling, 2001; Kaiser et al., 2002; Hiddink et al., 2006; Ragnarsson and Lindegarth, 2009) as well as changes in where sensitive species can be found (Josefson et al., 2018). However, these impacts can occur in isolation from each other as detailed by Ragnarsson and Lindegarth, (2009) and have not been identified in all trawling studies on muddy habitats (Ocean Ecology Ltd, 2018).

Some evidence suggests these impacts are likely to be greater in muddy habitats than sandy habitats (Bergman and Van Santbrink, 2000; Queirós et al., 2006; Rijnsdorp et al., 2020). However, this is inconclusive as other studies have found greater mortality rates of benthic fauna in sand habitats when compared with mud (Hiddink et al., 2006). Such conflicting evidence demonstrates that our understanding of how trawling impacts vary with habitat type remains incomplete (Hiddink et al., 2017).

Subtidal mixed sediments

Very little evidence is available regarding the impact of bottom towed gears on subtidal mixed sediments; however, the biological communities are likely vulnerable (Kaiser et al., 2006; Pikesley et al., 2021). Tillin et al. (2010) suggest mixed sediments are more susceptible to surface and subsurface penetration than subtidal sand and subtidal coarse sediments. Recovery may be slow with Blyth et al. (2004) finding that two years post bottom towed gear fishing, the benthic community composition of a mixed coarse substratum area impacted by towed gear was approaching but still not matching the composition of an adjacent area where only static gears were permitted.

8.6 Summary of the effects of bottom towed gear on sandbanks and sediments

Bottom towed gears have the potential to impact Annex I sandbank features, their sediment sub-features and MCZ sediment habitats. As such, management may be required for SACs and MCZs designated for these features. A site level assessment considering the site conservation objectives, intensity of fishing activity taking place, exposure to natural disturbance and potential presence of particularly sensitive species will be needed to determine whether management will be required.

The site level assessment will assess fishing activities for their impact upon protected habitats and species. Specifically, this assessment considers the potential for these activities to hinder the conservation objectives of the MCZ or have an adverse effect on the site integrity of the SAC. The data used in the assessment will include VMS data, as well as feature habitat data from JNCC and Natural England. Where the assessment concludes that the current level of management is not sufficient to protect the designated features of the site, recommended management options will be provided. MMO has regard to the best available evidence and through consultation with relevant advisors, stakeholders, and the public, will conclude which management option is implemented.

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Annex 1 Gear pressures on sensitive features – bottom towed gear

This annex summarises the pressures of bottom towed gear on the features described in this document.

JNCC and Natural England's advice on operations (AoO) provide generic information on pressures that may be exerted by all marine industries, they are an evidence-based product to be used to guide assessments together with bespoke advice from JNCC and Natural England. This is explained further in Natural England's conservation advice guidance.

The sensitivities of designated features to gear pressures were derived using a staged approach. JNCC and Natural England's conservation advice packages (CAP) and AoO have been used by MMO to determine the sensitivities of each feature to the potential pressures from bottom towed fishing gear, based on actual or representative sites to highlight subject areas for evidence gathering. JNCC and Natural England also provided additional guidance about pressure/feature interactions that should be considered.

An evidence-gathering activity was then carried out. Evidence gathering and analysis was focussed on interactions that were deemed sensitive and high risk, as these are likely to be the most relevant interactions to be considered at each site level assessment (Table A1. 1). Interactions where there was insufficient evidence (IE) are not considered further here. These interactions will be considered in site-level assessments where there is a known condition issue or further advice is received from JNCC or Natural England (Table A1. 1). Where multiple sensitivities exist for features located across different bioregions, the most precautionary sensitivity has been displayed. Site-specific sensitivities will be used at the site level assessment stage.

The pressures of bottom towed gear on designated features are displayed in Table A1. 2 (demersal seines and trawls) and Table A1. 3 (dredges). It summarises all the interactions according to the key in Table A1. 1.The pressures listed in Tables A1. 2 and A1. 3 are defined in JNCC AoO descriptions of pressures, based on Appendix 1 of the UK Marine Pressures-Activities Database 'PAD': Methods Report | JNCC Resource Hub (Robson et al., 2018).

Table A1. 1. Gear/feature interaction sensitivity key. Pressures discussed within this review will be shown in red.

Key	
S	Indicates the feature is sensitive.
S*	Indicates the feature is sensitive to the pressure in general, but fishing activity/gear type is unlikely to exert that pressure to an extent where impacts are of concern (i.e. will be below pressure benchmarks).
IE	Indicates there is insufficient evidence to make sensitivity conclusions or a sensitivity assessment has not been made for this feature to this pressure.
NS	Indicates feature is not sensitive to pressure.
NS*	Indicates the feature is currently listed as not sensitive but JNCC and Natural England have advised that it should be considered further on a case-by-case basis at the site level.
NR	Indicates the pressure is not relevant for the gear type. There is no interaction between the pressure and biotope/species and/or no association between the activity and the pressure.

Table A1. 2. Summary of the sensitivities of designated features to potential pressures from demersal seines and trawls. Pressures discussed within this review are shown in red.

	Designated Features						
	MCZ species			Annex I sandbanks and MCZ subtidal sediment habitats			
Potential Pressures	**Sea-pen and burrowing megafauna communities**	**Fan mussel**	**Ocean quahog**	**Subtidal coarse sediment**	**Subtidal mixed sediments**	**Subtidal mud**	**Subtidal sand**
Above water noise	NR	NR	NR	NR	NR	NR	NR
Abrasion or disturbance of the substrate on the surface of the seabed	S	S	S	S	S	S	S
Barrier to species movement	NR	NR	NR	NR	NR	NR	NR
Changes in suspended solids (water clarity)	NS	S*	NS	S	S	S	S
Collision ABOVE water with static or moving objects not naturally found in the marine environment	NR	NR	NR	NR	NR	NR	NR
Collision BELOW water with static or moving objects not naturally found in the marine environment	NR	NR	NR	NR	NR	NR	NR
Deoxygenation	S*	S*	NS	S*	S*	S*	S*
Hydrocarbon + PAH contamination	IE	IE	IE	IE	IE	IE	IE
Introduction of light	NS	NR	NR	S*	IE	NS	S*
Introduction of microbial pathogens	NR	NR	NR	NR	NR	NR	NR
Introduction or spread of invasive non-indigenous species	IE	IE	IE	S*	S*	S*	S*
Litter	IE	IE	IE	IE	IE	IE	IE
Nutrient enrichment	NS	NS	NS	NR	NR	NR	NR
Organic enrichment	S*	IE	NS	S*	S*	S*	S*
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	S	S	S	S	S	S	S
Physical change (to another seabed type)	S*	S*	S*	S*	S*	S*	S*
Physical change (to another sediment type)	S*	NS	S*	NR	NR	NR	NR
Removal of non-target species	S	S	S	S	S	S	S
Removal of target species	NS*	NR	NR	S	S	NS	S

	Designated Features						
	MCZ species			Annex I sandbanks and MCZ subtidal sediment habitats			
Potential Pressures	Sea-pen and burrowing megafauna communities	Fan mussel	Ocean quahog	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal mud	Subtidal sand
Smothering and siltation rate changes	NS	S	NS	S	S	S	S
Synthetic compound contamination	IE	IE	IE	IE	IE	IE	IE
Transition elements & organo-metal contamination	IE	IE	IE	IE	IE	IE	IE
Underwater noise changes	NR	NR	NR	NR	NR	NR	NR
Visual disturbance	NR	NR	NR	NR	NR	NR	NR

Table A1. 3. Summary of the sensitivities of designated features to potential pressures from dredges. Pressures discussed within this review are shown in red.

	Designated Features						
	MCZ species			Annex I sandbanks and MCZ subtidal sediment habitats			
Potential Pressures	**Sea-pen and burrowing megafauna communities**	**Fan mussel**	**Ocean quahog**	**Subtidal coarse sediment**	**Subtidal mixed sediments**	**Subtidal mud**	**Subtidal sand**
Above water noise	NR	NR	NR	NR	NR	NR	NR
Abrasion or disturbance of the substrate on the surface of the seabed	S	S	S	S	S	S	S
Barrier to species movement	NR	NR	NR	NR	NR	NR	NR
Changes in suspended solids (water clarity)	NS	S*	NS	S	S	S	S
Collision ABOVE water with static or moving objects not naturally found in the marine environment	NR	NR	NR	NR	NR	NR	NR
Collision BELOW water with static or moving objects not naturally found in the marine environment	NR	NR	NR	NR	NR	NR	NR
Deoxygenation	S*	S*	NS	S*	S*	S*	S*
Hydrocarbon + PAH contamination	IE	IE	IE	IE	IE	IE	IE
Introduction of light	NS	NR	NR	S*	IE	NS	S*
Introduction of microbial pathogens	S*	IE	NR	S*	S*	S*	S*
Introduction or spread of invasive non-indigenous species	IE	IE	IE	S*	S*	S*	S*
Litter	IE	IE	IE	IE	IE	IE	IE
Nutrient enrichment	NS	NS	NS	NR	NR	NR	NR
Organic enrichment	S*	IE	NS	S*	S*	S*	S*
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	S	S	S	S	S	S	S
Physical change (to another seabed type)	S*	S*	S*	S*	S*	S*	S*
Physical change (to another sediment type)	S*	NS	S*	S*	S*	S*	S*
Removal of non-target species	S	S	S	S	S	S	S
Removal of target species	NS*	NR	NR	S	S	S	S
Smothering and siltation rate changes	NS	S	NS	S	S	S	S

	Designated Features						
	MCZ species			Annex I sandbanks and MCZ subtidal sediment habitats			
Potential Pressures	Sea-pen and burrowing megafauna communities	Fan mussel	Ocean quahog	Subtidal coarse sediment	Subtidal mixed sediments	Subtidal mud	Subtidal sand
Synthetic compound contamination	IE	IE	IE	IE	IE	IE	IE
Transition elements & organo-metal contamination	IE	IE	IE	IE	IE	IE	IE
Underwater noise changes	NR	NR	NR	NR	NR	NR	NR
Visual disturbance	NR	NR	NR	NR	NR	NR	NR