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Evidence review in support of management advice on supporting services for mobile species MPAs

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Contents

1 Introduction

1.1 Purpose of report

This review has been prepared for JNCC. In their role as statutory advisor, JNCC are responsible for providing management advice against the conservation objectives for offshore marine protected areas (MPAs) including those for harbour porpoise *Phocoena phocoena* and Manx shearwater *Puffinus puffinus*.

The conservation objectives for Special Areas of Conservation (SACs) with harbour porpoise as a designated feature are:

1. Harbour porpoise is a viable component of the site.
2. There is no significant disturbance of the species.
3. The condition of supporting habitats and processes, and the availability of prey is maintained.

The conservation objectives for Special Protection Areas (SPAs) with Manx shearwater as a designated feature are:

1. Avoid significant mortality, injury and disturbance of the qualifying feature, so that the distribution of the species and ability to use the site are maintained in the long term.
2. Maintain the habitats and food resources of the qualifying feature in favourable condition.
3. Ensure access to the site from linked breeding colonies.

A key conservation objective of these sites is to maintain the supporting habitats and processes relevant to the designated features and their prey, to ensure the sites contribute to favourable conservation status.

To provide advice on this conservation objective there is a need to understand how activities that occur within these sites may impact supporting services through impacts to the seabed. Impacts on the seabed have the potential to affect the function of a habitat and prey availability and subsequently affect the designated species.

This review has sought to collate the available literature on the effects of eight pressures, exerted by a number of activities, on the seabed and which may have subsequent impacts on harbour porpoise and Manx shearwater prey, with consequent indirect impacts on these marine predator species. Prey availability is the key supporting service of designated sites and seabed pressures may reduce prey availability for harbour porpoise and Manx shearwater and result in changes in their distribution and abundance (Camphuysen 2005; JNCC 2015). Reduced prey availability may lead to displacement from an area, starvation or individuals switching to less favourable prey resulting in reduced fecundity or longevity (Camphuysen 2005; JNCC 2015). As such, a key objective of the review is to provide a baseline of evidence on how seabed pressures influence harbour porpoise and Manx shearwater prey availability, from which evidence gaps can be identified and management advice developed.

1.2 Designated sites and mobile species

The Special Areas of Conservation (SACs) designated for harbour porpoise in the UK are:

- Bristol Channel Approaches SAC;
- Inner Hebrides and the Minches SAC;

- North Anglesey Marine SAC;
- North Channel SAC;
- Southern North Sea SAC;
- West Wales Marine SAC; and
- Skerries and Causeway SAC.

The Special Protection Area (SPA) designated for Manx shearwater in the UK is:

- Irish Sea Front SPA.

Manx shearwater is also designated as part of the seabird feeding assemblage feature of Outer Firth of Forth and St Andrews Bay Complex, but this report focuses on the Irish Sea Front as for this site Manx Shearwater is a designated feature in its own right.

Harbour porpoises are primarily piscivorous and feed mainly on small demersal and pelagic shoaling fish but are also known to take gobies and squid (Santos & Pierce 2003). Harbour porpoise diets overlap with the diets of other marine predators including that of Manx shearwater, which are known to also feed on small shoaling fish, especially clupeids, sandeels and squid (Camphuysen 2005; Thompson 1987; Waggitt *et al.* 2018).

As such, the key prey species of harbour porpoise and Manx shearwater considered in this review are:

- Whiting (*Merlangius merlangus*);
- Atlantic cod (*Gadus morhua*);
- Gobies (*Gobiidae*);
- Sandeel (*Ammodytes* sp. and *Hyperoplus lanceolatus*);
- Mackerel (*Scomber scombrus*);
- Atlantic herring (*Clupea harengus*);
- Sprat (*Sprattus* sp.); and
- Cephalopods (squid and cuttlefish).

From herein, references to prey species refer to the above prey species of harbour porpoise and Manx shearwater.

2 Methodology

Google Scholar and Science Direct were used to collate literature from published peer reviewed papers and grey literature. Three to five keywords for each pressure were identified and Boolean search terms were built from combinations of key words and the prey species listed above for harbour porpoise and Manx shearwater. Search terms included common and scientific names for prey species and alternate spellings for example “sandeel” and “sand eel”.

The searches focussed on the UK and northeast Atlantic but included literature from outside this area where relevant. The first five pages of the search results were checked for relevant material, and available PDFs of references that appeared useful were saved. The list of search terms used is provided in Appendix 1.

3 Activities and Pressures

JNCC provided a list of the primary activities considered to occur in the Marine Protected Areas (MPAs):

- Offshore construction and installation of infrastructure (e.g. renewables, oil and gas, carbon capture and storage).
- Aggregate extraction.
- Cables (telecommunications and power) installation.
- Pipeline installation.
- Dredging and disposal.
- Commercial fishing.

These activities all interact with, and exert pressures upon, the seabed. A pressure is defined as 'the mechanism through which an activity has an effect on any part of the ecosystem' (Robinson *et al.* 2008). An activity can give rise to a number of different pressures. For example, commercial fishing using demersal gear types can cause abrasion and disturbance to the seabed, as well as causing changes in water clarity due to the resuspension of disturbed sediments. Similarly, the same pressure can be caused by a number of different activities. For example, the pressure 'abrasion/disturbance of the substrate on the surface of the seabed' can be caused by activities associated with offshore construction, the installation of pipelines and cables, dredging and commercial fishing.

The JNCC Pressures and Activities Database (JNCC PAD 2018) was consulted to identify the primary pressures associated with the above activities. From this list, those pressures that act upon the seabed were identified along with pressures that result from seabed activities but cause pressures in the water column (e.g. pressures associated with the resuspension and subsequent deposition of disturbed sediments). Based on this approach, it was agreed with JNCC that the following pressures would be included in the review:

- Abrasion/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.
- Habitat structure changes – removal of substratum (extraction) (temporary effect).
- Physical change (to another habitat/seabed type) (permanent effect).
- Smothering and siltation rate changes.
- Resuspension of contaminants.
- Changes in suspended solids (water clarity).
- Marine litter.

The marine litter pressure is not associated with the list of activities that exert pressures on the seabed but was included in the review at the request of JNCC.

The definitions of each pressure are provided below and follow those definitions in the JNCC PAD (JNCC PAD 2018).

3.1 Abrasion/disturbance of the substrate on the surface of the seabed

This pressure relates to damage / disturbance to the seabed surface. Activities that cause abrasion can cover relatively large spatial areas and subtidal areas, and these activities include fishing with towed demersal trawls (fish and shellfish) and disturbance due to anchor chains. Abrasion and surficial damage to sediment structures (e.g. sand waves or mega ripples), may affect features if these structures are required for spawning or shelter (e.g. herring spawning grounds).

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

This pressure refers to the disturbance of sediments where there is limited or no loss of substrate from the system. This pressure is associated with activities such as anchoring, cable burial (ploughing or jetting) and certain fishing activities (e.g. scallop dredging and beam trawling (physical effects of fishing gear on seabed habitats)). Agitation dredging, where sediments are deliberately disturbed and move by gravity and hydraulic dredging where sediments are deliberately disturbed and moved by currents could also be associated with this pressure type. Compression of sediments (e.g. from the legs of a jack-up barge) could also fit into this pressure type. Abrasion relates to the damage of the seabed surface layers (typically up to 50 cm depth). Due to overlap between this pressure and the ‘Abrasion/disturbance of the substrate on the surface of the seabed’ pressure, they have been considered together for the purposes of this review.

3.3 Habitat structure changes – removal of substratum (extraction) (temporary effect)

Unlike the ‘physical change’ pressure where there is a permanent change in seabed type (e.g. sand to gravel, or sediment to a hard artificial substrate) the ‘habitat structure changes’ pressure relates to a temporary and/or reversible change. For example, a reversible change occurs with marine mineral extraction where a proportion of seabed sands or gravels are removed but a residual layer of seabed is left which is similar to the pre-dredge structure and as such biological communities could re-colonise. Navigation dredging to maintain channels is another example where the silts or sands removed are replaced by non-anthropogenic mechanisms, so the sediment typology is not changed.

3.4 Physical change (to another habitat/seabed type) (permanent effect)

The permanent change of one marine habitat type to another marine habitat type, through the change in substratum, including change to artificial substrates (e.g. concrete). Associated activities include: the installation of infrastructure (e.g. surface of platforms or wind farm foundations, pipelines and cables); the placement of scour protection (where scour is the loss of seabed sediment due to the movement of water around marine structures) where soft sediment habitats are replaced by hard/coarse substrate habitats; removal of coarse substrate (marine mineral extraction) in those instances where surficial finer sediments are lost; capital dredging where the residual sedimentary habitat differs structurally from the pre-dredge state; creation of artificial reefs; mariculture (e.g. mussel beds); and the protection of pipes and cables using rock dumping and mattressing techniques.

3.5 Smothering and siltation

Siltation rate changes are an indirect effect on the seabed, or seabed habitats and species, and refer to when the natural rates of siltation are altered (either increased or decreased). Siltation (or sedimentation) is the settling out of silt/sediments suspended in the water column. Activities associated with this pressure type include mariculture, land claim, navigational dredging, disposal at sea, marine mineral extraction, cable and pipeline laying and various construction activities (such as offshore wind farms or tidal devices). It can result in short lived sediment concentration gradients and the accumulation of sediments on the sea floor. If the newly deposited sediments are physically different to the existing sediment type the effect would fall within the pressure ‘physical loss’. Two different pressure benchmarks are identified ‘High’ siltation rate and ‘Low’ siltation rate representing up to

30 cm and 5 cm of fine material added to the seabed in a single event within site, respectively.

3.6 Changes in suspended solids (water clarity)

Changes in water clarity (or turbidity) are due to changes in suspended sediment and organic particulate matter and chemical concentrations. It is related to activities disturbing sediment and/or organic particulate matter and mobilising it into the water column. It could be 'natural' land run-off and riverine discharges or from anthropogenic activities such as all forms of dredging, disposal at sea, cable and pipeline burial, or secondary effects of construction works (e.g. breakwaters). Particle size, hydrological energy (current speed and direction) and tidal excursion are all influencing factors on the spatial extent and temporal duration. Salinity, turbulence, pH and temperature may result in flocculation of suspended organic matter. Anthropogenic sources are mostly short lived and occur over relatively small spatial extents. Changes in suspended sediment loads can also alter the scour experienced by species and habitats. Therefore, the effects of scour are also considered as part of this pressure.

3.7 Marine litter

Marine litter is any manufactured or processed solid material from anthropogenic activities discarded, disposed or abandoned (excluding legitimate disposal) once it enters the marine and coastal environment including plastics, metals, timber, rope, fishing gear, and their degraded components (e.g. microplastic particles). This pressure, however, does not include pollution events such as oil spills. Ecological effects can be physical (smothering) or biological (ingestion, including uptake of microplastics; entangling; physical damage; accumulation of chemicals). This review focused on two key areas of marine litter, microplastics and ghost fishing.

4 Literature review on the effect of seabed pressures on prey species

4.1 Sediment disturbance pressures

This section examines the literature available on the effects on harbour porpoise and Manx shearwater prey of the pressures ‘Abrasion and disturbance of the surface of the seabed’ and ‘Penetration and / or disturbance of the substrate below the surface of the seabed, including abrasion.’ As indicated in Section 3, given the substantial overlap in their effects, and the activities that exert these pressures, they have been considered here as sediment disturbance pressures.

The primary activity that exert these pressures on the seabed is demersal fishing using dredges and trawls. Demersal fishing is the most spatially extensive source of anthropogenic physical disturbance to the seabed and benthic habitats (Rijnsdorp *et al.* 2020). However, other activities can cause impacts at finer spatial scales such as disturbance from anchor chains and cable laying may be important within the boundaries of designated sites.

Seabed disturbance is most likely to affect demersal prey species such as sandeels and gobies, species that spend time feeding at the seabed such as whiting, and prey species that have benthic spawning or nursery grounds such as herring, sprat and cod. However, this review found little documented evidence of the effects of seabed disturbance on these species, even from the historically well studied effects of demersal fishing on the seabed.

The direct effects of seabed disturbance from demersal fishing has been extensively studied with research and investigations mainly focussing on the effects of disturbance on benthic macrofauna living within and on the surface of the seabed (e.g. Jennings & Kaiser 1998; Kaiser *et al.* 1998; Kaiser *et al.* 2002).

Demersal fishing reduces seafloor habitat complexity through the removal of physical and biogenic structures and the smoothing of bedforms leaving a more homogenous habitat (Auster 1999; Kaiser *et al.* 2002; Collie *et al.* 2017; Carneiro & Martins 2021). Abrasion and penetration of the seabed can also disturb and damage demersal eggs and adult fish that spend time buried in the sediment such as sandeels (Staudinger *et al.* 2020).

Eleftheriou and Robertson (1992) investigated the effects of disturbance on benthic fauna caused by scallop dredging in a sandy bay in Scotland. The experimental site had an area of 25 m^2 and was in approximately 10 m water depths. The area was subjected to dredges over a period of nine days with the effects then investigated by grab and core sampling and direct observations by a dive team. The dredge had a penetration depth of 3 to 4 cm. Investigation after the dredge treatments indicated significant furrowing and loss of natural physical features such as ripples. This physical disturbance of the seabed had also caused significant mortality of sandeels whose bodies ‘littered’ a large part of the dredged area. The study did not quantify the extent of the mortality of sandeels but highlighted the potential effect that similar commercial dredging operations may have in sandeel habitats.

Tien *et al.* (2017) investigated the effect of shrimp and flatfish beam trawl fisheries on the distribution of sandeel in Dutch coastal waters. The study found that three sandeel species (lesser sandeel *Ammodytes tobianus*, Raitt’s sandeel *Ammodytes marinus* and great sandeel *Hyperoplus lanceolatus*) were only found in areas of low fishing intensity for both shrimp and flatfish fisheries. A greater effect was apparent in areas targeted by the flatfish trawl. This was attributed to the heavier gear used by the flatfish fishery, and the associated deeper sediment penetration depth.

A number of studies have investigated the effects of demersal fishing on the early life stages and survivorship of cod. Juvenile cod survivorship is greater in high complexity habitats where cover provides shelter from predators so a reduction in habitat complexity due to seabed disturbance adversely affects the growth rates, survivorship and recruitment of juvenile cod (Kaiser *et al.* 1998). One such study modelled the survivorship of juvenile cod across habitats disturbed by fishing and undisturbed habitats (Lindholm *et al.* 2001). The model demonstrated distinct patterns in juvenile survivorship and showed that habitat change caused by fishing has significant negative effects on survivorship.

Seabed disturbance adversely affects those species that require benthic habitat complexity and structure (Watling & Norse 1998), such as gobies, and benefits those species that do not require habitat structure and are able to take advantage of opportunistic feeding opportunities caused by the disturbance of the seabed and associated increases in prey availability. For example, seabed disturbance from demersal trawling has been shown to increase prey availability for some fish species including whiting that are able to scavenge on a wider range of prey made available to them by the disturbance of trawls (Kaiser & Spencer 1994). Hiddink *et al.* (2011) found that the indirect effects of bottom trawling had no effect on the feeding and condition of captured whiting, likely due to their bentho-pelagic feeding habits.

Similarly, Kenchington *et al.* (2002) investigated the effects of experimental otter trawling on demersal fish feeding over a three-year period. The study found significant increases in demersal fish, including cod, in the trawled area after trawling. Changes in the diet of fish were also attributed to the trawling, including an increase in the abundance of prey consumed and qualitative changes due to the opportunity to feed on novel prey items made available by the disturbance to the seabed caused by the trawling.

While these studies suggest a positive effect of seabed disturbance for some species, the effects are assumed to be limited both temporally and spatially. Studies providing empirical evidence on the effects of disturbance on fish growth, condition and populations is limited and changes in fish populations in particular may be hard to detect due to the high natural variations in recruitment and population dynamics (Collie *et al.* 2017).

Other sources of sediment disturbance effects include submarine cable installation and the associated installation activities such as ploughing and water jetting.

Studies investigating the effects of these activities focus on the seabed and benthic macrofaunal community effects (e.g. Bald *et al.* 2015) with no consideration of subsequent effects to fish populations. Disturbance effects from cable laying and associated activities are generally localised (Meissner *et al.* 2006, in Eassom *et al.* 2016) and due to their linear nature, relatively limited in spatial extent in any one area with disturbance usually occurring in a strip of between 2 to 8 m in width (Carter at al. 2010, in Benn *et al.* 2010). Unlike other seabed disturbance activities such as fishing and dredging, cable laying is a non-repetitive activity with effects restricted to cable installation and recovery phases (Meissner *et al.* 2006, in Eassom *et al.* 2016). The localised, spatially and temporally limited nature of these activities suggests that any effects on harbour porpoise and Manx shearwater may also be spatially and temporally limited and of minor magnitude relative to seabed disturbance caused by fishing activities.

Taormina *et al.* (2018) undertook a review of the available literature on the impacts of submarine power cables on the marine environment. The key effects on fish were considered to be a result of suspended sediment effects, underwater noise and electromagnetic fields with limited consideration of the effects of seabed disturbance on fish.

A number of Environmental Statements for cable laying projects that considered the effects of seabed habitat disturbance on fish were considered for this review (Aquafact 2008; National Grid 2014; AECOM 2022). These reports considered the effects of seabed disturbance on fish and their spawning and nursery grounds (including sandeels, herring, whiting, cod, mackerel and sprat). The impact of seabed disturbance from cable laying activities on fish, and spawning and nursery grounds, was assessed as minor in all reports primarily due to the ability of fish to move away from areas of disturbance, the localised and temporary nature of cable laying activities, and the spatial extent of the impact relative to available seabed habitat.

The effects of seabed disturbance from vessel anchors and anchor chains have been studied for benthic habitats and macrofaunal species (see reviews by Griffiths *et al.* 2017 and Broad *et al.* 2020). In particular, seagrass beds have been shown to be particularly sensitive to the effects of anchoring (e.g. Collins *et al.* 2010). However, very little literature was found on the effects on fish from this activity-pressure combination. Literature that was found in the searches related to tropical habitats and species, particularly on coral reefs, so was not considered appropriate for this review.

4.2 Habitat structure changes – removal of substratum (extraction) (temporary effect)

This pressure relates to the removal of seabed substrate with the associated change in habitat structure being temporary and reversible. The substrate that remains is similar to the pre-removal material. Activities associated with this pressure include aggregate extraction and navigational and channel dredging, although the literature is heavily focused on the aggregate extraction industry, especially in the UK.

The effects of this pressure on macrofaunal communities from aggregate extraction and dredging have been the subject of numerous studies. However, there is less information on the effects on prey species and fish in general.

In a recent review of the effects of marine aggregate extraction, Desprez *et al.* (2022) suggest that few studies have directly investigated disturbances to mobile fish species, or have found significant impacts, which makes it difficult to predict the effects of this pressure on mobile fish due to aggregate extraction.

In general, it is assumed that mobile fish will be less affected than other sessile species as they can avoid disturbed areas. Stelzenmuller *et al.* (2009) developed a sensitivity index to assess the vulnerability of 11 fish and shellfish species to aggregate extraction, including the key harbour porpoise prey species, whiting and cod. The index used life-history characteristics such as habitat vulnerability, affinity to seabed, ability to switch diet and reproductive strategy, along with geographical distribution on the UK continental shelf. Both whiting and cod were found to be relatively insensitive to aggregate extraction activities compared to other less mobile species that have a higher affinity to the seabed.

However, certain prey species may be particularly vulnerable to aggregate extraction and associated pressures where extraction activities overlap with breeding and spawning areas and cause a change in, or loss of, preferred sediment grain size (Desprez 2000; Desprez *et al.* 2022). For instance, herring and sandeel require certain substrate conditions for spawning or breeding activity (Desprez *et al.* 2022).

The sandeel's strong preference for sandy habitats means they are highly vulnerable to habitat loss. Herring are also highly vulnerable to habitat loss because they lay benthic eggs, primarily in coarse sand and gravel, which are the substratum types typically targeted for aggregate extraction.

The preference for coarse sand and gravel habitats for spawning herring means that eggs and larvae are at risk of being directly removed with the extraction of aggregate (Tillin *et al.* 2011). Eggs are typically laid in a layer of 1 to 2 cm thick across an area of up to 1.5 km^2 and removal from the seabed is expected to result in 100% mortality in dredged areas (Poseidon 2002, in Posford Haskoning 2002).

RPS Energy (2013) made comparisons of herring larvae data from before and after commencement of aggregate extraction operations in the East English Channel. The study suggested that there had been no detectable reduction in herring spawning activity since dredging commenced. However, due to the high geographical and temporal variability of herring spawning and the nature of the larval data there was low confidence in the assessment. They also noted that any potential impact on herring spawning grounds may be subtle and more readily apparent over the longer term.

Sandeel lay their eggs in the sand, and similar to herring eggs, it can be assumed that up to 100% mortality could occur if directly removed during aggregate extraction. During the summer months sandeel form large schools in the water column during the day and spend the remainder of the time buried in the sediment. During the remainder of the year, they remain buried in the sediment emerging briefly in the winter to spawn (Camphuysen 2005; Arnott & Ruxton 2002). Given that sandeel spend much of their time buried in the sediment there is additional risk from this pressure through the direct removal or damage to individuals of this species. The potential effects of this pressure on sandeels are readily acknowledged in the literature (e.g. de Groot 1979; ICES 1992; Desprez 2000, 2020; Drabble 2012), however, there is a shortage of evidence investigating the effects at the population level in impact areas.

Tillin *et al.* (2011) in their review of the impacts of aggregate extraction, suggest that because fish spawning areas are widely distributed relative to the footprint of aggregate extraction sites, only very localised effects are predicted.

The 'Habitat structure changes' pressure could affect prey species through the loss of their food sources in the form of benthic organisms (Desprez *et al.* 2022). The review of literature on this pressure identified a large number of studies investigating the effect of extraction on macrofaunal communities, however, the link between this and subsequent effects on harbour porpoise and Manx shearwater prey is studied infrequently.

One such study by Desprez *et al.* (2014) investigated the effects of aggregate extraction at two sites, one experimental site at Baie de Seine in the eastern English Channel, and one commercially exploited site at Dieppe. The two sites were subject to different extraction intensities with a low intensity at Dieppe of less than one hour of extraction per hectare per year, and medium to high intensity in the Baie de Seine of 4 to 10 hours of extraction per hectare per year. Four years of monitoring between 2007 and 2011 indicated a strong negative impact at Baie de Seine where fish species numbers were reduced by 50% and abundance and biomass were both reduced by 92% encompassing species important to harbour porpoise and Manx shearwater (cod, whiting and sandeels). At the less intensively exploited site at Dieppe there was a lesser impact on fish assemblages with no change in the number of fish species but a 35% reduction in abundance.

At the Baie de Seine site Desprez *et al.* (2014) also recorded a reduction in benthic species of 42% and a corresponding reduction in abundance of 71%. There were no significant changes in the diet of most fish species during the study years (including whiting and cod) suggesting that the reduction in the abundance of benthic species was the cause of the significant reduction in the fish assemblages of the site.

Pearce (2008) (reported in Desprez *et al.* 2020 and Oikos Storage 2021) studied the importance of benthic communities as a food resource for fish in aggregate extraction areas including cod, whiting and sandeel and noted that changes to benthic communities due to dredging had the potential to alter the diet of demersal fish. However, Pearce (2008) considered that given the trophic adaptability observed in these species, such changes may not be damaging to fish populations provided that sufficient prey biomass remains post-dredging.

Other studies such as Hwang *et al.* (2014) and de Jong *et al.* (2014) have demonstrated the significant impact of aggregate extraction activities on local fish assemblages due to changes in prey availability (however, the fish species in these studies are not typically prey items for harbour porpoise and Manx shearwater). For example, Hwang *et al.* (2014) demonstrated the negative influence of sand extraction in Gyeonggi Bay, South Korea. Their study indicated that fish species richness, diversity and abundance were all significantly lower at the impact site relative to two control sites with the difference attributed to the disturbance of the seabed from the sand extraction activities. De Jong *et al.* (2014) found that sand extraction over a four-year period at the Port of Rotterdam had a negative impact on the local fish assemblage including European flounder, plaice and turbot.

A number of studies have investigated the recovery of benthic communities after the cessation of aggregate extraction activities. Desprez (2000) studied the recovery of benthic communities at the industrial extraction site at Dieppe in the Eastern English Channel. The site was monitored over a 10-year extraction period with the original substrate of gravels and coarse sands being progressively replaced by fine sands deposited in the dredged furrows.

The peak impact on benthic macrofauna was an 80% reduction in species richness and a 90% reduction in both abundance and biomass with an associated change in the composition of the communities due to the change in sediment type. After the cessation of dredging, species richness was fully restored after 16 months while abundance and biomass were still 40% and 25% lower, respectively, after 28 months which was the end of the study period. In addition, the composition of the community remained altered from the original community due to the change in sediment type from coarse substrate to finer substrate.

In contrast to the above study, Boyd *et al.* (2004) studied the recovery of benthic communities at four aggregate extraction locations around the UK and found that benthic communities at some sites remained in a perturbed and reduced state between 4 to 7 years after the cessation of dredging with the local environmental conditions and dredging intensity thought to be the key factors in determining rates of recovery.

While these studies do not provide direct insight into the effects of a reduction in prey availability for fish species, it is assumed that medium term effects on benthic communities such as these may also have effects on fish species which are prey items for harbour porpoise and Manx shearwater over similar time periods, with associated implications for them within designated sites.

4.3 Physical change (to another habitat / seabed type) (Permanent effect)

This pressure results in a permanent change of one marine habitat type to another marine habitat type, through a change in substratum, including change to artificial substrates (e.g. concrete). This involves the permanent loss of one habitat type which is replaced by a different habitat type. Activities associated with this pressure include the construction and installation of offshore infrastructure such as wind farm foundations and pipelines, and the protection of infrastructure by rock dumping and concrete matressing. The removal of sediment through aggregate extraction that leads to a permanent change in the substrate of the extraction area is also associated with this pressure.

The effects of permanent changes in seabed habitat include the loss of suitable habitat for prey species, especially those species for which the seabed plays a critical role either as their primary habitat, such as sandeels and gobies, or those species that utilise benthic spawning and nursery grounds such as herring, sprat and cod.

The introduction of hard substrate in areas of soft substrate can also result in an artificial reef effect, which can cause a shift in the composition of the local fish assemblage and an increase in abundance of fish.

The effects of this pressure, particularly for the prey species, have been most extensively studied for the installation of offshore wind farms. This involves a change from soft sediment habitats to hard substrate in the footprint of the turbines. A large part of the footprint is the scour protection which, depending on local hydrographic conditions, typically consists of a combination of rocks and gravel positioned on the seabed around turbine foundations to prevent erosion (Glarou *et al.* 2020). Scour protection typically extends around 10 m out from the base of turbine foundations (Linley *et al.* 2007, in Wilson 2007).

The loss of habitat in the footprint of offshore wind farms due to this physical change is generally considered to be minimal (Wilson & Elliott 2009; Boon *et al.* 2010; Stenberg *et al.* 2015; Coolen *et al.* 2019) and is considered by some to be compensated for by the prevention of fishing in the vicinity of wind farms (Boon *et al.* 2010).

The impact of the installation of the Horns Rev 1 offshore wind farm into sand habitats and the short and long-term effects on the sandeel community was investigated by van Deurs *et al.* (2012). Surveys for sandeels were conducted prior to construction, one-year post-construction and seven years post-construction at both the impact site and a control site. Despite the loss of sand habitat to the wind farm foundations, a significant positive short-term effect of the offshore windfarm on both juvenile and adult sandeel densities was found, which was associated with an improvement in surrounding habitat quality due to a reduction in silt and clay content in the sediment. In the long-term, there was evidence for a negative effect on juvenile sandeels but this effect was found to only be reflected in the most dominant species (*Hyperoplus lanceolatus*). No differences between impact and control areas were found for *Ammodytes tobianus* and *A. marinus* but potential reasons for this were not given by the authors.

Lindeboom *et al.* (2011) investigated the short-term impacts of the introduction of new hard substratum at the Offshore windfarm Egmond aan Zee (OWEZ) Dutch offshore wind farm. Fish surveys were undertaken pre- and post-construction in the wind farm site and two control sites. Pre-construction surveys indicated a highly dynamic fish assemblage, which was repeated in the post-construction surveys with herring dominating the pre-construction assemblage and sandeels dominating post-construction. Wind farm structures would be expected to exclude sandeels from previously occupied habitat, however, in the post-construction surveys sandeel were recorded across the impact area with no evidence that the introduction of turbine structures was affecting them. Similar to the findings of van Deurs *et al.* (2012), species richness was higher in the short-term post-construction, however this was also the case in the control sites so was not attributed to the wind farm.

Post-construction increases in other demersal species, including whiting, suggested a possible effect of the wind farm. Analysis of video footage from the post-construction surveys also suggested that the new hard substrate provided by rocks deposited around monopiles for scour protection were providing shelter and food for various species including cod.

In a similar study, Stenberg *et al.* (2015) investigated the long-term effects of the Horns Rev 1 offshore wind farm on fish abundance, diversity and spatial distribution. The wind farm is situated on the Horns Reef sand bank in the North Sea. Fish surveys were conducted prior to the installation of the wind farm and again seven years post-construction at both impact and control locations so provide a useful comparative study of the effect of the construction and operation of the wind farm on local fish assemblages. The three most abundant species in the pre- and post-construction surveys included the prey species, sandeels and whiting. Neither of these species, nor other species or fish groups, indicated signs of negative long-term effects due to the wind farm. The surveys demonstrated an overall decline in whiting catch levels, which reflected a general decline in whiting stocks in the North Sea during this period. Stenberg *et al.* (2015) suggested the less significant decline around the wind farm, relative to the wider North Sea region, may be due to increased prey availability associated with the installation of the wind farm. Other prey species that had increased abundance post-construction were cod, herring, mackerel and sprat. Consequently, fish abundance was found to have increased, albeit only slightly, around the wind farm and it had decreased in the control area.

The results of this study indicate that the structures that act as artificial reefs were large enough to attract fish species but not large enough to have adverse effects on species inhabiting the sand habitats lost to the turbines such as sandeels. The conclusion that the offshore wind farm, and the associated pressure of a physical change in some favoured habitat, did not appear to affect sandeels, and other sand-dwelling species such as dab, is in agreement with the other studies cited here. This may primarily be due to the fact that direct seabed habitat loss due to the wind farm structures is relatively small (less than 1% of the area within the wind farm in this study).

Other studies on the effects of the introduction of hard substrate associated with offshore wind farms into soft sediment habitats have provided similar results to the above studies. The population density of Atlantic cod at a Belgian offshore wind farm was greatly increased around wind turbine foundations compared to sandy control areas (Reubens *et al.* 2013a; Reubens *et al.* 2013b). Wilhelmsson *et al.* (2006) found a similar increase in fish abundance around turbine foundations in the central Baltic Sea, especially for the gobies *Gobiusculus flavescens* (two-spotted goby), *Pomatoschistus minutus* (sand goby) and *Gobius niger* (black goby). The increase in abundance was shown across a range of age classes but was particulalry important for juvenile two-spotted and sand gobies. It was concluded that the increased densities of fish were a combination of increased refuge and food availability provided by the wind farm.

The installation of other marine renewable energy devices, such as tidal stream and wave devices in sandy habitats will also result in a physical change to areas of the seabed. The effects of these changes in habitat on fish assemblages is less well studied than for offshore wind farms partly due to operational challenges and partly due to there being far fewer deployments of these devices (Copping *et al.* 2022). Baseline data are lacking due to the challenge of operating in the high energy environments in which these projects are located. However, the results of those studies that have been undertaken for these devices, particularly in terms of artificial reef effects (e.g. Kramer *et al.* 2015; Langhammer & Wilhelmsson 2006), are considered comparable to what has been found at other offshore infrastructure developments (Copping *et al.* 2022).

The installation of linear marine infrastructure such as pipelines and cables into soft sediment habitats and associated installation of scour protection, also results in a physical habitat change. While these structures may span large distances in terms of length, given their limited footprint in terms of width (restricted by diameter of the pipeline or cable and associated amount of rock armour required), the extent of habitat change in any one area is also limited. The impact of this pressure from these installations is assumed to be minor for fish species that rely on the seabed for feeding, spawning and nursey grounds and for species that spawn in the water column (Nord Stream 2009; AECOM 2022).

The reef effect of pipelines and cables is less well studied compared to that of other marine infrastructure such as offshore wind farms. Ramboll (2014) monitored the effects of the Nord Stream gas pipeline in the Swedish Baltic Sea on fish assemblages through pre- and post-construction fish surveys and across impact and control sites. The monitoring found no effect on demersal fish assemblages due to the presence of the pipeline. There were significant increases in cod and herring in the post-construction surveys, and it was concluded that this was not attributable to the pipeline.

Keller *et al.* (2006) reported on two studies that investigated the reef effect of oil pipelines in Norwegian waters. The studies showed high concentrations of small fish in very close proximity to the pipeline (less than 1 m) attributed to the shelter and increased food supply provided by the pipeline but for commercially important species the pipeline only had a minor aggregation effect (specific species were not reported).

Physical change of seabed habitat can also occur due to aggregate extraction which can change the character of the seabed by changing the sediment composition. The most common change in sediment composition due to extraction activity in the UK is from sandy gravel to gravelly sand (Gubbay 2003). This change in sediment type is primarily due to the accumulation of fines from aggregate screening (Boyd *et al.* 2003, in Gubbay 2003; Hill *et al.* 2011), the removal of gravel where these overlay finer sediments, the settlement of fines from overspill water, and the natural infilling of dredged areas by the trapping of bedload sediments (Boyd *et al.* 2004; Hill *et al.* 2011).

Herring spawning grounds are generally small and are located on gravelly substrates to which the eggs attach. Herring select specific gravel beds within an area and demonstrate a high degree of site fidelity, returning year after year. As such, there is the potential for negative effects from changes in sediment composition to significantly affect successful spawning and recruitment (ICES 1992). Sediment screening to remove sand from extracted gravel may change a stable gravel bank into an area of mobile sand (de Groot 1995) and such a change from preferential gravel substrate to finer sediments may prevent herring eggs from adhering to the sediment (Posford Duvivier & Hill 2001).

A contrasting potential change is that the extraction of sand can lead to the exposure of coarser gravel deposits below the dredged layer (Hill *et al.* 2011). This shift from sand dominated seabed preferred by sandeels to a coarser sediment may influence sandeel habitat use, however, no studies providing evidence of this effect were found.

4.4 Smothering and siltation rate changes

This pressure results from the settling out of suspended sediments from the water column. Activities that result in this pressure include dredging and aggregate extraction, disposal at sea of sediment (e.g. dredge spoil), and various marine construction activities such as the burying of submarine cables.

The settling out of suspended sediments or the dumping of dredge spoil leads to the burial or smothering of benthic habitats and species (OSPAR 2008). Given this pressure is exerted on the seabed, it is most relevant to the prey species that have a close association with the seabed such as sandeels and gobies, and fish that have benthic spawning, nursery and feeding grounds such as herring, sprat, cod and whiting.

The effects of sedimentation and smothering on fish have not been studied as comprehensively as the effects of suspended sediments (Wilber 2005). Studies of sedimentation effects have largely focussed on the eggs of benthic-spawning species and species whose larvae are associated with the seabed and these are the life stages considered to be most at risk from smothering (Wilber 2005; Wilber & Clarke 2001). For the prey species of harbour porpoise and Manx shearwater, only a single experimental study on the effects of sedimentation on eggs was found. Messieh *et al.* (1981) found 100% mortality of herring eggs subjected to burial under a 1 cm layer of sediment and attributed this to a lack of oxygen due to the prevention of water circulation around the eggs.

This effect was also observed in the field by Morrison *et al.* (1991) who recorded the mass mortality of herring eggs over a six-day period due to smothering by a sedimenting diatom bloom.

A key activity that exerts this pressure is the disposal of dredge spoil from maintenance and capital dredging projects, which is the only licensed disposal activity in UK waters. Disposal of dredged material is a highly regulated activity and is only allowed within licensed disposal sites (Bolam 2021).

The focus of studies on the effects of smothering from dredge disposal is on benthic macrofaunal communities (e.g. Essink 1999; OSPAR 2008; Bolam 2006; Bolam 2021) rather than fish species. Despite this, understanding of the mechanisms for, and implications of, changes in macrofaunal communities due to dredge disposal is still relatively unknown (Bolam 2021). During this review, no literature was found relating to the effects of smothering resulting from dredge disposal activities on prey species or other fish species. This may be due to the fact mobile prey species can largely avoid areas of sediment deposition.

In addition, no information was found on the effects of smothering from dredge disposal on spawning or nursery grounds of key prey species. This may be due to the licensing requirements of disposal activities. As part of the licensing process, the effects of dredge disposal have to be assessed to understand what the impacts to benthic communities and fish spawning and nursery grounds are likely to be. If necessary, mitigation may be included as a licence condition to avoid impacts on sensitive species and habitats. Commonly used measures at disposal sites include restrictions on the volume of disposed material, ensuring material is spread across a disposal site rather than dumped in one area, using equipment that controls the volume and rate of disposal or using supplementary equipment such as silt curtains to prevent dispersion outside the disposal area. As such, the effects of this pressure from dredge disposal on fish species may not be a focus for researchers.

CEFAS (2016) undertook a dredged material site selection analysis to identify suitable disposal sites for dredged material removed as part of maintenance dredging activities in Plymouth Sound. As part of this assessment the sensitivity of spawning and nursery grounds of fish species was assessed, including consideration of whiting, mackerel, herring, sandeel and sprat. Whiting, mackerel, sandeel and sprat nursery and spawning grounds were assessed as having very low sensitivity, and herring spawning grounds were assessed as having low sensitivity to dredge disposal activities. The sensitivity assessment took into account the ecology of the species, their conservation status and also the consideration that the impact of a disposal site in a relatively small area is unlikely to have significant impacts on the overall reproduction of the fish species.

Two monitoring studies undertaken at five Belgian dredge disposal sites investigated the effects of dredge dumping on benthic communities and fish assemblages over a 10-year period (Lauwaert *et al.* 2008; Lauwaert *et al.* 2016). The monitoring compared benthic macrofaunal and fish diversity at impact and control sites. After 10 years of monitoring, it was concluded that disposal of dredged material at the sites was having minimal influence on the benthic and fish communities, with the exception of one dump site where species diversity and richness was consistently lower in the impact area, especially for the benthic communities. This suggested a long-term impact at that particular site which was attributed to a change in seabed structure and sediment composition due to regular disposal activities rather than smothering effects. The lower density of fish at that site may indicate that the impact site is a less profitable feeding ground due to a reduction in the diversity and abundance of benthic communities (Lauwaert *et al.* 2016).

It was concluded that the species at the sites, being either mobile or living within the sediment, were not sensitive to the smothering pressure and were more likely to be sensitive to other pressures associated with dredge dumping, particularly physical habitat change to another sediment type (Lauwaert *et al.* 2016).

These reports suggest that the effects of smothering and siltation rate changes from dredge disposal may not be important to demersal fish assemblages or their spawning and nursery grounds. There may also be minimal effects on fish prey availability unless sediment deposition causes a physical change in habitat structure and sediment composition.

Aggregate extraction can also result in smothering and siltation rate changes. Deposition of suspended sediments from the associated sediment plume can result in benthic communities being immediately smothered and buried (Tillin *et al.* 2011). As with other pressures, the effects on benthic communities are better researched and understood than the effects on fish communities, but in terms of fish species those with benthic eggs, larvae and benthic spawning and nursery grounds, especially those of sandeel and herring, are at the highest risk of effects from this pressure as a result of aggregate extraction (ICES 1992).

Sediments mobilised from aggregate extraction sites in the East English Channel have been shown to travel over 4 km from the extraction site (EMU Ltd. 2010, in RPS 2013). The subsequent deposition of such sediments may cause smothering with associated negative effects on herring eggs and, consequently, herring spawning potential (RPS Energy 2013). Fine sediment is unlikely to allow sufficient water circulation around herring eggs and is often associated with high herring egg mortality rates (Messieh *et al.* 1981; Morrison *et al.* 1991). However, herring larval abundance data prior and subsequent to the commencement of aggregate dredging in the East English Channel, indicated that spawning activity has not reduced since dredging began (RPS Energy 2013). It should be noted that this finding may be highly influenced by the fact that there are restrictions on dredging activity during herring spawning season.

The reports and studies considered in this section suggest that the pressure 'smothering and siltation rate changes' is not important in influencing the availability of prey species. Activities that result in this pressure tend to be spatially limited with effects generally considered as short-term and temporary.

4.5 Sediment resuspension pressures

Activities in the marine environment that interact with the seabed have the potential to cause disturbance to the seabed and the resuspension of sediment into the water column resulting in sediment plumes and changes to water clarity. The spatial extent and concentration of suspended sediment in the water column is dependent on the nature of the activity, the sediment composition and the local environmental conditions. In general, dredging activities result in the highest suspended sediment loads and the most extensive sediment plumes but other activities such as fishing and the installation of marine infrastructure such as piles, foundations and cables can also mobilise sediment.

In addition to effects of suspended sediment, the resuspension of sediments can also result in the release of contaminants into the water column that then become bioavailable to marine species.

This section reviews the literature on the effects of suspended sediment and remobilised contaminants on prey species.

4.5.1 Changes in suspended sediments

The sensitivity of fish to suspended sediment is species-specific and dependent on life stage and duration of exposure. Eggs, larvae and juveniles are more susceptible to effects than adult fish (Keller *et al.* 2006; Clarke & Wilber 2000).

A number of experimental studies have investigated the effects of suspended sediment on prey species, primarily on cod and herring.

The survival and development of planktonic eggs, such as those of cod, is dependent on the more favourable oxygen content and salinities found in the water column relative to those at the seabed. Suspended sediment can adhere to planktonic eggs making them heavier and causing them to sink to the seabed making them more susceptible to damage and predation (Birklund & Wijsman 2005). Westerberg *et al.* (1996) investigated this effect in laboratory experiments on cod eggs. The study found that even relatively low suspended sediment concentrations of 5 mg/l caused eggs to sink with the rate of sinking proportional to the amount of sediment that had accumulated on the surface of the egg.

Kiørboe *et al.* (1981) investigated the effects of suspended sediment on the development of herring eggs. It was found that, even at very high suspended sediment concentrations of

300 to 500 mg/l for one day, there was no effect on development of the eggs. Similarly, there was no increase in mortality at concentrations of 5 to 300 mg/l after 10 days of exposure.

Corell *et al.* (2023) investigated the effect of elevated suspended sediment concentrations due to bottom trawling on the Eastern cod in the southern Baltic Sea. They modelled the transport of sediment suspended by trawling activities around an Eastern cod spawning ground to estimate the degree to which cod eggs could be affected by increased suspended sediment. They concluded that bottom trawling around the spawning ground could decrease the reproductive success of cod due to increased suspended sediment concentrations and that such effects are likely to be seen in other fish populations with pelagic eggs where bottom trawling occurs in the vicinity of spawning grounds.

The results of mortality experiments undertaken by Westerberg *et al.* (1996) suggested that cod eggs are relatively insensitive to suspended sediment concentrations compared to cod larvae. For example, after three days of exposure at concentrations of 20 mg/l, egg mortality was less than 20%. At 200 mg/l over the same period, mortality increased to 40%. In contrast, larvae were more sensitive, with a threefold increase in mortality after one day of exposure to concentrations of 200 mg/l when compared to eggs after three days exposure at the same concentration levels. Significant mortality of cod larvae was also shown at 10 mg/l when exposed for six days, which was suggested to be primarily due to the clogging of larval gills by silt.

Another potential additional effect on larvae is that herring and cod larvae are visual predators and can only sight their prey at a distance of a few millimetres. As such, increases in suspended sediment can reduce larval feeding. Johnston and Wildish (1982) investigated the effect of increased levels of suspended sediment on the feeding rate of larval herring. They found that at concentrations of 20 mg/l, larval herring consumed far fewer prey items.

Other studies have examined the effects of increased sediment concentrations on juvenile and adult fish. Sediment plumes have the potential to affect fish movement and migration and both juvenile and adult fish have been shown to demonstrate avoidance behaviour around areas of increased suspended sediment from dredging and extraction activities (example Essink (1999) noted that herring and sprat avoided turbid areas in Dutch coastal waters).

Humborstad *et al.* (2006) exposed adult cod to worst case scenario suspended sediment concentrations of 550 mg/l recorded as a result of bottom trawling for periods of one, five and 10 days. No mortality of fish was observed in any group, however, after one day of exposure degenerative lesions on the gills were observed. Such gill lesions have been reported in other species from turbid environments and are thought to be reversible.

Messieh *et al.* (1981) indicated that juvenile herring demonstrated significant avoidance behaviour at suspended sediment concentrations of 12 mg/l and assumed a similar reaction would be shown by adults. This was shown by Johnston and Wildish (1981) (in Birkland & Wijsman 2005) who investigated the avoidance of suspended sediment from dredge disposal by adult herring and determined a threshold of 10 mg/l. This contrasts with Wildish *et al.* (1977) who reported herring avoiding suspended sediment from dredge spoil dumping at higher concentrations of 19 mg/l for fine sediments and 35 mg/l for sediments containing 30% sand.

These studies provide a useful guide as to possible thresholds for effects for some prey species of harbour porpoise and Manx shearwater and are likely to be relevant for other clupeidae and gadoid fish species.

Suspended sediment concentrations for various marine activities are reported in the literature and some example concentrations are provided here for context. Humborstad *et al.* (2006) report that the maximum suspended sediment concentration caused by bottom trawling is 550 mg/l. Posford Haskoning (2002) report that near bed increases in suspended sediment in aggregate extraction areas of the English Channel Region could be up to 300 mg/l in the immediate dredged area but these levels would last less than one tidal cycle. Further from the immediate dredged area, near bed concentrations of over 60 mg/l would be expected between 5 and 25 km^2 around the dredged area, depending on the size of the area. Depth averaged increases of 5 to 20 mg/l could be expected up to 10 km from the dredged area. Taormina *et al.* (2018) report on elevated suspended sediment concentrations from the installation of cables at the Nysted offshore windfarm in Denmark. Backhoe dredging resulted in mean concentrations of 14 mg/l (up to 75 mg/l) at 200 m from the trenching operation, and a mean of 2 mg/l (up to 18 mg/l) during water jetting. Elevated suspended sediment concentrations along a cable route will typically last from a few hours to a few days (Taormina *et al.* 2018) and are generally considered to be very localised and short-term with negligible impacts.

The studies and reports considered here have shown that the early life stages of fish are more susceptible to the effects of suspended sediment, although this varies between species. Avoidance behaviour by adult fish has been demonstrated at relatively low suspended sediment concentrations and below those levels that have been recorded in the field from both anthropogenic and natural sources of suspended sediment.

4.5.2 Resuspension of contaminated sediments

Marine sediments act as a sink for anthropogenic contaminants, however, the disturbance of the seabed and mobilisation of resuspended contaminated sediments (RCS) from activities such as dredging, and the construction of marine infrastructure can result in sediments acting as a source of contamination (Latimer *et al.* 1999). Once in the water column, sediment bound contaminants can potentially impact a wider range of organisms and trophic levels than contaminants in sediments that have not been mobilised (Roberts 2012).

The bioavailability of sediment bound contaminants after resuspension is complex and beyond the scope of this review (see Eggleton & Thomas 2004 for a review). Contaminants that desorb from sediment into a dissolved state are the most toxic form to marine life (Roberts 2012).

The uptake of bioavailable contaminants by fish is also dependent on a number of factors including: environmental conditions such as water temperature and salinity; food web trophic structure; physical factors such as fish lipid content; and exposure duration.

Roberts (2012) reviewed experimental and field studies on the effects of RCS on fish. Experimental studies indicated that RCS have a range of effects on fish under laboratory conditions and a number of these have shown marine fish to be sensitive to RCS. Fish may accumulate RCS via the gills or through the skin and direct exposure may impair chemosensory functions. Metal-contaminated suspended sediments have been shown to impair feeding in gobies which is a prey species for harbour porpoise and Manx shearwater, and polycyclic aromatic hydrocarbons (PAHs) contaminated sediments have been demonstrated to have a narcotic effect on fish with an associated reduction in their responses to external stimuli (Gregg *et al.* 1997, in Roberts 2012). Resuspended metal and PAH bound sediments have also been shown to illicit immune responses, affect feeding and survival and cause fin lesions (Roberts 2012).

Other than gobies, none of the experimental studies reported in Roberts (2012) were undertaken on the main prey species of harbour porpoise and Manx shearwater, although effects are assumed to be relevant across other fish species.

The only study found during this review examining the effects of RCS on prey species was Ruus *et al.* (2012), in which the effects of resuspended sediment bound polychlorinated biphenyls (PCBs) on cod was investigated. The study exposed cod to resuspended sediments with a PCB concentration of 10 µg/kg continuously for 129 days. No mortality of cod was recorded, and no other effects were noted.

While experimental studies provide confirmation that RCS can affect fish under laboratory conditions, they do not provide context for the potential for effects in the environment at an individual or community level. Long exposure durations such as that in the Ruus *et al.* (2012) study are unlikely to be realistic relative to the exposure durations that fish encounter in the environment due to the disturbance of contaminated sediment.

Field based ecological monitoring of responses to RCS have focused on dredging and dredge disposal activities (Roberts 2012), which are likely to be the primary activities that cause contaminated sediment to be resuspended. Incidences of acute toxicological and ecological effects due to remobilisation of contaminants from these activities are considered rare (OSPAR 2008). This is likely due to the strict licensing regime for dredging and dredge disposal that is in place in many countries, which requires testing of sediment contaminant concentrations before dredging activities are undertaken.

In OSPAR regions, there is a downward trend in contaminant concentrations in marine sediments and areas of significant sediment contamination around the UK are not widespread, tending to be concentrated in industrialised coastal and estuarine areas.

Marine infrastructure projects that cause disturbance and resuspension of sediments frequently analyse the levels of contaminants in sediments to enable considerations of the risks that may be associated with the resuspension of contaminated sediments. However, where this occurs, the resuspension of contaminants tends to be limited both spatially (i.e. the extent of a sediment plume) and temporally (i.e. the duration that material remains suspended (Roberts 2012).

Environmental impact assessments for marine infrastructure projects in UK waters such as offshore windfarms and cable laying projects typically conclude a minor or insignificant effect on fish from RCS due to the generally low levels of contaminants in UK sediments, and the temporary and short-term nature of the potential exposure to RCS. As such, it is considered that the resuspension of contaminated sediments is unlikely to be important in directly influencing prey availability, but the evidence base for this assumption is not robust.

4.6 Marine litter

Marine litter can be defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment (Galgani *et al.* 2013). Plastic waste and the fishing industry represent major and continuous sources of marine litter (Barboza *et al.* 2020; Consoli *et al.* 2019). Both microplastics and abandoned, lost, or discarded fishing gear (ALDFG) present potential risks prey species (Laist 1997; Mallik *et al.* 2021).

4.6.1 Microplastics

Microplastics are widely distributed throughout marine ecosystems. Ingested microplastics may potentially affect fish, including reduced feeding intensity, immuno-suppression, and inadequate gill performance and reproductivity (Mallik *et al.* 2021).

Foekema *et al.* (2013) investigated whether ingested plastic adversely affected the condition of fish caught in the North Sea, including the prey species cod, whiting, herring, and mackerel. No relationship was found between the condition factor (size−weight relationship) of the fish and the presence of ingested plastic particles. It was concluded that it is unlikely that the number of plastics that they encountered affected the condition of the fish (Foekema *et al.* 2013).

A study by Fernandez-Miguez *et al.* (2023), indicated that the inclusion of microplastics in the diet of broodstock Atlantic cod had no effect on feeding, nutrient digestibility, or physiological characteristics during maturation. There was also no effect on fecundity or egg quality during their spawning (Fernandez-Miguez *et al.* 2023). A study was conducted on the gastrointestinal tracts of cod, herring, and mackerel from the North and Baltic Sea, to investigate the occurrence and effects of plastic ingestion. No direct effects of microplastic ingestion on the condition of fish could be determined (Rummel *et al.* 2015).

Foley *et al.* (2018), however, conducted a meta-analysis of the effects of exposure to microplastics on fish and found that larval and juvenile fish feeding, and consumption of prey, was significantly negatively affected by exposure to microplastics. The meta-analysis did not demonstrate that adult fish were affected, however the number of studies focussed on adult fish was low (Foley *et al.* 2018). In addition, mackerel that were found to have ingested microplastics had significantly higher lipid peroxidation levels in the brain, gills, and dorsal muscle than fish where no microplastics were found (Barboza *et al.* 2020). This suggests damage to the gills and muscle, and neurotoxicity through lipid oxidative damage related to microplastics (Barboza *et al.* 2020).

Studies have been undertaken to investigate microplastic ingestion by sprat and sandeels, however, these studies do not investigate the effects of microplastic ingestion on these species (Kuhn *et al.* 2020). A study by Pennino *et al.* (2020) found that sardine individuals with lower body conditions, indicated by the prevalence of parasites, were found to have a significantly higher probability of ingesting microplastics.

Due to the lack of studies and inconclusive evidence surrounding the effects of microplastics on fish, it is difficult to determine the degree to which the prey species of harbour porpoise and Manx shearwater could be affected by microplastics, and therefore whether their populations and distributions could be affected. Harbour porpoise and Manx shearwater may, however, be vulnerable to the impact of microplastic contamination via indirect uptake from their prey (Yamashita *et al.* 2011; Zantis *et al.* 2021).

4.6.2 Ghost fishing

Several types of fishing gear continue fishing after they are abandoned, lost, or discarded, commonly referred to as ghost fishing. This is the case for both active and passive fishing gear (Do & Armstrong 2023).

Fish entanglements occur in abandoned, lost or otherwise discarded fishing gear (ALDFG) specifically designed to exploit their normal behaviour patterns. While the catch efficiency of ALDFG declines as nets collapse, and traps may have features to minimise ghost fishing, essentially all target and non-target species taken in commercial fisheries are also killed in ALDFG (Laist 1997).

The effect of entangling ALDFG is essentially the same for all species and is mainly mechanical. Animals that become entangled may exhaust themselves and drown, have their mobility impaired to a point where they can no longer catch food or avoid predators, become hung up on rocks or other fixed objects by trailing rope or line, or incur wounds and infections from the constriction or abrasion of attached debris (Laist 1997).

Decomposing organisms, caught in the ALDFG, attract scavengers. Scavenger feeding releases odours that attract more organisms. Some of the scavengers get caught and eventually decompose providing a continual source of food, potentially aggregating marine organisms until the ALDFG loses its fishing efficiency (Gilman 2015).

A meta-analysis of ALDFG entanglement records found 34 species of fish (including the prey species herring, cod, and whiting), but no species of squid, which are also a prey item for harbour porpoise and Manx shearwater. Almost all entanglement records involved dead animals and most of these were caught in drift, set and gill nets, and crab traps. The meta-analysis concluded that the records list seemed incomplete and that entanglement in ALDFG seems possible for virtually all species caught in active commercial fishing gear (Laist 1997).

Ghost fishing lobster traps have been observed to contain fish over the duration of a three-year study. A total of 66 fish species (5909 fish individuals) were caught in 120 lobster traps throughout the study, with 74% of observed dead fish found in wire lobster traps (Butler & Matthews 2015).

There is a lack of studies on the wider population level effects of ALDFG on prey species. It is likely, however, effects such as entanglement will occur for all the prey species.

5 Conclusions

This review has investigated the effects of seabed pressures from a range of activities on harbour porpoise and Manx shearwater prey. Prey availability is a key supporting service of MPAs and impacts on prey resulting in a reduction in prey availability can have indirect effects on harbour porpoise and Manx shearwater including displacement from an area, starvation and prey switching to less favourable prey items resulting in reduced fitness, fecundity and longevity.

This review has indicated that the pressures considered can affect species that are important components of harbour porpoise and Manx shearwater diets. However, it is considered that there are significant gaps in the evidence base to support the development of management advice for MPAs. This includes gaps in relation to local population level effects, the permanency of effects and how the pressures considered here may cause the displacement of prey communities that may affect harbour porpoise and Manx shearwater populations in MPAs.

Much of the information found relates to prey species that are also important commercial species such as herring, cod and sandeel. For most pressures researched, very little information was found for other prey species of harbour porpoise and Manx shearwater, especially cephalopods.

The review found very little evidence of the long-term or permanency of effects on prey species, with the exception of the physical change pressure from the introduction of marine infrastructure onto the seabed, where some multi-year studies demonstrated reef effects and seemingly no effect on resident sand dwelling species due to the permanent change in habitat.

The findings of the review for each pressure considered (seabed disturbance, habitat structure changes – removal of substratum, physical change, smothering and siltation rate changes, sediment resuspension pressures, and marine litter) are summarised below.

5.1 Seabed disturbance

- Seabed habitat complexity is important to the early life stages of some prey species and seabed disturbance that reduces complexity can have an impact on juvenile survival.
- Seabed disturbance, especially that associated with demersal fishing, can provide short-term beneficial effects to some fish species by improving access to prey items. As such, seabed disturbance may attract mobile fish species into an area of disturbance to take advantage of such opportunities, though such benefits are assumed to be limited both spatially and temporally.
- Very little literature on the effects of seabed disturbance on fish from marine infrastructure and associated activities was found. Environmental impact assessments conducted for these activities typically concluded any effect to fish and spawning and nursery areas was of minor significance due to the spatially and temporally limited extent of the impacts.

5.2 Habitat structure changes – removal of substratum (temporary effect)

- Removal of substratum is not thought to have significant direct effects on mobile fish species such as cod and whiting.
- Harbour porpoise and Manx shearwater prey species that have a close association with the seabed, such as sandeels and herring, and their spawning grounds, are most at risk from extraction activities.
- Very few studies were found that assessed the impact of extraction activities on prey species. Studies that were found that assessed the effect on spawning acknowledged that there was low confidence in the conclusions and a general lack of supporting field data.

5.3 Physical change (to another seabed/habitat type) (permanent effect)

- The development of offshore wind farms has provided opportunities to undertake longer term studies on the effects of this pressure including before, after, control, impact (BACI) studies. These provide useful information for potential effects by comparing the pre-construction environment to the post-construction environment.
- Many of these offshore wind farm studies focus on the artificial reef effect and the increase in fish diversity and abundance around turbine foundations, including species which are important prey items for harbour porpoise and Manx shearwater.
- Studies that considered the effect of habitat loss due to this pressure did not observe population level effects or displacement for prey species. This may be due to the fact that even large marine infrastructure projects, such as offshore wind farms, result in small areas of habitat change relative to the total available habitat. The exclusion of fishing activity from offshore wind farm sites may also be important.
- The effect of this pressure from linear marine infrastructure such as pipelines and cables is generally thought to be minor for fish species due to the very small footprint of these structures. However, there are far fewer studies investigating this compared to offshore wind farms.

- The effect of this pressure from aggregate extraction, where suitable spawning habitat is removed or replaced due to screening, may be important for prey species. The requirements of the marine licensing regime may limit the effect or removal of spawning habitat as there is a requirement that the seabed substrate being removed is not completely removed resulting in a different substrate post-extraction (e.g. removal of all sand above a layer of gravel such that only gravel remains). The effect of the replacement of substrate over time due to screening (e.g. sand replacing extracted gravel) may not be as effectively controlled and the impacts of this on local fish communities is acknowledged but do not appear to have been well researched.

5.4 Smothering and siltation rate changes

- Studies of the effects of smothering and siltation rate changes on fish have largely focused on eggs and larvae as these are thought to be the life stages most at risk. Studies on the prey species of harbour porpoise and Manx shearwater were very limited in the literature searches.
- Very little information on the effects of this pressure from dredge disposal and aggregate extraction on spawning and nursery ground of prey species was found in the searches. This may be due to the fact these activities are highly regulated through the licensing process with specific mitigation measures applied to avoid such impacts.
- Those monitoring studies that did investigate the effects of dredge dumping and included prey species found no effect on these species at most sites other than the most heavily impacted (highest dredge disposal event frequency). However, it was considered that physical habitat change was the most important pressure influencing the local fish community and not smothering and siltation.
- Environmental impact assessments that consider the effects of this pressure on fish and their spawning and nursery grounds from marine infrastructure projects typically conclude minor or negligible effects. The reasoning typically being that only a very small area is likely to be affected, the effects will be short term and temporary, and the magnitude of the effect (e.g. limited deposition depth) is low.
- The literature considered in this review suggest that this pressure may not be important to prey species, but it is considered that more field data are required to have confidence in this conclusion.

5.5 Sediment resuspension pressures

5.5.1 Suspended sediment

- The effects of suspended sediment are species specific and dependent on life stage with early fish life stages more susceptible to effects than adult fish.
- Laboratory experiments have shown that fish eggs are relatively insensitive to suspended sediment and can tolerate high concentrations. However, it is unknown how such experiments relate to effects in the natural environment.
- A recent modelling study in the Baltic Sea, however, has shown that cod spawning may be affected by suspended sediment concentrations only 1 mg/l above background levels.
- Laboratory and modelling studies provide useful insight into possible threshold levels for effects of suspended sediment on early life stages and adult fish, but the searches did not include much literature from the field that corroborate these findings or provide important context.

5.5.2 Resuspended contaminated sediments

- Studies have demonstrated clear direct effects of RCS on fish. However, these are primarily laboratory experiments, and it is less clear how the findings of these studies relate to exposure in the natural environment where the degree to which sediment bound contaminants can become bioavailable is complex and associated with a range of factors.
- Incidences of toxicological effects from RCS in the natural environment are considered rare and information on long-term chronic effects was not found in the searches. Similarly, very few studies were found in the searches that related directly to harbour porpoise and Manx shearwater prey species.
- Activities that cause the resuspension of contaminated sediments do so across limited spatial and temporal extents so exposure of prey species to these effects may be limited.
- The relative importance of bioaccumulation of contaminants from RCS due to consumption of contaminated prey is unknown and could be an area of future research.

5.6 Marine litter

5.6.1 Microplastics

- The effect of microplastics has been investigated for a number of prey species. The evidence is somewhat contradictory with some studies suggesting no effects and others showing behavioural, physiological and toxicological effects and further research is required.
- These studies provide insight into the potential effects on individuals, but no literature was found that considered how microplastic accumulation in fish may influence local population levels and subsequently prey availability for harbour porpoise and Manx shearwater. It may be that the most important aspect for these species is the accumulation of microplastics through their feeding.

5.6.2 Ghost fishing

- The review found that all species are vulnerable to being caught by abandoned or lost fishing gear, which may continue to fish for many years.
- The long-term effects of this on local populations of fish and how it may influence harbour porpoise and Manx shearwater prey availability in MPAs is unknown.

This review has provided an overview of the effects of a selection of key pressures on harbour porpoise and Manx Shearwater prey. It is recommended that future work focuses resources on individual pressures, or smaller groups of related pressures, to build on the findings of this review. Potential future areas of focus to build on the findings of this review include the following:

- Completion of similar reviews to have a narrower focus on individual pressures, or smaller groups of related pressures, to update the evidence base for these pressures.
- Additional work to examine linkages between seabed pressures, benthic assemblages and prey species. This review has primarily focussed on the direct effects of the pressures on prey species, but it is clear that there is more information on the effects of these pressures on benthic macrofaunal species and communities. The link between effects on these communities and subsequent effects on prey species may be as important in influencing prey availability as direct effects on the prey themselves and could be the subject of future work.

- Additional work to examine effects on early life stages of prey species. Adult prey species are mobile and able to avoid many of the direct effects of pressures on the seabed, however, early life stages have been shown to be vulnerable to these pressures and further investigation of the effects on these life stages would aid understanding of how this influences prey availability.
- Future work could also focus on developing our understanding of the importance of seabed habitats in providing supporting services in a given MPA to support the development of conservation measures and allow more robust assessment of the potential effects of activities in specific locations.

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Appendix 1

The list of search terms used on both Google Scholar and Science Direct.

Table A1: Habitat Change – Extraction.

Keyword(s)	Search Terms
habitat change **sand extraction** **gravel extraction** **navigation dredging** **maintenance dredging**	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("fish spawning" OR "fish nursery")
	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("fish")
	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("gobies" OR "gobiidae")
	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("sandeel" OR “sand eel” OR "ammodytes")
	("effect" OR "Impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("mackerel" OR "scomber scrombus")
	("effect" OR "impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("gravel extraction" OR "sand extraction" OR "mineral extraction") AND ("sardine")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("fish spawning" OR "fish nursery")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging") AND ("fish")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("gobies" OR "gobiidae")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("sandeel" OR “sand eel” OR "ammodytes")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("mackerel" OR "scomber scrombus")

Keyword(s)	Search Terms
habitat change **sand extraction** **gravel extraction** **navigation dredging** **maintenance dredging**	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("squid" OR "cephalopods")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "Impact") AND ("navigation dredging" OR "Channel dredging" OR "maintenance dredging") AND ("sardine")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("fish")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("sardine")
	("effect" OR "impact") AND ("habitat change" OR "habitat structure") AND ("fish eggs" OR "fish larvae" OR "juveniles")

Table A.2: Penetration and Disturbance.

Keyword(s)	Search Terms
scallop dredging **cable burial / laying** **seabed / sediment compression** **seabed / sediment penetration** **subsea cable plough** **water jetting** **anchoring** **demersal trawling**	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression"") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("sardine")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("sediment penetration" OR "sediment compression") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("sardine" OR "Clupeidae")

Keyword(s)	Search Terms
scallop dredging **cable burial / laying** **seabed / sediment compression** **seabed / sediment penetration** **subsea cable plough** **water jetting** **anchoring** **demersal trawling**	("effect" OR "impact") AND ("seabed penetration" OR "seabed compression") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("seabed disturbance" OR "seabed damage")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("fish")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("sardine")
	("effect" OR "impact") AND ("cable burial" OR "cable laying") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("scallop dredging") AND ("seabed disturbance" OR "seabed damage")
	("effect" OR "impact") AND ("scallop dredging") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("scallop dredging") AND ("fish")
	("effect" OR "impact") AND ("scallop dredging") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("scallop dredging") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("scallop dredging") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("scallop dredging") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("scallop dredging") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("scallop dredging") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("scallop dredging") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("scallop dredging") AND ("sardine")
	("effect" OR "impact") AND ("scallop dredging") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("anchoring") AND ("seabed disturbance" OR "seabed damage")
	("effect" OR "impact") AND ("anchoring") AND ("fish spawning" OR "fish nursery")

Keyword(s)	Search Terms
scallop dredging **cable burial / laying** **seabed / sediment compression** **seabed / sediment penetration** **subsea cable plough** **water jetting** **anchoring** **demersal trawling**	("effect" OR "impact") AND ("anchoring") AND ("fish")
	("effect" OR "impact") AND ("anchoring") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("anchoring") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("anchoring") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("anchoring") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("anchoring") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("anchoring") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("anchoring") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("anchoring") AND ("sardine")
	("effect" OR "impact") AND ("anchoring") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("water jetting") AND ("seabed disturbance" OR "seabed damage")
	("effect" OR "impact") AND ("water jetting") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("water jetting") AND ("fish")
	("effect" OR "impact") AND ("water jetting") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("water jetting") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("water jetting") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("water jetting") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("water jetting") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("water jetting") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("water jetting") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("water jetting") AND ("sardine")
	("effect" OR "impact") AND ("water jetting") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("seabed disturbance" OR "seabed damage")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("fish")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("sand eel" OR “sandeel” OR "ammodytes")

Keyword(s)	Search Terms
scallop dredging **cable burial / laying** **seabed / sediment compression** **seabed / sediment penetration** **subsea cable plough** **water jetting** **anchoring** **demersal trawling**	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("sardine")
	("effect" OR "impact") AND ("seabed preparation" OR "pre-sweeping") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("fish")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("sardine")
	("effect" OR "impact") AND ("seabed abrasion" OR "marine habitat abrasion") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("spawning grounds" OR "nursery grounds")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("fish")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("sand eel" OR “sandeel” OR "ammodytes")

Keyword(s)	Search Terms
scallop dredging **cable burial / laying** **seabed / sediment compression** **seabed / sediment penetration** **subsea cable plough** **water jetting** **anchoring** **demersal trawling**	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("seabed disturbance" OR "sediment disturbance") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND "dredging" AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND “dredging" AND ("spawning grounds" OR "nursery grounds")
	("effect" OR "impact") AND "dredging" AND ("fish")
	("effect" OR "impact") AND "dredging" AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND "dredging" AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND "dredging" AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND "dredging" AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND "dredging" AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND "dredging" AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND "dredging" AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND "dredging" AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND "dredging" AND ("fish eggs" OR "fish larvae" OR "juveniles")

Table A.3: Smothering and Siltation.

Keyword(s)	Search Terms
dredge disposal or dumping **smothering** **siltation** **sea disposal**	("effect" OR "impact") AND ("smothering" OR "siltation")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("fish")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("dredge disposal" OR "dredge dumping") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("fish")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("smothering" OR "siltation" OR "sedimentation") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("fish")

Keyword(s)	Search Terms
dredge disposal or dumping **smothering** **siltation** **sea disposal**	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("sea disposal" OR "disposal at sea") AND ("fish eggs" OR "fish larvae" OR "juveniles")

Table A.4: Marine Litter.

Keyword(s)	Search Terms
Microplastics **Ghost fishing** **Marine litter**	("effect" OR "Impact") AND ("microplastics") AND ("fish spawning" OR "fish nursery")
	("effect" OR "Impact") AND ("microplastics") AND ("fish")
	("effect" OR "Impact") AND ("microplastics") AND("whiting" OR "Merlangius merlangus")
	("effect" OR "Impact") AND ("microplastics") AND ("goby" OR "Gobiidae")
	("effect" OR "Impact") AND ("microplastics") AND ("sand eel" OR “sandeel” OR "Ammodytes")
	("effect" OR "Impact") AND("microplastics") AND ("Mackerel" OR "Scromber scrombus")
	("effect" OR "Impact") AND("microplastics") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "Impact") AND ("microplastics") AND ("squid" OR "cephalopods")
	("effect" OR "Impact") AND("microplastics") AND ("sprat" OR "Sprattus sprattus")
	("effect" OR "Impact") AND ("microplastics") AND ("sardine")
	("effect" OR "Impact") AND ("ghost fishing" OR “marine litter") AND ("fish spawning" OR "fish nursery")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("fish")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("whiting" OR "Merlangius merlangus")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("goby" OR "Gobiidae")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("sand eel" OR “sandeel” OR "Ammodytes")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("Mackerel" OR "Scromber scrombus")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("squid" OR "cephalopods")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("sprat" OR "Sprattus sprattus")
	("effect" OR "Impact") AND ("ghost fishing" OR "marine litter") AND ("sardine")

Table A.5: Physical Change to Seabed.

Keyword(s)	Search Terms
rock dumping or rock armour mattressing or concrete mattresses **scour protection** **offshore windfarms** **marine or seabed infrastructure** **habitat change**	("marine infrastructure" OR "seabed infrastructure") AND ("habitat change" OR "seabed change")
	("offshore windfarm" OR "offshore wind farm") AND ("habitat change" OR "seabed change")
	"scour protection" AND ("habitat change" OR "seabed change")
	("rock dumping" OR "rock armour") AND ("habitat change" OR "seabed change")
	("concrete matressing" OR "concrete mattresses") AND ("habitat change" OR "seabed change")
	("offshore wave devices" OR "wave energy devices") AND ("habitat change" OR "seabed change")
	("tidal energy devices" OR "tidal stream devices") AND ("habitat change" OR "seabed change")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("fish spawning" OR "fish nursery")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("fish")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("marine infrastructure" OR "seabed infrastructure") AND ("fish eggs" OR "fish larvae" OR "juveniles")

Table A.6: Resuspension of Sediments.

Keyword(s)	Search Terms
remobilisation **resuspension** **contaminants** **pollutants** **suspended sediment** **turbidity** **sediment plumes**	("effect" OR "impact") AND "suspended sediment" AND ("fish spawning" OR "fish nursery") AND "marine"
	("effect" OR "impact") AND "suspended sediment" AND ("marine fish")
	("effect" OR "impact") AND "suspended sediment" AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND "suspended sediment" AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND "suspended sediment" AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND "suspended sediment" AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND "suspended sediment" AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND "suspended sediment" AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND "suspended sediment" AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND "suspended sediment" AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND "suspended sediment" AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND "sediment plumes" AND ("fish spawning" OR "fish nursery") AND "marine"
	("effect" OR "impact") AND "sediment plumes" AND ("marine fish")
	("effect" OR "impact") AND "sediment plumes" AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND "sediment plumes" AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND "sediment plumes" AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND "sediment plumes" AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND "sediment plumes" AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND "sediment plumes" AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND "sediment plumes" AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND "sediment plumes" AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND "sediment plumes" AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND "turbidity" AND ("fish spawning" OR "fish nursery") AND "marine"
	("effect" OR "impact") AND "turbidity" AND ("marine fish")
	("effect" OR "impact") AND "turbidity" AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND "turbidity" AND ("gobies" OR "gobiidae")

remobilisation **resuspension** **contaminants** **pollutants** **suspended sediment** **turbidity** **sediment plumes**	("effect" OR "impact") AND "turbidity" AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND "turbidity" AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND "turbidity" AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND "turbidity" AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND "turbidity" AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND "turbidity" AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND "turbidity" AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("fish spawning" OR "fish nursery") AND "marine"
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("marine fish")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sand eel" OR “sandeel” OR "ammodytes")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	"bioaccumulation" AND ("contaminants" OR "pollutants") AND "marine fish"
	("effect" OR "impact") AND "bioaccumulation" AND ("contaminants" OR "pollutants") AND ("whiting" OR "merlangius merlangus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("gobies" OR "gobiidae")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sand eel" OR “sandeel” OR "ammodytes")

remobilisation **resuspension** **contaminants** **pollutants** **suspended sediment** **turbidity** **sediment plumes**	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("mackerel" OR "scomber scombrus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("atlantic herring" OR "clupea harengus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("squid" OR "cephalopods")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sprat" OR "sprattus sprattus")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("sardine" OR "Clupeidae")
	("effect" OR "impact") AND ("remobilisation" OR "resuspension") AND ("contaminants" OR "pollutants") AND ("fish eggs" OR "fish larvae" OR "juveniles")
	("effect" OR "impact") AND ("resuspended contaminated sediment") AND ("sardine" OR "Clupeidae")