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Assessing the sensitivity of blue mussels (*Mytilus edulis*) to pressures associated with human activities

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Summary

The Joint Nature Conservation Committee (JNCC) commissioned this project to generate an improved understanding of the sensitivities of blue mussel (*Mytilus edulis*) beds, found in UK waters, to pressures associated with human activities in the marine environment. The work will provide an evidence base that will facilitate and support management advice for Marine Protected Areas, development of UK marine monitoring and assessment, and conservation advice to offshore marine industries.

Blue mussel beds are identified as a Habitat of Principle Importance (HPI) under the Natural Environment and Rural Communities (NERC) Act 2006, as a Priority Marine Feature (PMF) under the Marine (Scotland) Act 2010, and included on the OSPAR (Annex V) list of threatened and declining species and habitats.

The purpose of this project was to produce sensitivity assessments for the blue mussel biotopes included within the HPI, PMF and OSPAR habitat definitions, and clearly document the supporting evidence behind the assessments and any differences between them.

A total of 20 pressures falling in five categories - biological, hydrological, physical damage, physical loss, and pollution and other chemical changes - were assessed in this report. The review examined seven blue mussel bed biotopes found on littoral sediment and sublittoral rock and sediment. The assessments were based on the sensitivity of *M. edulis* rather than associated species, as *M. edulis* was considered the most important characteristic species in blue mussel beds.

To develop each sensitivity assessment, the resistance and resilience of the key elements are assessed against the pressure benchmark using the available evidence gathered in this review. The benchmarks were designed to provide a ‘standard’ level of pressure against which to assess sensitivity. Blue mussel beds were highly sensitive to a few human activities:

- introduction or spread of non-indigenous species (NIS);
- habitat structure changes - removal of substratum (extraction); and
- physical loss (to land or freshwater habitat).

Physical loss of habitat and removal of substratum are particularly damaging pressures, while the sensitivity of blue mussel beds to non-indigenous species depended on the species assessed. *Crepidula fornicata* and *Crassostrea gigas* both had the potential to out-compete and replace mussel beds, so resulted in a high sensitivity assessment.

Mytilus spp. populations are considered to have a strong ability to recover from environmental disturbance. A good annual recruitment may allow a bed to recovery rapidly, though this cannot always be expected due to the sporadic nature of *M. edulis* recruitment. Therefore, blue mussel beds were considered to have a 'Medium' resilience (recovery within 2-10 years). As a result, even where the removal or loss of proportion of a mussel bed was expected due to a pressure, a sensitivity of 'Medium' was reported. Hence, most of the sensitivities reported were 'Medium'. It was noted, however, that the recovery rates of blue mussel beds were reported to be anywhere between two years to several decades.

In addition, *M. edulis* is considered very tolerant of a range of physical and chemical conditions. As a result, blue mussel beds were considered to be 'Not sensitive' to changes in temperature, salinity, de-oxygenation, nutrient and organic enrichment, and substratum type, at the benchmark level of pressure.

The report found that no distinct differences in overall sensitivity exist between the HPI, PMF and OSPAR definitions. Individual biotopes do however have different sensitivities to pressures, and the OSPAR definition only includes blue mussel beds on sediment. These differences were determined by the position of the habitat on the shore and the sediment type. For example, the infralittoral rock biotope (A3.361) was unlikely to be exposed to pressures that affect sediments. However in the case of increased water flow, mixed sediment biotopes were considered more stable and 'Not sensitive' (at the benchmark level) while the remaining biotopes were likely to be affected.

Using a clearly documented, evidence-based approach to create sensitivity assessments allows the assessment basis and any subsequent decision making or management plans to be readily communicated, transparent and justifiable. The assessments can be replicated and updated where new evidence becomes available ensuring the longevity of the sensitivity assessment tool. For every pressure where sensitivity was previously assessed as a range of scores in MB0102, the assessments made by the evidence review have supported one of the MB0102 assessments. The evidence review has reduced the uncertainty around assessments previously undertaken in the MB0102 project (Tillin *et al* 2010) by assigning a single sensitivity score to the pressures as opposed to a range. Finally, as blue mussel bed habitats also contribute to ecosystem function and the delivery of ecosystem services, understanding the sensitivity of these biotopes may also support assessment and management in regard to these.

Whatever objective measures are applied to data to assess sensitivity, the final sensitivity assessment is indicative. The evidence, the benchmarks, the confidence in the assessments and the limitations of the process, require a sense-check by experienced marine ecologists before the outcome is used in management decisions.

Contents

1 Introduction

This project was commissioned to improve understanding of the sensitivities of blue mussel (*Mytilus edulis*) beds, found in UK waters, to pressures associated with human activities in the marine environment. This work will provide an evidence base that will facilitate and support management advice for Marine Protected Areas, development of UK marine monitoring and assessment, and conservation advice to offshore marine industries.

Blue mussel beds are identified as a Habitat of Principle Importance (HPI) under the Natural Environment and Rural Communities (NERC) Act 2006, as a Priority Marine Feature (PMF) under the Marine (Scotland) Act 2010, and included on the OSPAR (Annex V) list of threatened and declining species and habitats.

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2 Methodology

2.1 Definition of sensitivity, resistance and resilience

The concepts of resistance and resilience introduced by Holling (1973) are widely used to assess sensitivity (Table 2.1). The UK Review of Marine Nature Conservation (Defra 2004) defined sensitivity as 'dependent on the intolerance of a species or habitat to damage from an external factor [pressure] and the time taken for its subsequent recovery'.

Resistance is an estimate of an individual, a species population and/or habitat's ability to resist damage or change as a result of an external pressure. It is assessed in either quantitative or qualitative terms, against a clearly defined scale. While the principle is consistent between approaches, the terms and scales vary. Resistance and tolerance are often used for the dame concept, although other approaches assess 'intolerance' which is the reverse of resistance.

Table 2.1. Definition of sensitivity and associated terms.

Term	Definition	Sources
Sensitivity	A measure of susceptibility to changes in environmental conditions, disturbance or stress which incorporates both resistance and resilience.	Holt *et al* (1995), McLeod (1996), Tyler-Walters *et al* (2001), Zacharias & Gregr (2005)
Resistance (Intolerance/tolerance)	A measure of the degree to which an element can absorb disturbance or stress without changing in character.	Holling (1973)
Resilience (Recoverability)	The ability of a system to recover from disturbance or stress.	Holling (1973)
Pressure	The mechanism through which an activity has an effect on any part of the ecosystem. The nature of the pressure is determined by activity type, intensity and distribution.	Robinson *et al* (2008)

Resilience is an estimate of an individual, a species population and/or habitat's ability to return to its prior condition, or recover, after the pressure has passed, been mitigated or removed. The term resilience and recoverability are often used for the same concept, and are effectively synonymous[1].

Sensitivity can be understood, therefore, as a measure of the likelihood of change when a pressure is applied to a feature (receptor) and is a function of the ability of the feature to tolerate or resist change (resistance) and its ability to recover from impact (resilience). The detailed definitions and ranks used in this study are given in Appendix 1.

2.2 Sensitivity assessment methodology

Tillin *et al* (2010) method was developed to assess the sensitivity of certain marine features, considered to be of conservation interest, against physical, chemical and biological pressures resulting from human activities. The sensitivity assessments made by Tillin *et al* 2010) were based on expert judgement. For the purpose of this report, the Tillin *et al* (2010)

[1] The terms 'resilience' and 'recoverability' are used to describe an ability or characteristic, while 'recovery' and or 'recovery rate' are used to denote the process.

methodology was modified to include a review of available evidence, rather than expert judgement alone, as the basis for sensitivity assessment. The methodology, definitions and terms are summarised in Appendix 1.

The sensitivity assessment method used (Tillin *et al* 2010) involves the following stages, which are explained in Appendix 1.

A. Defining the key elements of the feature to be assessed (in terms of life history, and ecology of the key and characterising species).
B. Assessing feature resistance (tolerance) to a defined intensity of pressure (the benchmark).
C. Assessing the resilience (recovery) of the feature to a defined intensity of pressure (the benchmark).
D. The combination of resistance and resilience to derive an overall sensitivity score.
E. Assess level of confidence in the sensitivity assessment.
F. Written audit trail.

So that the basis of the sensitivity assessment is transparent and repeatable the evidence base and justification for the sensitivity assessments is recorded. A complete and accurate account of the evidence used to make the assessments is presented for each sensitivity assessment in Section 4 (literature review) and summarised in the Excel ‘pro-forma’ spreadsheet which presents the summary of the assessment, the sensitivity scores and the confidence levels

2.3 Human activities and pressures

A pressure is defined as ‘the mechanism through which an activity has an effect on any part of the ecosystem’ (Robinson *et al* 2008). Pressures can be physical (e.g. subsurface abrasion), chemical (e.g. organic enrichment) or biological (e.g. introduction of non-native species).

An activity may give rise to more than one pressure. For example, a number of pressures are linked to the cultivation of oysters on trestles including, possible introduction on non-native species, change in water flow, increased siltation/organic matter sedimentation, shading and trampling (physical abrasion and sub-surface damage) of sediments as trestles are visited. Rather than assessing the impact of activities as a single impact, the pressure-based approach supports clearer identification of the pathway(s) through which impacts on a feature may arise from the activity. If the pressures are not separated then it could be difficult to identify the stage in the operation which gives rise to the impact. This approach is especially useful to assess the impacts of activities that involve a number of different stages that are carried out in different habitats.

It should be noted that the same pressure can also be caused by a number of different activities, for example, fishing using bottom gears and aggregate dredging both cause abrasion and sub-surface damage which are classified as a habitat damage pressure (Tyler-Walters *et al* 2001; Robinson *et al* 2008).

Adoption of a pressure based approach means that a wide range of evidence, including information from different types of activities that produce the same pressures, field observations and experimental studies can be used to inform sensitivity assessments and to check these for consistency. To be meaningful and consistent sensitivity to a pressure should be measured against a defined pressure benchmark.

Pressure definitions and an associated benchmark were supplied by JNCC for each of the pressures that were to be assessed (Appendix 2). The pressures JNCC supplied were a modified version of the Intercessional Correspondence Group on Cumulative Effects (ICG-C) (OSPAR 2011). The ICG-C list contained a list of pressure definitions, but not benchmarks; as it was developed after the MB0102 project (Tillin *et al* 2010). MB0102 has very similar pressures to the ICG-C list and therefore JNCC have taken the benchmarks from MB0102 and applied to the ICG-C list of pressures. The pressures considered relevant to Blue mussel beds are assessed in Section 4.

2.4 Literature Review

The literature review used the following resources to identify relevant published literature and grey literature:

- the MarLIN Biology and Sensitivity Key Information database;
- latest reports by the project team relevant to the project and the project teams personal collections of papers and references;
- National Marine Biological Library (NMBL) library catalogue and ePrints Archive;
- abstracting journals provided by the NMBL, for example:
    - Aquatic Sciences and Fisheries Abstracts (ASFA);
    - Web of Science (citation index) and Web of Knowledge;
    - Science Direct;
    - Wiley On-line library;
    - NMBL electronic journal access; and
    - Google Scholar.

A systematic approach to the literature review was undertaken based on a defined list of key words and search terms. The literature review examined the following areas.

- Concepts of resistance and resilience relevant to the habitat and characteristic species.
- Effects of the agreed pressures on the habitats with an emphasis on UK but with other examples where relevant/required.
- Evidence of the magnitude, extent (spatial) and duration (temporal) of direct and indirect effects of pressures.
- Structural and functional effects of pressures, including effects on the sedimentary habitats and associated species assemblages.
- Likely rates of recovery based on the habitats and the characteristic species present within the habitats.

3 Description of blue mussel bed habitats and relevant pressures

This section briefly describes the habitat and relevant definitions, characteristic species and ecology of blue mussel beds. This section also summarises key recovery information for these habitats, other relevant features e.g. habitat substratum, and any important characterizing species.

3.1 Definition and characteristics of feature - including characteristic species

Mytilus edulis, also known as the blue mussel, is a suspension feeding bivalve that can be found from the stand-line down to the sublittoral. It is a eurytopic species found from the sub tropics to Svalbard in a variety of salinities and exposures. Blue mussels can be found as individuals but they often form dense beds with multiple layers; sometimes forming the basis of a biogenic reef (Holt *et al* 1998).

M. edulis beds are found at a wide range of shore heights from in the strandline down to the shallow sublittoral (Connor *et al* 2004). Their upper limits are controlled by temperature and desiccation (Suchanek 1978; Seed & Suchanek 1992; Holt *et al* 1998) while the lower limits are set by predation, competition (Suchanek 1978) and sand burial (Daly & Mathieson 1977). Mussels found higher up the shore display slower growth rates (Buschbaum & Saier 2001) due to the decrease in time during which they can feed and also a decrease in food availability. It has been estimated that the point of zero growth occurs at 55% emergence (Baird 1966) although this figure will vary slightly depending on the conditions of the exposure of the shore (Baird 1966; Holt *et al* 1998). Increasing shore height does, however, increase the longevity of the mussels due to reduced predation pressures (Seed & Suchanek 1992; Holt *et al* 1998), resulting in a wider age class of mussels is found on the upper shore.

M. edulis is the dominant species defining the blue mussel bed biotopes reviewed. Without abundant *M. edulis* the habitat could no longer be classified as a blue mussel bed. The blue mussel bed provides additional substratum and niches for colonisation, but in rocky habitats, most of the species associated with the beds are found on the surrounding the rock. In sedimentary habitats, blue mussel beds stabilise the substratum, modify the sedimentary habitat and provide hard substratum in an otherwise sedimentary habitat.

Although a wide range of species are associated with *Mytilus edulis* reef or bed biotopes these characterizing species occur in a range of other biotopes and are therefore not considered to be obligate associates. *M. edulis* beds are not dependent on associated species to create or modify habitat, provide food or other resources, although their loss would represent a loss of diversity. It should be noted that for attached organisms the sensitivity of the *M. edulis* biotope would be of primary concern as removal of the reef would also lead to removal of the attached species.

The sensitivity assessments are therefore based on *M. edulis* and only consider the sensitivity of associated species where they might augment and impact of or cause secondary impacts.

3.1.1 Ecological function and conservation

Dense aggregations of blue mussels (living and dead) form a single or multi-layered framework, held together by byssus threads that stabilise sediment, and provide a habitat for many infaunal and epifaunal species. Beds may be transient and dynamic or permanent and persistent.

Blue mussels act as a habitat engineer. Their beds provide additional niches (e.g. interstices and shelter) on hard substrata. While on sediment, they provide hard substratum (shell), stabilise the sediment surface, and provide interstices and shelter for colonisation by other organisms. Blue mussel beds therefore enhance local biodiversity. The diversity of associated communities increases with age (and size) of the mussel bed.

The mussel bed supports an assemblage of suspension feeders including barnacles, polychaetes and ascidians. Barnacles (*Semibalanus balanoides, Austrominius modestus* or *Balanus crenatus*) often encrust mussels. Where boulders are present in the habitat, they can support limpets (e.g. *Patella vulgata*) and dog whelks (*Nucella lapillus*). Winkles, *Littorina littorea*, and small individuals of the crab *Carcinus maenas* are common amongst mussel beds, whilst areas of sediment may contain the lugworm *Arenicola marina*, the sand mason *Lanice conchilega*, the cockle *Cerastoderma edule*, and other infaunal species.

'Mussel mud', composed of faeces, pseudofaeces and sediment, accumulates underneath mussel beds. In sheltered habitats, pseudofaeces (undigested, filtered particles) can build up forming a thick layer of anoxic mud. The layer of mud may prevent the attachment of mussels to the underlying substratum. 'Mussel mud' (that is not anoxic) supports a diverse range of infauna.

Macroalgae (e.g. *Chondrus crispus, Fucus vesiculosus, Saccharina latissima* and *Ulva* spp.) provide primary production to blue mussel beds and the surrounding ecosystem directly to grazers, or indirectly in the form of algal particulates and detritus, algal spores, algal exudates and dissolved organic matter.

Starfish, crabs, demersal fish, dog whelks and birds are predators on mussel beds. Predation influences population size structure and often prevents extension of beds subtidally. For example, crabs predate upon small, juvenile mussels. The starfish *Asterias rubens* preys heavily on large mussels on the lower shore and sublittoral communities. Mussels may employ defence mechanisms against predators; for example, the immobilisation of dog whelks through the production of byssus threads.

Fouling epifauna (e.g. barnacles, seaweeds, ascidians) increase weight and drag, this may result in increased risk of removal from substratum by waves and tidal scour. However, sea urchins, chitons, and gastropods graze on epifauna and algae on the mussels, preventing excess fouling which might otherwise be detrimental to the bed.

Larval production by *Mytilus edulis* constitutes a significant proportion of the zooplankton community providing an important food source to many organisms. Adult mussels are also an important food source to many organisms ranging from wading birds to intertidal predators.

Mussel beds are also of high commercial and economic importance as they are cultivated in large numbers for harvesting. *Mytilus edulis* also plays a vital role in pelagic-benthic coupling, as it takes pelagic primary production and converts it to secondary production adding nutrients and carbon to the benthic communities. Mussels beds (and beds of other filter feeding bivalves) play a key role in filtering the phytoplankton from the water column (Coen & Luckenbach 2000; Dame 2011). Therefore the removal of large numbers of mussels (as found in beds) is likely to upset this balance and result in decreased delivery of primary and secondary productivity to the seabed.

3.1.2 *Mytilus edulis* biotope descriptions

The purpose of this project was to produce sensitivity assessments with supporting evidence for the HPI, OSPAR and PMF Blue Mussel beds habitat definitions. Each of the habitat definitions includes two or more EUNIS[2] biotopes classifications (see Table 3.1, for constituent biotopes for each definition). The EUNIS biotopes are described in detail in Appendix 3. The descriptions were taken from the EUNIS website and were developed from Connor *et al* (2004).

The broad habitat definitions (HPI, PMF, and OSPAR) include beds of the blue mussel *Mytilus edulis* in a range of conditions from open coasts to estuaries and marine inlets. Component biotopes vary depending on sediment type (e.g. A2.7212 on sand, A2.7213 on mud and A2.7211 on mixed), the abundance of fan worms (A2.212), and intertidal or subtidal habitat (A5.625) or reduced salinity rock (A3.361). Intertidal mussel bed biotopes may be influenced by the amount of pseudofaeces that accumulate amongst the mussels.

Table 3.1. Constituent EUNIS biotopes included within the PMF, HPI and OSPAR definitions of blue mussel habitats.

EUNIS Code		HPI	PMF	OSPAR
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	X	X	
A2.721	*Mytilus edulis* beds on littoral sediments	X	X	
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	X	X	X
A2.7212	*Mytilus edulis* beds on littoral sand	X	X	X
A2.7213	*Mytilus edulis* beds on littoral mud	X	X	
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	X	X	
A5.625	*Mytilus edulis* beds on sublittoral sediment	X	X	

Although, blue mussels may form beds in all the selected habitats, Holt *et al* (1998) note that only '*Mytilus edulis* beds on littoral mixed substrata' can be regarded as a biogenic reef.

3.2 Resilience (recovery rates) of blue mussel beds

Blue mussels are sessile, attached organisms that are unable to repair significant damage to individuals. Blue mussels do not reproduce asexually and therefore the only mechanism for recovery from significant impacts (where resistance is assessed as None, Low or medium) is larval recruitment to the bed or the area where previously a bed existed.

Spawning occurs in spring and later summer allowing two periods of recruitment (Seed 1969). *Mytilus edulis* has a high fecundity producing >1,000,000 eggs per spawning event. The larvae released in spring are able to take advantage of the spring phytoplankton bloom whereas the larvae released late summer are at the mercy of the environmental conditions (Tyler-Walters 2008). Larvae stay in the plankton for between 20 days to two months depending on water temperature (Bayne 1976). In unfavourable conditions they may delay metamorphosis for 6 months (Lane *et al* 1985). Larval dispersal depends on the currents and the length of time they spend in the plankton. Larvae subject to ocean currents for up to six months can have a high dispersal potential.

Settlement occurs in two phases, an initial attachment using their foot (the pediveliger stage) and then a second attachment by the byssus thread before which they may alter their location to a more favourable one (Bayne 1964). The final settlement often occurs around or between individual mussels of an established population.

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[2] EUNIS-European Nature Information System, website available at http://www.eunis.eea..europa.eu

Larval mortality can be as high as 99% due to adverse environmental conditions, especially temperature, inadequate food supply (fluctuations in phytoplankton populations), inhalation by suspension feeding adult mytilids, difficulty in finding suitable substrata and predation (Lutz & Kennish 1992). After settlement the larvae and juveniles are subject to high levels of predation as well as dislodgement by waves and sand abrasion depending on the area of settlement.

In the northern Wadden Sea, strong year classes (resulting from a good recruitment episode) that lead to rejuvenation of blue mussel beds are rare, and usually follow severe winters, even though mussel spawning and settlement are extended and occur throughout the year (Diederich 2005). In the List tidal basin (northern Wadden Sea) a mass recruitment of mussels occurred in 1996 but had not been repeated by 2003 (the date of the study), i.e. for seven years (Diederich 2005).

Therefore, recruitment of *Mytilus edulis* is often sporadic, occurring in unpredictable pulses (Seed & Suchanek 1992), although persistent mussel beds can be maintained by relatively low levels or sporadic recruitment (McGrorty *et al* 1990). In areas of high water flow the mussel bed will rely on recruitment from other populations as their larvae will be swept away and therefore recovery will depend on recruitment from elsewhere. A good annual recruitment could result in rapid recovery (Holt *et al* 1998). However, the unpredictable pattern of recruitment based on environmental conditions could result in recruitment taking much longer.

Their height on the shore generally determines life span with mussels in the low shore only surviving between 2-3 years due to high predation levels whereas higher up on the shore a wider variety of age classes are found (Seed 1969). Theisen (1973) reported that specimens of *M. edulis* could reach 18-24 years of age.

Seed and Suchanek (1992) reviewed studies on the recovery of 'gaps' in *Mytilus* spp. beds. It was concluded that beds occurring high on the shore and on less exposed sites took longer to recover after a disturbance event than beds found low on the shore or at more exposed sites. However, the slowest recovering sites (high shore and sheltered shores) are at the least risk of natural disturbance and often considered more 'stable' (Lewis 1964) as they are less vulnerable to removal by wave action or wave driven logs. Continued disturbance will lead to a patchy distribution of mussels.

In some long term studies of *Mytilus californianus* it was observed that gaps could continue to increase in size post disturbance due to wave action and predation (Paine & Levin 1981; Brosnan & Crumrine 1994; Smith & Murray 2005) potentially due to the weakening of the byssus threads leaving them more vulnerable to environmental conditions (Denny 1987). On rocky shores barnacles and fucoids are often quick to colonise the 'gaps' created. The presence of macroalgae appears to inhibit recovery whilst the presence of barnacles enhances subsequent mussel recruitment (Seed & Suchanek 1992).

Brosnan and Crumrine (1994) observed little recovery of *Mytilus californianus* in two years after trampling disturbance. Paine and Levin (1981) estimated that recovery times could be between 8-24 years while Seed and Suchaneck (1992) suggested it could take up to hundreds of years. It has, however, been suggested that *Mytilus edulis* recovers quicker than other *Mytilus* species (Seed & Suchanek 1992), which may mean that these predicted recovery rates are too low for *Mytilus edulis.*

3.3 Resilience (recovery) assessment

Overall, *Mytilus* spp. populations are considered to have a strong ability to recover from environmental disturbance (Holt *et al* 1998; Seed & Suchaneck 1992). A good annual recruitment may allow a bed to recovery rapidly, though this cannot always be expected due to the sporadic nature of *Mytilus edulis* recruitment (Lutz & Kennish 1992; Seed & Suchanek 1992). Resilience will vary depending of larval supply and wave exposure with areas with low larval supply and high wave exposure on sandy substrata experiencing the longest recovery rates. The resilience assessments used throughout the report (unless there is directly applicable recovery evidence relating to the assessed pressure) are summarised below (Table 3.2).

Where resistance is ‘High’ then there is no effect to recover from and resilience is assessed as ‘High’ (not shown in table). Littoral and sublittoral beds are considered to have ‘Medium’ resilience (2 -10 years) to represent the potential for recovery within a few years where a proportion of the bed remains (‘Medium’ or ‘Low’ resistance) but possibility of longer term recovery due to the sporadic nature of recruitment. Resilience is assessed as ‘Low’ (over 10 years) for all biotopes where resistance is assessed as ‘None’, as recovery is dependent on recruitment from other areas and recruitment can be sporadic. Due to the variation in recovery rates reported in the literature, while the evidence for resilience is of ‘High’ quality and ‘High’ applicability (for recovery from the same pressures), the degree of concordance is ‘Medium’.

Table 3.2. Resilience assessments for biotopes where resistance is ‘None’, ‘Low’ and ‘Medium’.

EUNIS Code			**Resistance**		
	Biotope		**Medium**	**Low**	**None**
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	**Resilience**	**Medium**	**Medium**	**Low**
A2.721	*Mytilus edulis* beds on littoral sediments		**Medium**	**Medium**	**Low**
A2.7211	*Mytilus edulis* beds on littoral mixed substrata		**Medium**	**Medium**	**Low**
A2.7212	*Mytilus edulis* beds on littoral sand		**Medium**	**Medium**	**Low**
A2.7213	*Mytilus edulis* beds on littoral mud		**Medium**	**Medium**	**Low**
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock		**Medium**	**Medium**	**Low**
A5.625	*Mytilus edulis* beds on sublittoral sediment		**Medium**	**Medium**	**Low**

4 Review of the effects of pressures

This section reviews the current understanding of the resistance and resilience of each of the seagrass habitat/biotopes, to relevant pressures. Each pressure is considered in a separate section that describes the characteristics and properties of the particular feature that are likely to be affected by the pressure, making clear where there are differences between the biotope or habitat definitions. The pathways through which effects are transmitted are described and evidence or hypotheses for the direction and potential magnitude of effects and the spatial and temporal scale at which change might occur is outlined. This information forms the basis of the resistance, resilience and sensitivity.

It should be noted that absence of an activity within a pressure discussion for this habitat, does not mean that there is no pressure-activity linkage, only that there may be a lack of evidence for the effect of that activity on this habitat. For more information, please refer to the standardised UK pressure-activities matrix (JNCC 2013b).

From the initial list of pressures provided (see Appendix 2) pressures that were unlikely to affect the habitat, or where the evidence base was known to be incomplete, were excluded from the review and subsequent assessment. The pressures listed in Table 4.1 were assessed in the report, while those listed in Table 4.2 were excluded.

Table 4.1. Assessed pressures.

Pressure theme	ICG-C Pressure
Biological pressures	Genetic modification and translocation of indigenous species
	Introduction of microbial pathogens
	Introduction or spread of non-indigenous species (NIS)
	Removal of non-target species
	Removal of target species
Hydrological changes (inshore/local)	Emergence regime changes – local including tidal level change considerations
	Salinity changes - local
	Temperature changes - local
	Water flow (tidal current) changes - local, including sediment transport considerations
Hydrological changes (inshore/local)	Wave exposure changes - local
Physical damage (Reversible Change)	Abrasion/disturbance of the substratum on the surface of the seabed
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion
	Changes in suspended solids (water clarity)
	Habitat structure changes - removal of substratum (extraction)
	Siltation rate changes, including smothering (depth of vertical sediment overburden)
Physical Loss (Permanent Change)	Physical change (to another seabed type)
	Physical loss to (to land or freshwater habitat)
Pollution and other chemical changes.	De-oxygenation
	Nutrient enrichment
	Organic enrichment

Table 4.2. Non-assessed pressures.

Pressure Theme	ICG-C Pressure	Reason for exclusion
Biological pressures	Visual disturbance	*Mytilus* species have limited visual perception
Other physical pressures	Barrier to species movement[3]	Applicable to mobile species only e.g. fish and marine mammals
	Death or injury by collision	Applicable to mobile species only e.g. fish and marine mammals
	Electromagnetic changes	*Mytilus* species are not know to be effected by electromagnetic field
	Introduction of light	*Mytilus* species have limited visual perception
	Litter	No benchmark proposed
	Underwater noise changes	*Mytilus* species have limited acoustic perception
Pollution and other chemical changes	De-oxygenation	Biotopes are considered to be 'Not Sensitive' at the pressure benchmark
	Hydrocarbon & PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Biotopes are considered to be 'Not Sensitive' at the pressure benchmark
	Introduction of other substances (solid, liquid or gas)	No benchmark proposed
	Radionuclide contamination	Biotopes are considered to be 'Not Sensitive' at the pressure benchmark
	Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Biotopes are considered to be 'Not Sensitive' at the pressure benchmark

Evidence or hypotheses for the rates at which affected characteristic species are likely to recover is also provided for each pressure where this was found. This evidence, alongside the generic recovery information outlined in Section 3, was used to derive the subsequent resilience assessments presented below. Any differences in resistance/resilience between the constituent biotopes are fully detailed and tabulated. Resistance, resilience, sensitivity and confidence scores are included in the summary proforma provided with the report.

4.1 Biological pressures

Biological pressures only address the ‘biological’ or ‘community effects’ on the species population and/or habitat. For example, changes in the structure of the community or food web, or removal of species on which the feature depends. Physical and chemical impacts are addressed in later sections.

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[3] Physical and hydrographic barriers may limit the dispersal of larvae. But larval dispersal is not considered under the pressure definition and benchmark.

4.1.1 Genetic modification and translocation of indigenous species

ICG-C pressure description
Genetic modification can be either deliberate (e.g. introduction of farmed individuals to the wild, GM food production) or a by-product of other activities (e.g. mutations associated with radionuclide contamination). The former is related to escapees or deliberate releases e.g. cultivated species such as farmed salmon, oysters, and scallops, if GM practices employed. The scale of pressures is compounded if GM species are "captured" and translocated in ballast water. Mutated organisms from the latter could be transferred on ships hulls, in ballast water, with imports for aquaculture, aquaria, live bait, species traded as live seafood or 'natural' migration.

Pressure benchmark
Translocation outside of a geographic areas; introduction of hatchery – reared juveniles outside of geographic area from which adult stick derives.

Evidence description
Blue mussels are species of commercial interest as a fishery (through hand picking, raking or dredging), collection for bait, or cultivation around the coasts of the UK. The cultivation process involves the collection of juvenile mussel ‘seed’ or spat[4] from wild populations, and its transportation around the UK. The ‘seed’ are re-laid in favourable locations to grow before subsequent harvesting. As the seed is harvested from wild populations from various locations the gene pool will not necessarily be decreased by translocations. Movement of mussel seed has the potential to transport pathogens and non-native species (see section 4.1.2 and 4.1.3 respectively). This section reviews and assesses the potential impacts on the target biotopes of genetic flow between translocated stocks and wild mussel beds.

Two species of *Mytilus* occur in the UK, *M. edulis* and *M. galloprovincialis. M. edulis* appears to maintain genetic homogeneity throughout its range whereas *M. galloprovincialis* can be genetically subdivided into a Mediterranean group and an Atlantic group (Beaumont *et al* 2007). *M. edulis* and *M. galloprovincialis* have the ability to hybridise in areas where their distribution overlaps e.g. around the Atlantic and European coast (Gardner 1996; Daguin *et al* 2001; Bierne *et al* 2002; Beaumont *et al* 2004). In the UK overlaps occur on the North East coast, North East Scotland, South West England and in the North, West and South of Ireland (Beaumont *et al* 2007). It is difficult to identify *M. edulis*, *M. galloprovincialis* or hybrids based on shell shape because of the extreme plasticity of shape exhibited by mussels under environmental variation, and a genetic test is required (Beaumont *et al* 2007). There is some discussion questioning the distinction between the two species as the hybrids are fertile (Beaumont *et al* 2007). Hybrids reproduce and spawn at a similar time to both *M. edulis* and *M. galloprovincialis* which supports genetic flow between the taxa (Doherty *et al* 2009).

There is some evidence that hybrid larvae have a faster growth rate to metamorphosis than pure individuals which may leave pure individuals more vulnerable to predation (Beaumont *et al* 1993). As the physiology of both the hybrid and pure *M. edulis* is so similar there is likely to be very little impact on the tolerance of the bed to neither pressures nor a change in the associated fauna.

A review by (Svåsand *et al* 2007) concluded that there was a lack of evidence distinguishing between different populations to accurately assess the impacts of hybridisation and in particular how the gene flow may be affected by aquaculture. Therefore, it cannot be

[4] The terms mussel ‘seed’ or ‘spat’ refer to newly settled juveniles ca 1-2cm in length.

confirmed whether farming will have an impact on the genetics of this species beyond a potential for increased hybridisation.

Sensitivity assessment

No direct evidence was found regarding the potential for negative impacts of translocated mussel seed on adjacent natural beds. While it is possible that translocation of mussel seed could lead to genetic flow between cultivated beds and local wild populations, there is currently no evidence to assess the impact (Svåsand *et al* 2007). Hybrid beds perform the same ecological functions as *M. edulis* so that any impact relates to genetic integrity of a bed alone. This impact is considered to apply to all mussel biotopes equally, as the main habitat forming species *M. edulis* is translocated. Also, given the uncertainty in identification of the species, habitats or biotopes described as dominated by *M. edulis* may well be dominated by *M. galloprovincialis,* their hybrids or a mosaic of the three*.*

Presently, there is no evidence of impact due to genetic modification and translocation; therefore a **sensitivity** of **'No evidence'** is reported. The range of *Mytilus galloprovincialis* is thought to be extending northwards (Beaumont *et al* 2007) and this assessment may require updating in the future.

4.1.2 Introduction of microbial pathogens/parasites

ICG-C pressure description
Untreated or insufficiently treated effluent discharges and run-off from terrestrial sources and vessels. It may also be a consequence of ballast water releases. In mussel or shellfisheries where seed stock is imported, 'infected' seed could be introduced, or it could be from accidental releases of effluvia. Escapees, e.g. farmed salmon, could be infected and spread pathogens in the indigenous populations. Aquaculture could release contaminated faecal matter, from which pathogens could enter the food chain.

Pressure benchmark
The introduction of microbial pathogens *Bonamia* sp. and *Marteilia refringens* to an area where they are not present currently.

Evidence description
Mytilus edulis can host a diverse array of disease organisms, parasites and commensals from many animal and plant groups including bacteria, blue green algae, green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, copepods and decapods (Bower 1992; Gray *et al* 1999; Bower 2010).

The benchmark for this pressure refers to two protozoan parasites that infect shellfish. Whilst one of the benchmark species, *Bonamia*, has been shown not to infect *Mytilus edulis* (Culloty *et al* 1999), the other benchmark species *Marteilia refringens* can infect and have significant impacts on the health of *M. edulis*. Its distribution, impacts on the host, diagnostic techniques and control measures are reviewed by Bower (2011). There is some debate as to whether there are two species of *Marteilia,* one which infects oysters (*M. refringens*) and another that infects blue mussels (*M. maurini*) (Le Roux *et al* 2001) or whether they are just two strains of the same species (Lopez-Flores *et al* 2004; Balseiro *et al* 2007). Both species are present in southern parts of the United Kingdom. The infection of *Marteilia* results in Marteiliosis which disrupts the digestive glands of *M. edulis* especially at times of spore release. Heavy infection can result in a reduced uptake of food, reduced absorption efficiency, lower carbohydrate levels in the haemolymph and inhibited gonad development particularly after the spring spawning resulting in an overall reduced condition of the individual (Robledo *et al* 1995).

Recent evidence suggests that *Marteilia* is transferred to and from *M. edulis* via the copepod *Paracartia grani*. This copepod is not currently prevalent in the UK waters, with only a few records in the English Channel and along the South coast. However, it is thought to be transferred by ballast water and so localised introductions of this vector may be possible in areas of mussel seed transfer e.g. the Menai Strait. The mussel populations here are considered to be naive (i.e. not previously exposed) and therefore could be heavily affected, although the likelihood is slim due to the dependence on the introduction of a vector that is carrying *Marteilia* and then it being transferred to the mussels.

Berthe *et al* (2004) concluded that *M. edulis* is rarely significantly affected by *Marteilia* sp. However, occasions have been recorded of nearly 100% mortality when British spat have been transferred from a 'disease free area' to areas in France were *Marteilia sp.* are present. This suggests that there is a severe potential risk if naive spat are moved around the UK from northern waters into southern waters where the disease is resident (enzootic) or if increased temperatures allow the spread of *Marteilia sp.* northwards towards the naive northern populations. In addition, rising temperatures could allow increased densities of the *Marteilia sp.* resulting in heavier infections which can lead to mortality.

Sensitivity assessment

Bower (2010) noted that although *Marteilia* was a potentially lethal pathogen of mussels, most populations were not adversely affected by marteilioisis but that in some areas mortality can be significant in mariculture (Berthe *et al* 2004). The resultant population would be more sensitive to other pressures, even where the disease only resulted in reduced condition. Therefore, a precautionary **resistance** of **'Medium'** is suggested (<25% mortality), with a **resilience** of **'Medium'** resulting in a **sensitivity** of **'Medium'.** This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as **'Medium' sensitivity.**

Resistance confidence

Quality of evidence is 'Medium' - based peer reviewed and grey literature but where the effects vary with location or environmental conditions.
Applicability is 'Medium' - based on the effects on the same pressure on cultivated rather than wild populations, outside the UK.
Concordance is 'Medium' - based on similar effects but a variable magnitude.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

4.1.3 Introduction or spread of non-indigenous species

ICG-C pressure description
The direct or indirect introduction of non-indigenous species, e.g. Chinese mitten crabs, slipper limpets, Pacific oyster and their subsequent spreading and out-competing of native species. Ballast water, hull fouling, stepping stone effects (e.g. offshore wind farms) may facilitate the spread of such species. This pressure could be associated with aquaculture, mussel or shellfishery activities due to imported seed stock imported or from accidental releases.

Pressure benchmark
A significant pathway exists for introduction of one or more invasive non-indigenous species (NIS) (e.g. aquaculture of NIS, untreated ballast water exchange, local port, terminal harbour or marina); creation of new colonisation space > 1ha. One or more NIS has been recorded in the relevant habitat.

Evidence description

Aquaculture of *Mytilus edulis* requires regular movement of mussel seed from one area to another providing a significant pathway for the introduction of non-indigenous species. Sewell *et al* (2008) reviewed species with the potential to be introduced to and impact mussel beds. These included *Botrylloides violaceus*, *Corella eumyota*, *Crepidula fornicata*, *Didemnum vexillum*, *Eriocheir sinensis*, *Rapana venosa*, and *Crassostrea gigas* and *Aulocomya ater*.

Botrylloides violaceus (a sea squirt)

Botrylloides violaceus is a suspension feeding, mat-forming, tunicate. *B. violaceus* is quick to colonise new substrata via budding and larval dispersal and can greatly increase competition for space with native epibenthic species; potentially smothering and overgrowing those already settled.

It has been reported to grow on fouling mussels (*Mytilus* sp.) in Ireland (Minchin 2007) and to often overgrow mussels, barnacles, sea mats and solitary sea squirts in the USA (Cohen 2011). Mussel spat could provide an appropriate substratum for *B. violaceus*; from which they may spread to the surrounding habitat (Sewell *et al* 2008).

The import of Pacific oyster (*Crassostrea gigas*) and hull fouling are likely pathways for *Botrylloides violaceus* to enter British waters and then transported to areas with mussel beds (Dijkstra *et al* 2007; Cohen 2011). Leisure boats that have been fouled with *B. violaceus* have the potential to spread the species.

B. violaceus can grow over mussel themselves. It is also likely to reduce feeding grounds and settlement areas, and compete for food with other suspension feeders including the mussels. Hence, it is likely to reduce growth rates of mussels and their hence their viability, as well as reduce mussel recruitment. However, no evidence of direct effects on mussel beds was found.

B. violaceus favours hard surfaces in the low intertidal (low water) and upper subtidal although it is unlikely to be found on open coasts. All mussel beds could provide a hard surface and therefore the key factor that will determine which biotopes are likely to be affected is the depth or height on the shore at which the beds are found.

Corella eumyota (orange–tipped sea squirt)

Corella eumyota is found currently along the south coast and Irish coastline. It is known to colonise a wide range of substrata including native oysters, intertidal cobbles and boulders, and conspecifics. It persists all year round, which gives *C. eumyota* a strong chance to colonise, particularly when seasonal organisms leave bare substrata over the winter months. Therefore is likely to colonise mussel seed beds, which can then spread when the mussel seed are collected and re-laid near to more mature beds of mussels. It is thought that *C. eumyota* has a high chance of surviving transportation of mussel seed, increasing the potential for its spread. It is thought to have first been introduced from hull fouling (Lambert 2004) which is another potential pathway for its spread around the UK.

Corella eumyota has not yet been observed growing on *M. edulis.* But if *C. eumyota* is introduced onto a mussel bed it is likely to compete for space, smoother and reduce space for settlement of native species and increase competition with other suspension feeders (Sewell *et al* 2008). However, no evidence of direct impact on mussel beds was found.

C. eumyota favours hard surfaces in the lower intertidal and upper subtidal and therefore is likely to affect similar biotopes to *B. violaceus* at risk of colonisation. All mussel beds could provide a hard surface and therefore the key factor that will determine which biotopes are likely to be affected is the depth or height on the shore at which the beds are found.

Crepidula fornicata (slipper limpet)

Crepidula fornicata is reported to settle and establish themselves amongst mussel beds, and is often transported with the transfer of oysters and oyster dredging (Minchin 1995; Blanchard 1997; Thieltges 2005; Rayment 2007) as well as by hull fouling (Rayment 2007). If *C. fornicata* becomes established in a bed it is likely to alter the bed structure particularly if it is on a coarse sand or hard substrata.

C. fornicata has high fecundity and can disperse its larvae over large areas making mussel beds highly vulnerable if *C. fornicata* is introduced even large distances away. The larvae of *C. fornicata* can survive transport in ballast water for a number of days allowing it to travel large distances before needing to settle in the areas the ballast water is released (Blanchard 1997). By settling in an area and increasing the amount of pseudofaeces the substratum may be altered from hard substratum to soft sediment which again will reduce substratum availability for settlement.

Thieltges (2005) reported a 28-30% mortality of *M. edulis* when *C. fornicata* was introduced to the beds in experimental studies. He also found that mussel shell growth was reduced by 3 to 5 times in comparison to unfouled mussels and that extra energy was probably expended on byssus production. The most significant cause of mortality was increased drag on mussel due to the growth of stacks of *C. fornicata* on the shells of the mussel. He concluded that *C. fornicata* is potentially an important mortality factor for *M. edulis* (Thieltges 2005). Thieltges *et al* (2003) reported that *C. fornicata* was abundant on mussel beds in the intertidal to subtidal transition zone, in the northern Wadden Sea in the year 2000. Thieltges (2005) also observed mussel beds in the shallow subtidal infested with high abundances of *C. fornicata* with almost no living mussels, along the shore of the List tidal basin, northern Wadden Sea.

C. fornicata is found in a wide range of substrata from hard substratum to mud so that all the biotopes assessed may be colonised. However, it is not likely to colonise in areas with strong tidal currents which will result in some mussel biotopes having environmental protection. Temporary mussel beds such as commercial beds are also less likely to be colonised as it takes over a year for the density of *C. fornicata* to increase (Thieltges 2005).

C. fornicata is likely to alter water flow over mussel beds. They form stacks of individuals that alter water flow across the sediment surface. When these stacks occur on the shells of *M. edulis* they increase the drag on the mussel, increase the demands on the mussel's energy reserves for attachment (e.g. byssus formation) and, hence, effect fecundity and survival (Sewell *et al* 2008). The increased drag may also result in clumps of mussels being removed by water flow. Competition for suspended organic matter and space is also increased. Space for the settlement of macrobenthic organisms (Blanchard 1997) including mussels is particularly reduced. In addition to the reduced space for settlement, larvae of macrobenthic organisms are also consumed by the slipper limpet and effect recruitment to an area.

Didemnum vexillum (carpet sea squirt)

Didemnum vexillum is a suspension feeding tunicate capable of forming very large colonies; hence it is called the carpet sea squirt. It is highly competitive in colonizing new substrata, by budding, fragmentation and larval dispersal, and has a fast growth rate (Minchin & Sides 2006; Auker & Oviatt 2007; Auker & Oviatt 2008).

It is reported to known to grow on and over *M. edulis* on pontoons and settlement panels (Minchin & Sides 2006; Auker & Oviatt 2007). When growing on the mussels themselves *D. vexillum* restricted the opening of valves and increased mortality (Auker & Oviatt 2007). Auker and Oviatt (2007) also observed a decreased recruitment rate in settlement panels colonised by *D. vexillum* but could not rule out other factors and concluded that further research was required to determine this relationship. Currently *D. vexillum* is found mainly in marinas around the UK and is thought to have been brought in by hull fouling, through the movement of oyster stock, and as colony fragments in ballast water (Minchin & Sides 2006; Cohen 2011). Small leisure boats are a significant pathway for the spread of this species to many other areas around the UK.

Valentine *et al* (2007) reported that when temperatures dropped over winter *D. vexillum* colonies in tide pools showed declined health and an increased predation by the common periwinkle (*Littorina littorea*). Colonies cannot survive exposure to air in winter (Valentine *et al* 2007) so it is only the subtidal blue mussel bed biotopes that are at high risk from colonisation, although due to its fast growth damage to intertidal biotopes could occur over summer. In addition, *D. vexillum* does not tolerate low salinities (Auker & Oviatt 2008) so the biotopes in reduced salinities are at less risk.

D. vexillum can grow over mussel themselves. It is also likely to reduce feeding grounds and settlement areas, and compete for food with other suspension feeders including the mussels. Hence, it is likely to reduce growth rates of mussels, their viability, and mussel recruitment. *D. vexillum* has been reported to smother benthos. In the Oosterschelde it reached high cover (>95%) in some locations resulting in a marked decrease in brittlestar and sea urchin populations, while on pebble gravel bottom of Georges Bank off Massachusetts, where it covered the majority of the seabed locally, it resulted in significant change in the sedimentary community (GBNNSIP 2014). However, no evidence of direct effects on mussel beds was found.

D. vexillum has the potential to smother mussel beds, increase mortality, and reduce recruitment, but no evidence of direct effects on blue mussel beds was found.

Eriocheir sinensis (Chinese mitten crab)

Mussel beds located around river estuaries are known to be a suitable habitat for juvenile *Eriocheir sinensis* and sometimes gravid females. Mitten crabs are opportunistic scavengers that feed on benthic macroinvertebrates and aquatic vegetation (Rudnick *et al* 2005). E. *sinensis* will compete with native species, particularly *Carcinus maenas* and other macroinvertebrate predators, for space and food, and potentially change the species composition of the biotope. Increased predation is likely to increase the mortality of the mussels in the bed. It is thought that a pathway for the introduction of *E. sinensis* is ballast water (Rudnick *et al* 2003; Rudnick *et al* 2005). However, no evidence of direct impact on mussel beds was found.

Rapana venosa (veined rapa whelk)

Although *Rapana venosa* has not yet been recorded along the UK coastline, it has been recorded offshore and is known to have a fast rate of migration so could affect the UK coastal habitats in the near future (Sewell *et al* 2008). *R. venosa* is known to feed on mussels and other bivalves and therefore are likely to be attracted to areas of high bivalve concentration e.g. mussel beds. The presence of *R. venosa* could increase the mortality of mussels as well as increase competition with other predatory gastropods, potentially causing a shift in the species composition of the biotope. *R. venosa* has been seen to cause a decline in the abundance of *Mytilus galloprovincialis* in Bulgaria (Mann & Harding 2000).

R. venosa is tolerant to a range of salinities and is more likely to settle on areas of hard substrata with epifaunal species (Harding & Mann 1999; Mann & Harding 2003) though it can settle on all substrata if there are attached bivalves. There is high potential for *R. venosa* to be transported with oyster spat (Mann & Harding 2000) and in ballast water (Mann & Harding 2000). No evidence of direct effects was found.

Aulocomya ater (Magellan mussel)

Aulocomya ater is a bivalve species currently confined to the Moray Firth in Scotland (Baxter 1997). *A. ater* has a stronger byssal attachment than *Mytilus edulis* and, therefore, has the ability to replace *M. edulis* on more exposed shores. Potential impacts will be limited to Scotland for the time being. Fouling on hulls would be a likely cause for transfer to other regions (Baxter 1997). No evidence of direct effects was found.

Crassostrea gigas (Pacific oyster)

Crassostrea gigas is the most widely grown bivalve in aquaculture around the world at present and an important nuisance species in marine waters (Padilla 2010). Adults are long-lived so that populations can survive with infrequent recruitment. It has a high fecundity, a long-lived pelagic larval phase and hence high dispersal potential (>1000km). *C. gigas* does not spawn at water temperatures below ca 20°C but adults grow in colder waters, so that it was thought that this species could not escape from cultivation in cold water areas. However, it has been suggested that climate change and warmer waters have allowed *C. gigas* to expand into and reproduce in previously unsuitable areas. Established feral populations have been reported to spread via larvae (Padilla 2010). It is found form the mid-littoral to the upper subtidal, and grows on hard substrata but also on other bivalves (e.g. blue mussels) and polychaete reefs (Padilla 2010).

C. gigas can outcompete *M. edulis* (Padilla 2010). In the Wadden Sea and North Sea, *C. gigas* overgrows mussel beds in the intertidal zone (Diederich 2005, 2006; Kochmann *et al* 2008), although they did show preference for settling on conspecifics before the mussels and struggled to settle on mussels with a fucoid covering. Diederich (2005, 2006) examined settlement, recruitment and growth of *C. gigas* and *M. edulis* in the northern Wadden Sea. *C. gigas* recruitment success was dependant on temperature, and in the northern Wadden Sea, only occurred in six of the 18 years since *C. gigas* was first introduced. Survival of juveniles is higher in milder than cold winters. Also survival of both juveniles and adults on mussel beds is higher than that of the mussels themselves. However, recruitment of *C. gigas* was significantly higher in the intertidal than the shallow subtidal, although the survival of adult oysters or mussels in the subtidal is limited by predation. Deiderich (2005) concluded that hot summers could favour *C. gigas* reproduction while cold winters could lead to high mussel recruitment the following summer. Diederich (2005, 2006) noted that the high survival rate of *C. gigas* adults and juveniles in the intertidal was likely to compensate for years of poor recruitment. *C. gigas* also prefer to settle on conspecifics, so that it can build massive oyster reefs, which themselves are more resistant of storms or ice scour than the mussel beds they replace; as oysters are cemented together, rather than dependent on byssus threads. *C. gigas* also grows faster than *M. edulis* in the intertidal and reach by ca 2-3 times the length of mussels within one year. In addition, growth rates in *C. gigas* were independent of tidal level (emergence regime, substratum, *Fucus* cover and barnacle epifauna (growing on both mussels and oysters), while growth rate of *M. edulis* was decreased by these factors. The faster growth rate could make *C. gigas* more competitive than *M. edulis* where space or food is limiting. Diederich (2006) concluded that the massive increase in *C. gigas* in the northern Wadden Sea was caused by high recruitment success, itself due to anomalously warm summer temperatures, the preference for settlement on conspecifics (and hence reef formation), and high survival rates of juveniles. Since temperature is an important factor, climate change may be an important factor in the expansion of *C. gigas* in the Wadden Sea (Diederich 2006). As oyster reefs form on former mussel beds, the available habitat for *M. edulis* could be restricted (Diederich 2006).

It has been observed that mussel beds in the Wadden Sea that are adjacent to oyster farms were quickly converted to oyster beds (Kochmann *et al* 2008). Padilla (2010) predicted that *C. gigas* could either displace or overgrown mussels on rocky and sedimentary habitats of low or high energy. Kent and Essex Inshore Fisheries and Conservation Authority (IFCA) (cited in Herbert *et al* 2012) reported that *C. gigas* had developed a significant stock on mussel beds on the Southend foreshore and that, by 2012, there were few mussels left in the affected area, but made no conclusions as to the reason for the decline in mussels (Kent and Essex IFCA per comm cited in Herbert *et al* 2012).

Sensitivity assessment

Evidence on any effects of *A. ater* or *E. sinensis* are lacking and **'Not evidence'** is reported. The rapa whelk (R. *venosa*) has been shown to cause declines of *M. galloprovincialis* populations, and may have the potential to do so with blue mussel beds in the UK but at present there is no direct evidence; therefore '**No evidence'** is reported.

The sea squirts *C. eumyota* and *B. violaceus* have both been recorded growing on mussels and are likely to reduce both viability and recruitment. But no evidence of resultant mortality was found. Therefore, a **resistance** of '**High'** is suggested for subtidal blue mussel bed biotopes, although as **resilience** is by definition therefore **'High'**, a sensitivity of **'Not sensitive'** is reported. Further monitoring of their effects is required.

The carpet sea squirt *D. vexillum* has the potential to smother areas of seabed, and presumably mussel beds, and has been shown to reduce growth, recruitment and increase mortality of mussel on artificial substrata. Therefore, a **precautionary resistance** of **'Low'** has been recorded for subtidal biotopes, except in reduced salinity areas (A3.361), and is based on expert judgement (**confidence** is **'Low'**). **Resilience** is assessed as **'Medium'** (see section 3.3) but assumes that the carpet sea squirt is removed. Therefore, a **sensitivity** of **'Medium'** is suggested for the effects of this species.

C. fornicata modifies the sediment and competes with blue mussels. In the Wadden Sea, *C. fornicata* may outcompete and replace mussel beds. Although, no records of *C. fornicata* replacing or dominating mussel beds in the UK were found, it has the potential to do so. Therefore, a precautionary **resistance** of **'Low'** is suggested (significant, 25-75%, mortality and effects on the physiochemical character of the habitat) for subtidal biotopes. *C. fornicata* is unlikely to reach high abundances in the intertidal in the UK. **Resilience** is likely to be **'Low'** as the slipper limpet population would need to be removed for recovery to occur. Therefore, a **sensitivity** of **'High'** is reported.

Nevertheless, *C. gigas* was reported to outcompete and replace mussel beds in the intertidal and was predicted to do so, on both soft sediment and rocky habitats (Padilla 2010). In the upper subtidal, *C. gigas* may also develop reefs or grow on mussel beds but it the evidence is less clear. Herbert *et al* (2012) noted that blue mussels were found in areas dominated by *C. gigas*. But small clumps or occasional individuals would not constitute a blue mussel bed, so that the component biotopes would be lost. Therefore, a precautionary **resistance** of

'None' is suggested (severe decline, >75% mortality and effects on the physiochemical character of the habitat) for intertidal blue mussel beds and **'Medium'** to represent competition for food or space and potential loss of blue mussel abundance. **Resilience** is likely to be **'Very low'** as the *C. gigas* population would need to be removed for recovery to occur. Therefore, a **sensitivity** of **'High'** is reported in the intertidal but **'Medium'** in the subtidal.

The sensitivity score for each biotope is shown in Table 4.3 except where 'Not sensitive' is suggested. The **sensitivity** score for each of the **HPI, OSPAR and PMF** blue mussel bed definitions was recorded as **'High'**, because one or more biotope within each definition was assessed as 'High' sensitivity to against one of the NIS discussed above.

Resistance confidence

Quality of evidence is 'Medium' – as evidence on individual NIS varied.
Applicability is 'Medium' – applicability of evidence on individual NIS varied.
Concordance is 'Medium' –evidence agreed on direction but varied on magnitude.

Resilience confidence

Quality of evidence is 'High' – based on the nature of the NIS affecting the habitat, and the fact that the NIS would need to be removed before recovery could occur.
Applicability is 'High' - based the effects of this pressure.
Concordance is 'High' – based on the natural of the NIS affecting the habitat.

Table 4.3. Summary of the sensitivities of blue mussel bed biotopes to three non-indigenous species (NX = not exposed).

EUNIS Code	Biotope	*Didemnum vexillum*	*Crepidula fornicata*	*Crassostrea gigas*
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	NX	NX	High
A2.721	*Mytilus edulis* beds on littoral sediments	NX	NX	High
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	NX	NX	High
A2.7212	*Mytilus edulis* beds on littoral sand	NX	NX	High
A2.7213	*Mytilus edulis* beds on littoral mud	NX	NX	High
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	NX	High	High
A5.625	*Mytilus edulis* beds on sublittoral sediment	Medium	High	Medium

4.1.4 Removal of non-target species

ICG-C pressure description
By-catch associated with all fishing activities. The physical effects of fishing gear on sea bed communities are addressed by the 'abrasion' pressure type (D2) so B6 addresses the direct removal of individuals associated with fishing/ harvesting. Ecological consequences include food web dependencies, population dynamics of fish, marine mammals, turtles and sea birds (including survival threats in extreme cases, e.g. Harbour Porpoise in Central and Eastern Baltic).

Pressure benchmark
Removal of features through pursuit of a target fishery at a commercial scale.

Evidence description
The ‘removal of non-target species’ pressure refers to the removal of other organisms, either as by-catch or via targeted harvesting, on the bed of *Mytilus edulis*. The direct physical effects arising from commercial fishing activities are described in (section 4.3.1 and 4.3.4).

The removal of *M. edulis* predators including the starfish *Asterias rubens* and *Luidia ciliaris* and the crabs *Cancer pagurus* and *Necora puber* as by-catch through commercial fishing activities could potentially benefit beds of mussels but the population of starfish and crabs are highly mobile and probably attracted to damaging and dying organisms left after dredging, and therefore likely to recover before the mussels are able to recruit (Gubbay & Knapman 1999). Fishing activities may expose infauna, and leave dead and damaged species on the seabed, and areas where discards and by-catch have been deposited, may also attract predators and scavengers. But this potentially heightened level predation only lasts for seven days (Dolmer *et al* 2001) and therefore is unlikely to have an impact on the bed as a whole.

As *M. edulis* does not depend on the presence of any other macroinvertebrate species in terms of the food web or other key ecological interactions, removal of associated species will themselves have little impact.

Sensitivity assessment

No obligate species associations were identified for blue mussel beds and the removal of non-target species will therefore not have a significant impact. **Resistance** to this pressure is deemed **‘High’**. **Resilience** is also **‘High**’ as there are no ecological impacts to recover from, resulting in an assessment of **‘Not Sensitive**’. This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as **'Not sensitive'.**

Resistance confidence

Quality of evidence is ‘Low’ – based on expert judgement.
Applicability is ‘Not assessed’ – based on expert judgement.
Concordance is ‘Not assessed’ – based on expert judgement.

Resilience confidence

Quality of evidence is ‘High’ – based on no impacts to recover from.
Applicability ‘is ‘High’ – based on no impacts to recover from.
Concordance ‘is ‘High’ – based on no impacts to recover from.

4.1.5 Removal of target species

ICG-C Pressure description
The commercial exploitation of fish and shellfish stocks, including smaller scale harvesting, angling and scientific sampling. The physical effects of fishing gear on sea bed communities are addressed by the "abrasion" pressure type so this pressure addresses the direct removal/harvesting of biota. Ecological consequences include the sustainability of stocks, impacting energy flows through food webs and the size and age composition within fish stocks.

Pressure benchmark
Removal of target species that are features of conservation importance or sub-features of habitats of conservation importance at a commercial scale.

Evidence description

Mytilus edulis is a commercially targeted species worldwide and has been fished for hundreds of years and managed in England and Wales for the last hundred years (Holt *et al* 1998). Mussels are collected on a commercial scale, in both the intertidal and subtidal, by dredges of various forms and by divers (Narvarte *et al* 2011). Damage caused by direct physical impacts which are assessed in under 'abrasion' and 'penetration and/or disturbance of the surface of the seabed' pressures (section 4.3.1 and 4.3.4).

M. edulis is the most important characterising species defining the assessed biotopes and therefore any removal of the species will result in the removal of its associated fauna and a decline in species richness (Tyler-Walters & Durkin 2001). Removal of most of the mussel biomass will also lead to loss of or reclassification of the biotope. The sensitivity to removal can be characterised as the immediate direct impact of harvesting and subsequent indirect effects.

Reports of dredging efficiency vary from 15% using Baird dredges on ground previously dredged for oysters (Palmer 2007) to 90% using artisanal dredges (Narvarte *et al* 2011). Mussels are also regularly hand collected by fisherman for bait and food from intertidal beds which can also result in significant damage to the bed (Holt *et al* 1998; Smith & Murray 2005).

Smith and Murray (2005) examined the effects of low level disturbance on an extensive bed of *M. californianus* (composed of a single layer of mussels) in southern California. They observed a significant decrease in mussel mass (g/m^2), density (no./m^2), percentage cover and mean shell length due to low-intensity simulated bait-removal treatments (2 mussels/month) for 12 months (Smith & Murray 2005). They also stated that the initial effects of removal were 'overshadowed' by loss of additional mussels during time periods between treatments, probably due to the indirect effect of weakening of byssal threads attachments between the mussel leaving them more susceptible to wave action (Smith & Murray 2005). The low-intensity simulated bait-removal treatments had reduced percentage cover by 57.5% at the end of the 12 month experimental period. Smith and Murray (2005) suggested that the losses occurred from collection and trampling are far greater than those that occur by natural causes. This conclusion was reached due to significant results being displayed for human impact despite the experiment taking place during a time of high natural disturbance from El Niño–Southern Oscillation (ENSO).

In addition, Holt *et al* (1998) recorded an incident of the removal of an entire bed that is adjacent to a road in Anglesey due to fishermen bait collecting.

Commercial removal of mussels can often be responsible for the depletion of mussel stocks. For example, a substantial reduction in the mussel stock was observed in the Wash (England) during the 1990's due to high fishing mortality and low recruitment (Atkinson *et al* 2003). The dredging fishery for mussels in the Limfjorden, Denmark, was reported to reduce the stock size of mussels (Dolmer *et al* 1999). The total stock of mussel in the Limfjorden was estimated to be 771kt to 616kt in 1993-1994, while the mean exploitation rate of the fishery was 14%. In 1993-94 the size of mussel landings was found to correlate with a reduction in the overall stock size of the area, suggesting that mussel mortality was significantly increased by the fishery. However, in 1995 the total stock had fallen to 494kt and the mean exploitation rate was 15% but with no significant relationship between landings and stock size (Dolmer *et al* 1999). Divers observed that dense beds are likely to be more efficiently dredged due to their byssal attachments detaining the dredge bellow the carpet of the mussels whilst mussels in low density beds cause the dredge to bounce along the seabed resulting in reduced efficiency (Dolmer *et al* 1999). A low level of exploitation may actually increase the growth rate of the mussels by reducing the intraspecific competition for food (Dolmer *et al* 1999). However, Dolmer *et al* (2001) observed that the mussel biomass was significantly lower in dredged areas suggesting that the lowering of the intraspecific competition does not increase the accumulation of biomass.

Recreational fishermen will often collect moulting *Carcinus maenas* or whelks by hand from intertidal mussel beds for bait. The removal of predatory crabs could actively benefit the population this effect could be beneficial to mussel populations.

Sensitivity assessment

Mytilus edulis beds have no avoidance mechanisms to escape targeted harvesting and as a result a significant proportion of the bed is removed (Palmer 2007; Narvarte *et al* 2011). Dredging occurs on both subtidal and intertidal soft sediment and results in the removal of the mussel beds which defines the biotope. As the majority of the mussel beds that are harvested in the UK are regularly replenished with seed, the recovery rate for maintained beds should be rapid. In natural (wild) beds, the recovery could be significantly longer due to indirect effects from wave action and the sporadic nature of recruitment (Paine & Levin 1981; Seed & Suchanek 1992). Mussel beds on hard substrata are unlikely to be affected by dredges and are therefore only vulnerable in the intertidal areas where they may be accessed for hand picking. However, even hand-picking for bait can result in a significant decrease in cover, especially in beds composed of a single layer of mussels (Smith & Murray 2005). It should be noted that dense, multi-layered mussel beds may be more resistant to the gaps and bait collection, as damage to the upper layer may not effect deeper layers, so that attachment to the substratum and each other is maintained (Brosnan & Crumrine 1994).

All *M. edulis* beds are therefore considered to have '**Low' resistance** to this pressure and '**Medium' resilience**. Blue mussel beds are therefore considered to be **'Medium' sensitivity** to the removal of targeted organisms including *M. edulis* itself.

This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as **'Medium' sensitivity.**

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence in UK and other areas.
Concordance is 'High' – studies agree on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

4.2 Hydrological changes (inshore/local)

4.2.1 Emergence regime changes - local

ICG-C pressure description
Changes in water levels reducing the intertidal zone (and the associated/dependant habitats). The pressure relates to changes in both the spatial area and duration that intertidal species are immersed and exposed during tidal cycles (the percentage of immersion is dependent on the position or height on the shore relative to the tide). The spatial and temporal extent of the pressure will be dependent on the causal activities but can be delineated. This relates to anthropogenic causes that may directly influence the temporal and spatial extent of tidal immersion, e.g. upstream and downstream of a tidal barrage the

emergence would be respectively reduced and increased, beach re-profiling could change gradients and therefore exposure times, capital dredging may change the natural tidal range, managed realignment, saltmarsh creation. Such alteration may be of importance in estuaries because of their influence on tidal flushing and potential wave propagation. Changes in tidal flushing can change the sediment dynamics and may lead to changing patterns of deposition and erosion. Changes in tidal levels will only affect the emergence regime in areas that are inundated for only part of the time. The effects that tidal level changes may have on sediment transport are not restricted to these areas, so a very large construction could significantly affect the tidal level at a deep site without changing the emergence regime. Such a change could still have a serious impact. This excludes pressure from sea level rise which is considered under the climate change pressures.

Pressure benchmark
Intertidal species (and habitats not uniquely defined by intertidal zone): a 1 hour change in the time covered or not covered by the sea for a period of 1 year. Habitats and landscapes defined by intertidal zone: an increase in relative sea level or decrease in high water level of 1mm for one year over a shoreline length >1km.

Evidence description
A number of human activities may result in an increase or decrease in the high water line. For example, upstream of a tidal barrage the water level will be reduced, whereas downstream the water level will increase. Other activities that may cause a change in water level include dredging, beach re-profiling and saltmarsh creation.

Mytilus edulis beds are found at a wide range of shore heights from in the strandline down to the shallow sublittoral (Connor *et al* 2004). Their upper limits are controlled by temperature and desiccation (Suchanek 1978; Seed & Suchanek 1992; Holt *et al* 1998) while the lower limits are set by predation, competition (Suchanek 1978) and sand burial (Daly & Mathieson 1977). Mussels found higher up the shore display slower growth rates (Buschbaum & Saier 2001) due to the decrease in time during which they can feed and also a decrease in food availability. It has been estimated that the point of zero growth occurs at 55% emergence (Baird 1966) although this figure will vary slightly depending on the conditions of the exposure of the shore (Baird 1966; Holt *et al* 1998). Increasing shore height does, however, increase the longevity of the mussels due to reduced predation pressures (Seed & Suchanek 1992; Holt *et al* 1998), resulting in a wider age class of mussels is found on the upper shore.

Increased emergence will effectively move the upper limits of the biotope further up the intertidal zone. Growth rates decrease with increasing shore height and tidal exposure, due to reduced time available for feeding and reduced food availability, although longevity increases (Seed & Suchanek 1992; Holt *et al* 1998). It would also increase the risk of desiccation and vulnerability to extreme temperatures. The risk of predation from subtidal and lower intertidal species (e.g. starfish and crabs) will decrease while the predation from birds e.g. oystercatchers (and humans) may increase. This has the potential to reduce their upper limit and overall span on the shore. Subtidal biotopes are unlikely to be affected by the increase in emergence.

A decrease in emergence is likely to have a positive effect on *Mytilus* beds as the amount of time available to feed will increase as will the food availability, increasing the growth rate. The risk of desiccation and vulnerability to extreme temperatures will also be reduced by a decrease in emergence, potentially allowing the bed to extend its range on the shore (Tyler-Walters & Durkin 2001). The lower limit of *Mytilus* beds is mainly set by predation from *Asterias rubens* and *Carcinus maenas* which may increase with a decrease in emergence potentially reducing the lower limit or reducing the number of size classes and age of the mussels at the lower range of the bed (Saier 2002; Tyler-Walters 2002).

Sensitivity assessment

An increase in emergence by 1 hour is likely to reduce the abundance of the biotope at the upper limit due to desiccation and the mussels are likely to be replaced by barnacles on rocky shores, particularly on sheltered shores where there is little spray. Increased emergence is likely to have more of an impact on sandy substrata where burial by sand could limit the mussels' ability to extend its lower range resulting in a reduced mussel bed. A decrease in emergence would probably reduce the abundance of mussels at the lower limit due to increased predation but allow the bed to extend further up the shore.

Intertidal *Mytilus edulis* beds are considered to express **'Medium' resistance** (some mortality, loss of <25% of species abundance or extent) to changes in emergence with mussels at the upper and lower limits exhibiting the greatest effects (Table 4.4). **Resilience** is assessed as **'Medium'** (see section 3.2). **Sensitivity** is therefore assessed as **'Medium'**. Subtidal biotopes are considered to be **'Not exposed'**.

Table 4.4. Sensitivity score of individual biotopes within each habitat definition to the changes in emergence pressure (NX = not exposed).

EUNIS Code	Biotope	PMF	HPI	OSPAR
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	**Medium**	**Medium**	
A2.721	*Mytilus edulis* beds on littoral sediments	**Medium**	**Medium**	
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	**Medium**	**Medium**	**Medium**
A2.7212	*Mytilus edulis* beds on littoral sand	**Medium**	**Medium**	**Medium**
A2.7213	*Mytilus edulis* beds on littoral mud	**Medium**	**Medium**	
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	**NX**	**NX**	
A5.625	*Mytilus edulis* beds on sublittoral sediment	**NX**	**NX**	

The **sensitivity** score for each of the **HPI, OSPAR and PMF** blue mussel bed definitions was recorded as **'Medium'**, because one or more biotope within each definition was assessed as 'Medium' sensitivity to against this pressure.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence in UK and other areas.
Concordance is 'Medium' – studies agree on direction but vary on magnitude.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

4.2.2 Salinity changes - local

ICG-C pressure description

Events or activities that increase or decrease local salinity. This relates to anthropogenic sources/causes that have the potential to be controlled, e.g. freshwater discharges from pipelines that reduce salinity, or brine discharges from salt caverns washings that may increase salinity. This could also include hydromorphological modification, e.g. capital navigation dredging if this alters the halocline, or erection of barrages or weirs that alter freshwater/seawater flow/exchange rates. The pressure may be temporally and spatially delineated, derived from the causal event/activity and local environment.

Pressure benchmark
Increase from 35 to 38 units[5] for one year or a decrease in salinity by 4-10 units a year.

Evidence description
Mytilus edulis is found in a wide range of salinities from variable salinity areas (18-35ppt) such as estuaries and intertidal areas, to areas of more constant salinity (30-35ppt) in the sublittoral (Connor *et al* 2004). Furthermore, mussels in rock pools are likely to experience hypersaline conditions on hot days. Newell (1979) recorded salinities as high as 42psu in intertidal rock pools, suggesting that *M. edulis* can tolerate high salinities. Also, *M. edulis* was recorded to grow in a dwarf form in the Baltic sea where the average salinity was 6.5psu (Riisgård *et al* 2013).

M. edulis exhibits a defined behavioural response to reducing salinity, initially only closing its siphons to maintain the salinity of the water in its mantle cavity, which allows some gaseous exchange and therefore maintains aerobic metabolism for longer. If the salinity continues to fall the valves close tightly (Davenport 1979; Rankin & Davenport 1981). In the long term (weeks) *M. edulis* can acclimate to lower salinities (Almada-Villela 1984; Seed & Suchanek 1992; Holt *et al* 1998). Almada-Villela (1984) reported that the growth rate of individuals exposed to only 13psu reduced to almost zero but had recovered to over 80% of control animals within one month. Observed differences in growth are due to physiological and/or genetic adaptation to salinity.

Decreased salinity has physiological effects on *M. edulis*; decreasing the heart rate (Bahmet *et al* 2005), reducing filtration rates (Riisgård *et al* 2013), reducing growth rate (Gruffydd *et al* 1984) and reducing the immune function (Gidman *et al* 2009). Both Bahmet *et al* (2005) and Riisgård *et al* (2013) noted that filtration and heart rates return to normal within a number of days acclimation or a return to the original salinity. However, Riisgard *et al* (2013) did observe that mussels from an average of 17psu found it harder to acclimate between the salinity extremes than those from an average of 6.5psu. This observation may mean that mussels in a variable/ lower salinity environment are more able to tolerate change than those found at fully marine salinities. A sharp salinity change also induces a behavioural response to close the shell (Riisgård *et al* 2012) to maintain the salinity within the mantle cavity.

M. edulis is an osmoconformer and maintains its tissue fluids iso-osmotic (equal ionic strength) with the surrounding medium by mobilisation and adjustment of the tissue fluid concentration of free amino acids (e.g. taurine, glycine and alanine) (Bayne 1976; Newell 1989). But mobilizing amino acids may result in loss of protein, increased nitrogen excretion and reduced growth. However, Koehn (1983) and Koehn and Hilbish (1987) reported a genetic basis to adaptation to salinity. In addition, *M. edulis* thrives in brackish lagoons and estuaries, although, this is probably due to the abundance of food in these environments rather than the salinity (Seed & Suchanek 1992).

In extreme low salinities, e.g. resulting from storm runoff, large numbers of mussels may be killed (Keith Hiscock pers comm., Tyler-Walters 2008). However, Bailey *et al* (1996) observed very few mortalities when exposing *M. edulis* to a range of salinities as low as 0ppt for two weeks at a range of temperatures. It was also noted that there was a fast recovery rate.

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[5] Salinity is a dimensionless quantity and is described in terms of ‘units’. In the past it has been described as practical salinity units (psu) or parts per thousand (ppt), and occasionally other units. As these units may not all by equivalent to each other, the units used in the original source text are quoted.

Sensitivity assessment

Most of the literature found on this topic considered short term (days to weeks) impacts of changes to salinity whilst the benchmark refers to a change for one year. However, *M. edulis* was shown to be capable of acclimation to changes in salinity. Increased salinity is likely to change a reduced salinity area to a fully marine area where it is known that mussels can survive in abundance. Also, an increase in salinity from full to raised salinity (38 units) is less than that encountered in rock pools, where *M. edulis* survives. Therefore, *M. edulis* is recorded as having a '**High' resistance** to an increase in salinity and a **'High' resilience**.

As *Mytilus edulis* found in salinities to as low as 4-5psu (Riisgård *et al* 2013), it is likely to be able to acclimate to a decrease in salinity of 4-10 units for a year. Therefore, *Mytilus edulis* is recorded as having a **'High' resistance to a decrease in salinity** and a **'High' resilience** (no impact to recover from). The blue mussel bed biotopes are therefore considered to be **'Not Sensitive'** at the benchmark level.

This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as '**Not sensitive'.**

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence in UK and other areas.
Concordance is 'Medium' – studies agree on direction but vary on magnitude.

Resilience confidence

Quality of evidence is 'High' – based on the intrinsic recovery from High resistance.
Applicability is 'High' - based on the intrinsic recovery from High resistance.
Concordance is 'High' – based on the intrinsic recovery from High resistance.

4.2.3 Temperature changes - local

ICG-C Pressure description
Events or activities increasing or decreasing local water temperature. This is most likely from thermal discharges, e.g. the release of cooling waters from power stations. This could also relate to temperature changes in the vicinity of operational sub-sea power cables. This pressure only applies within the thermal plume generated by the pressure source. It excludes temperature changes from global warming which will be at a regional scale (and as such are addressed under the climate change pressures).

Pressure benchmark
A 5°C change in temp for one month period, or 2°C for one year

Evidence description
Mytilus edulis is a eurytopic species found in a wide temperature range from mild, subtropical regions to areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek 1992). In recent years *M. edulis* has been observed to be expanding its range pole-wards and has reappeared in Svalbard, due to an increase of sea temperature in that region (Berge *et al* 2005), whilst its equatorial limits are contracting due to increases in water temperature beyond the lethal limit (Jones *et al* 2010). In British waters 29°C was recorded as the upper sustained thermal tolerance limit for *M. edulis* (Read & Cumming 1967; Almada-Villela *et al* 1982), although it is thought that European mussels will rarely experience temperatures above 25°C (Seed & Suchanek 1992).

Tsuchiya (1983) documented the mass mortality of *M. edulis* in August 1981 due to air temperatures of 34°C that resulted in mussel tissue temperatures in excess of 40°C. In one hour, 50% of the *M. edulis* from the upper 75% of the shore had died. It could not be concluded from this study whether the mortality was due to high temperatures, desiccation or a combination of the two. Lethal water temperatures appear to vary between areas (Tsuchiya 1983) although it appears that their tolerance at certain temperatures vary, depending on the temperature range to which the individuals are acclimatised (Kittner & Riisgaard 2005). After acclimation of individuals of *M. edulis* to 18°C, Kittner and Riisgaard (2005) observed that the filtrations rates were at their maximum between 8.3 and 20°C and below this at 6°C the mussels closed their valves. However, after being acclimated at 11°C for five days, the mussels maintained the high filtration rates down to 4°C. Hence, given time, mussels can acclimatise and shifting their temperature tolerance. Filtration in *M. edulis* was observed to continue down to -1°C, with high absorption efficiencies (53-81%) (Loo 1992).

At the upper range of a mussels tolerance limit, heat shock proteins are produced, indicating high stress levels (Jones *et al* 2010). After a single day at 30°C, the heat shock proteins were still present over 14 days later, although at a reduced level. Increased temperatures can affect reproduction in *M. edulis* (Myrand *et al* 2000). In shallow lagoons mortality began in late July at the end of a major spawning event when temperatures peaked at >20°C. These mussels had a low energetic content post spawning and had stopped shell growth. It is likely that the high temperatures caused mortality due to the reduced condition of the mussels post spawning (Myrand *et al* 2000). Gamete production does not appear to be affected by temperature (Suchanek 1985).

Shell growth is not expected to be majorly influenced by low temperatures. Bayne (1976) demonstrated that between 10-20°C water temperature had little effect on scope for growth, similar to the findings of (Page & Hubbard 1987) who found that a temperature range of 10-18°C did not influence growth rate. In addition, Loo (1992) recorded growth rates of up to 0.7% at temperatures as low as -1°C, with an excess of seston, a rate higher than the same author recorded in mussel culture in Sweden (Loo & Rosenberg 1983). They concluded that food availability was more of a limiting factor to growth than temperature (Loo 1992).

The lower lethal limit of *M. edulis* depends on the length of time exposed to a low temperature and the frequency of exposure (Bourget 1983). Williams (1970) observed that *M. edulis* tolerated a tissue temperature as low as -10°C. In a laboratory experiment, Bourget (1983) showed that the median lethal temperature for 24 hour of exposure in *M. edulis* was -16°C for large mussels (>3cm) and -12.5°C for juveniles (<1.5cm). However, when exposed to reduced temperatures for only 16 hours, the median lethal temperature of large mussels decreased to -20°C. It was also reported that mussels exposed to sub-lethal temperatures cyclically, e.g. -8°C every 12.4 hours for 3-4 days, suffered significant damage likely to lead to death (Bourget 1983), which suggested that while *M. edulis* could tolerate occasional sharp frost events it was not likely to survive prolonged periods of very low temperatures. During the cold winter of 1962/63, *M. edulis* was reported to have experienced relatively few effects with only 30% mortality being recorded from the south east coast of England (Whitstable area) and only about 2% mortality was reported from Rhosilli in South Wales (Crisp 1964). Crisp (1964) also noted that the mortality was mainly from predation on the individuals that were weakened by the low temperatures rather than the temperature itself. It is thought that the use of nucleating agents in the haemolymph and the maintenance of a high osmotic concentration in the mantle fluid during periods of winter isolation allows *M. edulis* to tolerate such low temperatures (Aunaas *et al* 1988).

Temperature changes may also lead to indirect effects For example, an increase in temperature increases the mussels' susceptibility to pathogens (*Vibrio tubiashii*) in the presence of relatively low concentrations of copper (Parry & Pipe 2004). Increased temperatures may also allow for range expansion of parasites or pathogens which will have a negative impact upon the health of the mussels if they become infected (see section 4.1.2).

Power stations have the potential to cause an increase in sea temperature of up to 15°C (Cole *et al* 1999), although this impact will be localised. However, as mussels are of the most damaging biofouling organisms on water outlets of power stations, they are clearly not adversely affected (Whitehouse *et al* 1985; Thompson *et al* 2000).

Sensitivity assessment

Based on the wide range of temperature tolerance of *Mytilus edulis* and its limited effect on its physiology, it is concluded that the acute and chronic changes described by the benchmarks of 2-5°C would have limited effect. Therefore the biotopes are considered to have a **'High' resistance** to temperature change and **'High' resilience**. The assessed biotopes are therefore considered to be '**Not Sensitive'**.

This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as '**Not sensitive'.**

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence in UK and other areas.
Concordance is 'Medium' – studies agree on direction but vary on magnitude, as temperature tolerance varies with location and natural range of temperatures experienced by the population.

Resilience confidence

Quality of evidence is 'High' – based on the intrinsic recovery from High resistance.
Applicability is 'High' - based on the intrinsic recovery from High resistance.
Concordance is 'High' – based on the intrinsic recovery from High resistance.

4.2.4 Water flow changes - local

ICG-C pressure description
Changes in water movement associated with tidal streams (the rise and fall of the tide, riverine flows), prevailing winds and ocean currents. The pressure is therefore associated with activities that have the potential to modify hydrological energy flows, e.g. Tidal energy generation devices remove (convert) energy and such pressures could be manifested leeward of the device, capital dredging may deepen and widen a channel and therefore decrease the water flow, canalisation and/or structures may alter flow speed and direction; managed realignment (e.g. Wallasea, England). The pressure will be spatially delineated. The pressure extremes are a shift from a high to a low energy environment (or *vice versa*). The biota associated with these extremes will be markedly different as will the substratum, sediment supply/transport and associated seabed elevation changes. The potential exists for profound changes (e.g. coastal erosion/deposition) to occur at long distances from the construction itself if an important sediment transport pathway was disrupted. As such these pressures could have multiple and complex impacts associated with them.

Pressure benchmark
A change in peak mean spring tide flow speed of between 0.1m/s to 0.2m/s over an areas > 1km^2 or 50% of width of water body for more than 1 year.

Description
Changes in water flow have the potential to alter sediment composition. Fine sediments may be resuspended and removed following increases in flow, conversely decreased flow may result in enhanced deposition (Tyler-Walters 2008). Changes in sediment character are described in the ‘physical changes to another sediment type’ pressure (4.4.1). Therefore, the following assessment only considers changes in water flow.

Blue mussels are active suspension feeders and not entirely dependent on water flow to supply food (organic particulates and phytoplankton). Therefore, they can survive in very sheltered areas, but water flow (due to tides, currents or wave action) can enhance the supply of food, carried from outside the area or resuspended into the water column.

The growth rate of *M. edulis* in relation to water flow was investigated by Langan and Howell (1994). They found that the growth rate over 24 days was 0.1, 1.8, 2.0, 1.9 and 1.5mm at flow rates of 0, 0.01, 0.02, 0.04 and 0.08m/s respectively. The only growth rate found to be significantly different was at zero flow. However, the pattern did follow that predicted by the “inhalant pumping speed” hypothesis that suggested maximal growth at water speeds of about 0.02m/s and decreased growth rates at higher and lower speeds (Langan & Howell 1994). Higher current speed brings food to the bottom layers of the water column, and hence near to the mussels, at a higher rate (Frechette *et al* 1989). Frechette *et al* (1989) developed a model based on measurements in the St. Lawrence River estuary (Québec). The model suggested that *M. edulis* consumption rate depends on the flow of water.

But Widdows *et al* (2002) found that there was no change in filtration rate of *M. edulis* between 0.05 and 0.8m/s. They noted that their finding contradicted earlier work that found a marked decline in filtration rates from 0.05 to 0.25m/s (Newell 1999; cited in Widdows *et al* 2002) but suggested that the difference might be caused in differences in population studied, as the earlier work was based in the USA and their study used mussels from the Exe estuary in the UK. Widdows *et al* (2002) also noted that above 0.8m/s the filtration rate declined mainly because the mussels became detached from the substratum in the experimental flume tank. Widdows *et al* (2002) noted that their results were consistant with field observations, as mussels show preferential settlement and growth in areas of high flow, such as the mouth of estuaries and at the base of power station cooling systems (Jenner *et al* 1998). They also reported that Jenner *et al* (1998; cited in Widdows *et al* 2002) observed that biofouling of cooling water systems by mussels was only reduced significantly when mean current speeds reached 1.8-2.2 m/s and was absent at >2.9m/s.

Increased flow rate increases the risk of mussels being detached from the bed and transported elsewhere where their chance of survival will be majorly reduced due to the risk of predation and siltation (Dare 1976). It is the strength of the byssal attachment that determines the mussel’s ability to withstand increases in flow rate. Flow rate itself has been shown to influence the strength and number of byssus threads that are produced by *Mytilus edulis* and other *Mytilus spp.* with mussels in areas of higher flow rate demonstrating stronger attachment (Dolmer & Svane 1994; Alfaro 2006). Dolmer and Svane (1994) estimated the potential strength of attachment for *M. edulis* in both still water and flows of 1.94m/sec, by counting the number of established byssus threads and measuring the strength of attachment of individual detached byssus threads. It was found that in still water the strength of the attachment was 21% of the potential strength whilst at 19.4cm/sec it was 81% of the potential strength, suggesting that *M. edulis* has the ability to adapt the strength of its attachment based on flow rate. The mussels were then able to withstand storm surges up to 16m/s. Young (1985) demonstrated that byssus thread production and attachment increased with increasing water agitation. She observed the strengthening of byssal attachments by 25% within eight hours of a storm commencing and an ability to withstand surges up to 16m/s. However, it was concluded that sudden surges may leave the mussels susceptible to being swept away (Young 1985) as they need time to react to the increased velocity to increase the attachment strength. *M. edulis* beds could, therefore, adapt to changes in water flow at the pressure benchmark.

Alfaro (2006) found that when a sudden increase in flow (to 0.13m/s) was experienced by *Perna canaliculus* (another mussel species) in areas of low flow rate they were more susceptible to detachment than those that had been exposed to a higher flow rate. It was also noted that the individuals kept at higher water flows (e.g. 10cm/sec) produced more byssus threads. The increased energy used for byssus production in the high flow environments may reduce the energy that is available for other biological activities (Alfaro 2006).

Individuals attached to solid substrata (rock) are likely to display more resistance than individuals attached to boulders, cobbles or sediment. For example, mussel reefs in the Wash, Morecambe Bay and the Wadden Sea are vulnerable to destruction by storms and tidal surges (Holt *et al* 1998). Widdows *et al* (2002) examined mussel beds in the mouth of the Exe estuary and along the coast at Exmouth. In flume tank studies between 0.1 and 0.35m/s, the resuspension rate of sediment in mussel beds on sandy substrata was four and five times higher for areas with 25% and 50% mussel cover compared to bare sediment due to the increased turbulence and scouring around the mussels. However, at high densities (100% cover) the beds remained stable (up to 0.35m/s), with resuspension being about three times lower than areas with 0% cover, due to the high number of byssal attachments between individuals (Widdows *et al* 2002). Where mussel beds occurred on pebble and sand substrata (mixed substrata) sediment erosion was lower than that of the 100% cover on the sandy substrata regardless of mussel density. Low density mussel beds formed small clumps with a lower mass ratio of mussels attached to the substratum to increase anchorage. In low density beds, increased scour resulted in some mussel detaching from the bed and in areas with 50% cover the erosion of the bed resulted in the burial of a large proportion of the mussels. The mussels returned to the surface afterwards and recovered in 1-2 days. Widdows *et al* (2002) also noted a linear relationship between mussel beds density and sediment stability on cohesive mud substratum, taken from Cleethorpes, and exposed to currents of 0.15 to 0.45m/s. Again increased mussel cover increased sediment stability. Widdows *et al* (2002) found that the mussel bed at Exmouth experienced a peak flow of 0.9m/s before and after high water, which only reduced to 0.2m/s at slack water.

Water flow also affects the settlement behaviour of larvae. Alfaro (2005) observed that larvae settling in a low water flow environment are able to first settle and then detach and reattach displaying exploratory behaviour before finally settling and strengthening their byssus threads. However, larvae settling in high flow environments did not display this exploratory behaviour. Pernet *et al* (2003) found that at high velocities larvae of *Mytilus spp.* were not able to able to exercise much settlement preference. It was thought that when contact with suitable substratum is made the larvae probably secure a firm attachment. Movement of larvae from low shear velocities, where they use their foot to settle, to high shear velocities where they use their byssal thread to settle was observed by Dobretsov and Wahl (2008).

Sensitivity assessment

The blue mussel bed biotopes assessed are recorded from week (<0.5m/s) to strong (up to 3m/s) tidal streams. Based on the above evidence it could be expected that change of 0.1m/s or 0.2m/s are unlikely to impact blue mussel (*Mytilus edulis)* beds on rock. Little mortality is expected due to an increase in flow rate other than those from a sudden storm surge in excess of 16m/s, which is more likely to be influenced by wave exposure (see section 4.2.5) or on sandy substrata with low density beds.

The sensitivity of sedimentary biotopes to increased flow is dependent on the substratum and the degree of cover, with dense beds of ca 100% cover being more stable the patchy beds, and more stable on mixed substrata with cobble and boulders than sand and mud. Connor *et al* (2004) noted that the build-up of mussel mud beneath beds could result in a change from sandy to muddy substrata underneath the bed, and reduce attachment resulting in increased risk of removal by storms.

A decrease in water flow is unlikely to affect adversely blue mussel beds directly. Evidence above suggest that they can grow at water flow as low as 0.01 – 0.02m/s and filter at 0.05m/s; significantly less than weak tidal streams (<0.5m/s). At very low or negligible water flow, the effects of siltation may have adverse effects (see section 4.3.5).

Therefore, on rocky substrata **resistance** to change in water flow is probably **'High'**; and **resilience** is therefore assessed as **'High'** (no effect to recover from) and the biotope is assessed as **'Not Sensitive'**. Dense beds are probably stable on mixed substrata, so **resistance** to change in water flow is probably **'High', resilience** is assessed as **'High'** (no effect to recover from) and the biotope is assessed as **'Not Sensitive'**. However, on sandy substrata and possible to a greater extent on muddy substrata, especially where mussel mud have accumulated and/or the beds are patchy; an increase of water flow at the benchmark level is likely to result in removal of parts of the bed. Therefore, **resistance** to change in water flow is probably **'Medium', resilience** is assessed as **'Medium'** and the biotopes are assessed as **'Medium' sensitivity** (Table 4.5). It should be noted that storm related changes in water flow (or wave meditated flow) is likely to damage blue mussel beds.

The **sensitivity** score for each of the **HPI, OSPAR and PMF** blue mussel bed definitions was recorded as **'Medium'**, because one or more biotope within each definition was assessed as 'Medium' sensitivity to against this pressure.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence in UK and other areas.
Concordance is 'Medium' – studies agree on direction but vary on magnitude.

Resilience confidence

When a resistance score of high is given (i.e. rocky and mixed substrata):

Quality of evidence is 'High' – based on the intrinsic recovery from High resistance.
Applicability is 'High' - based on the intrinsic recovery from High resistance.
Concordance is 'High' – based on the intrinsic recovery from High resistance.

When a resistance score of medium is given (i.e. sandy substrata):

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

Table 4.5. Sensitivity score of individual biotopes within each habitat definition to the change in the water flow pressure (Not Sens =Not sensitive).

EUNIS Code	Biotope	PMF	HPI	OSPAR
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	**Not Sens**	**Not Sens**	
A2.721	*Mytilus edulis* beds on littoral sediments	**Medium**	**Medium**	
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	**Not Sens**	**Not Sens**	**Not Sens**

A2.7212	*Mytilus edulis* beds on littoral sand	**Medium**	**Medium**	**Medium**
A2.7213	*Mytilus edulis* beds on littoral mud	**Medium**	**Medium**	
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	**Not Sens**	**Not Sens**	
A5.625	*Mytilus edulis* beds on sublittoral sediment	**Medium**	**Medium**	

4.2.5 Wave exposure changes-local

ICG-C pressure description
Local changes in wave length, height and frequency. Exposure on an open shore is dependent upon the distance of open seawater over which wind may blow to generate waves (the fetch) and the strength and incidence of winds. Anthropogenic sources of this pressure include artificial reefs, breakwaters, barrages, wrecks that can directly influence wave action or activities that may locally affect the incidence of winds, e.g. a dense network of wind turbines may have the potential to influence wave exposure, depending upon their location relative to the coastline.

Pressure benchmark
A change in nearshore significant wave height >3% but <5%.

Evidence description
Blue mussel beds are found in a wide range of wave exposures, from extremely exposed areas to extremely sheltered (Seed 1976; Connor *et al* 2004). The littoral mixed sediment biotope (A2.7211) is found from wave exposed to very sheltered conditions, the sand and mud biotopes (A2.7212, A2.7213) occur in moderate wave exposure to sheltered conditions, while A2.212 occurs in sheltered conditions (sheltered to extremely sheltered), A5.625 occurs in moderately wave exposed to sheltered conditions, and the infralittoral rock biotope (A3.361) occurs in very wave exposed to extremely sheltered but tide swept conditions. None of the evidence found discussed change in terms of wave height, and the term exposure is often undefined in reports.

Mytilus edulis are able to increase the strength of their attachment to the substratum in more turbulent conditions (Price 1982; Young 1985). Young (1985) demonstrated an increase in strength of the byssal attachment by 25% within 8 hours of a storm commencing. When comparing mussels in areas of high flow rate and low flow rate those at a higher flow rate exhibit stronger attachments than those in the areas of lower flow (Dolmer & Svane 1994; Alfaro 2006). Dolmer and Svane (1994) found that in still water the strength of the attachment was 21% of the potential strength whilst at 1.94m/sec it was 81% of the potential strength. The mussels were then able to withstand storm surges up to 16m/s. Alfaro (2006) also noted that the individuals kept at higher water flows produce more byssal threads. The increased energy used for byssus production in the high flow environments may reduce the energy that is available for other biological activities (Alfaro 2006). Whilst this clearly demonstrates the ability of mussels to adapt to the various conditions to avoid dislodgement the mussels are unlikely to adapt instantly and a sudden increase in flow is likely to result in dislodgement (Young 1985).

Individuals attached to solid substrata (rock) are likely to display more resistance to wave action than individuals attached to boulders, cobbles or sediment (Holt *et al* 1998). Widdows *et al* (2002) examined mussel beds in the mouth of the Exe estuary and along the coast at Exmouth. Where the mussel beds occurred on sandy substratum the re-suspension rate was four and five times higher for areas with 25% and 50% mussel cover compared to bare sediment due to the increased turbulence and scouring around the mussels. In low density beds this increased scour resulted in some mussels detaching from the bed and in areas with 50% cover the erosion of the bed resulted in the burial of a large proportion of the mussels. The mussels returned to the surface after 1-2 days and recovered. However, at high densities (100% cover) the beds remained stable, with re-suspension being about 3 times lower than areas with 0% cover, due to the high number of byssal attachments between individuals (Widdows *et al* 2002). Where mussel beds occurred on pebble and sand substratum (mixed substratum) sediment erosion was lower than that of the 100% cover on the sandy substratum regardless of density despite experiencing flows of 0.9m/s. The low density mussels were observed to form small clumps with a lower mass ratio of mussels attached to the substratum to increase anchorage.

Widdows *et al* (2002) suggest that 100% mussel cover on sandy substrata reduces the risk of dislodgement. However, Harger and Landenberger (1971) suggest that growth in mussel beds results in fewer mussels being attached to the substratum and therefore strong seas can “roll up the whole mass of mud and mussels like a carpet and break it to pieces on the foreshore”. It was also noted that on gravelly substratum, single layer mussel beds incurred less damage in storm conditions than heavier multi-layered beds (Harger & Landenberger 1971).

Large scale destruction of mussel beds has been reported in many areas such as the Wash, Morecambe Bay and the Wadden Sea (Holt *et al* 1998) and it appears that because of this high wave exposure and destruction, reefs found in wave exposed areas are likely to be more dynamic (Nehls & Thiel 1993) and patchy (Tyler-Walters 2002). Furthermore, increased wave exposure leads to a higher risk of damage from drift logs (or other flotsam), which once they have destroyed a patch of mussels leave the mussels around that patch at a higher risk of erosion (Seed & Suchanek 1992). Mussels with high abundance of epizoic and epiphytic (e.g. barnacles and macroalgae) growth are also more susceptible to removal in areas of high exposure due to increased drag caused by these fouling organisms (Suchanek 1985; Seed & Suchanek 1992). However, mussel beds are prevalent in areas of high wave exposure suggesting a high resilience despite destruction.

Blue mussels display a high resistance to increases in water flow, but the oscillatory water movement that occurs on shores of higher wave exposure is likely to have a higher impact due to the ‘to and fro’ motion which is more likely to weaken the attachments (Tyler-Walters 2001). Subtidal beds are protected by depth but beds in the shallow sublittoral may still be effected by this wave action (Tyler-Walters 2001). Westerbom and Jattu (2006) found that in subtidal mussel beds, mussel densities increased with increasing wave exposure. The highest biomass was found in areas of intermediate exposure, potentially due to the larger mussels being removed at high wave exposure levels. It was suggested that the lower densities found in more sheltered areas were due to low recruitment, early post-recruitment mortality, increased predation or stagnant settlement on rocks. Furthermore, it was also noted that high sedimentation which is more prevalent in sheltered areas, as there is less energy for re-suspension, prevents colonisation and result in the death of small mussels that are living close to the sediment surface by smothering and the clogging up of their feeding apparatus (Westerbom and Jattu 2006). Therefore, colonisation of new space in sheltered areas could be slow, particularly in areas where there is low availability of adult mussels.

An increase in wave exposure may increase density in subtidal beds (Westerbom and Jattu 2006), unless there is a very sudden storm surge. Mussels on sedimentary substrata are exposed to a higher risk of dislodgement (Widdows *et al* 2002). A decrease in wave exposure is likely to result in increased sedimentation and reduced densities (Westerbom & Jattu 2006) although the risk of dislodgement will be greatly reduced creating more stable beds (Nehls & Thiel 1993).

The above evidence is variable as different studies have examined beds that differ in habitat, wave exposure, substratum, and mussel density. However general trends can be seen. In rocky habitats, increased wave exposure allows mussel to dominate and form beds, especially where the rock surface has a low slope. Where the beds are patchy or damaged (from natural or human activities) they are more susceptible to further damage as a result of wave action or storms (Seed & Suchanek 1992; Brosnan & Crumrine 1994). Multi-layered mussel beds are less susceptible to damage, especially where only the surface layer is removed. It has been noted that the build-up of mussel mud (pseudofaeces) under the bed can reduce the attachment of the bed to the underlying substratum. But in areas of wave exposure, the flow of water through the bed will probably prevent the ‘mussel mud’ accumulating.

On sedimentary habitats, which themselves occur in wave sheltered environments, the mussel beds stabilise the sediment surface (Widdows *et al* 2002), especially at high percentage cover, although at low cover (e.g. in patchy beds) turbulent flow caused by the mussels may increase erosion of the sediment. Coarse and mixed sediments were more stable, although Widdows *et al* (2002) also noted that cohesive muds were also stabilised by mussel beds. Nevertheless, strong wave action or storms can roll up an entire bed or section of a bed (Harger & Landenberger 1971), and presumably remove patches of mussels, and that multi-layered bed suffered more damage. In sedimentary, wave sheltered habitats the build-up of mussel muds may reduce attachment to the substratum and increase the susceptibility of the bed to wave action (Seed & Suchanek 1992). The growth of other organisms on the mussels themselves, will increase drag and hence increase the possibility of damage due to wave action. In sheltered conditions, large macroalgae (e.g. kelps, fucoids) growing on mussels may result in removal of clumps of mussels.

Sensitivity assessment

A decrease in wave exposure is unlikely to adversely affect beds in sheltered, sedimentary habitats, except that muddy sediment will probably increase. In rocky intertidal habitats, a decrease in wave exposure will favour communities associated with lower wave exposure, and although the mussel bed will probably survive, increased fucoid cover may result in the slow loss of the bed. However, the infralittoral rock biotope (A3.361) is found in tide-swept basin entrances or sea lochs where water flow from currents is more important that from wave exposure.

Blue mussel beds on infralittoral rock are unlikely to be significantly affected by an increase in wave exposure at the level of the benchmark, although increased wave height could increase the possibility of storm damage, so a **resistance** of **‘Medium’** is suggested due to possible damage at the upper limit of the biotope where wave action is highest, with a **resilience** of **‘Medium’,** resulting in a sensitivity of **‘Medium’.** Blue mussel beds on sediment, including the shallow subtidal sediment (A5.625), may be more susceptible to damage, as increased wave height increases the possibility of pieces of the bed being removed, or even ‘rolled up, especially in stormy weather. Therefore, a **resistance** of **‘Low’** is suggested, with a **resilience** of **‘Medium’,** resulting in a sensitivity of **‘Medium’.**

This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as ‘**Medium’.**

Resistance confidence

Quality of evidence is ‘High’ – based on peer reviewed evidence.
Applicability is ‘Medium’ –although based on directly applicable evidence in UK and other areas, the evidence is not directly comparable to the benchmark.
Concordance is ‘Medium’ – studies agree on direction but vary on magnitude (as the effects vary with location and substratum).

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

4.3 Physical damage (reversible change)

4.3.1 Abrasion/disturbance of the substratum on the surface of the seabed

ICG-C pressure description
The disturbance of sediments where there is limited or no loss of substratum from the system. This pressure is associated with activities such as anchoring, taking of sediment/geological cores, cone penetration tests, cable burial (ploughing or jetting), propeller wash from vessels, certain fishing activities, e.g. scallop dredging, beam trawling. Agitation dredging, where sediments are deliberately disturbed by and 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 sea bed surface layers (typically up to 50cm depth). Activities associated with abrasion can cover relatively large spatial areas and include: fishing with towed demersal trawls (fish and shellfish); bio-prospecting such as harvesting of biogenic features such as maerl beds where, after extraction, conditions for recolonisation remain suitable or relatively localised activities including: seaweed harvesting, recreation, potting, aquaculture. Change from gravel to silt substratum would adversely affect herring spawning grounds.

Pressure benchmark
Damage to seabed surface features.

Evidence description
Mytilus edulis lives on the surface of the seabed held by byssus threads attached to either the substratum or to other mussels in the bed. Activities resulting in abrasion and disturbance can either directly affect the mussel by crushing them, or indirectly affect them by the weakening or breaking of their byssus threads making them vulnerable to displacement (Denny 1987) where they are unlikely to survive (Dare 1976). In addition, abrasion and sub-surface damage may attract mobile scavengers and predators including fish, crabs, and starfish to feed on exposed, dead and damaged individuals and discards (Kaiser & Spencer 1994; Ramsay *et al* 1998; Groenewold & Fonds 2000; Bergmann *et al* 2002). This effect will increase predation pressure on surviving damaged and intact *Mytilus edulis*. A number of activities or events that result in abrasion and disturbance and their impacts on mussel beds are described below.

Trampling

The effects of trampling have been more widely studied in the terrestrial community showing that when areas are intensively trampled bare patches are likely to result as a result of erosion or equally soil compaction may result (Liddle 1997). There are a number of studies which have focused on the impact of trampling on the intertidal rocky shore whereas the impact on sedimentary shores is relatively poorly studied (Tyler-Walters & Arnold 2008). In general, studies have found that trampling is an additional disturbance to the natural disturbances that the intertidal organisms are adapted to tolerate.

Large declines of the mussel *(Mytilus californianus)* from mussel beds due to trampling have been reported (Brosnan 1993; Brosnan & Crumrine 1994; Smith & Murray 2005). Brosnan and Crumrine (1994) recorded the loss of 54% of mussels from a single experimental plot on one day. Mussels continued to be lost throughout the experimental period, forming empty patches larger than the experimental plots. The empty patches continued to expand after trampling had ceased, due to wave action. At another site, the mussel bed was composed of two layers, so that while mussels were lost, cover remained. Brosnan (1993) also reported a 40% loss of mussels from mussel beds after three months of trampling, and a 50% loss within a year. Van de Werfhorst and Pearse (2007) examined *M. californianus* abundance at sites with differing levels of trampling disturbance. The highest percentage of mussel cover was found at the undisturbed site while the severely disturbed site showed low mussel cover.

Smith and Murray (2005) examined the effects of low level disturbance on an extensive bed of *M. californianus* (composed of a single layer of mussels) in southern California. Smith and Murray (2005) reported that in experimental plots exposed to trampling, mussel loss was 20-40% greater than in untreated plots. A decrease in mussel mass, density, cover and maximum shell length where recorded even in low intensity trampling events (429 steps/m^2). However, only 15% of mussel loss was as a direct result of trampling, with the remaining loss occurring during intervals between treatment applications.

Brosnan and Crumrine (1994) suggested that trampling destabilizes the mussel bed, making it more susceptible to wave action, especially in winter. Smith and Murray (2005) suggested that an indirect effect of trampling was weakening of byssal threads, which increases mussel susceptibility to wave disturbance (Denny 1987). Brosnan and Crumrine (1994) observed recruitment within experimental plots did not occur until after trampling had ceased, and no recovery had occurred within 2 years

Brosnan and Crumrine (1994) noted that mussels that occupied hard substrata but did not form beds were also adversely affected. Although only at low abundance (2.5% cover), all mussels were removed by trampling within 4 months. Brosnan and Crumrine (1994) noted that mussels were not common and confined to crevices in heavily trampled sites. Similarly, the mussel bed infauna (e.g. barnacles) was adversely affected, and were crushed or lost with the mussels to which they were attached. However, Beauchamp and Gowing (1982) did not observe any differences in mussel density between sites that differed in visitor use.

Paine and Levine (1981) examined natural patch dynamics in a *M. californianus* bed in the USA. They suggested that it may take up to seven years for large barren patches to recover. However, chronic trampling may prevent recovery altogether. This would result in a shift from a mussel dominated habitat to one dominated by an algal turf or crust (Brosnan & Cumrine 1994), completely changing the biotope. However, a small period of trampling could allow communities to recover at a similar rate to that of natural disturbance as the effects are similar.

The associated epifauna and epiflora suffer the greatest amount of damage as they are the first organisms that a foot makes contact with (Brosnan & Crumrine 1994). The loss of epifauna and epiflora could initially be of benefit to the mussel bed, despite the obvious decrease in species diversity, as there will be a decrease in drag for the mussels reducing the risk of dislodgement (Witman & Suchanek 1984) and freeing up more energy for growth and reproduction. However, it is likely that after continued trampling this effect will be minimal compared with the increased risk of dislodgement caused by trampling.

No studies assessing the effect of trampling on mussels on intertidal muddy sand or sediments were found. Losses to the adult mussels by crushing or by suffocation where these are forced into the sediment are expected. There is the potential that this will open up areas for new recruitment or it may just create a similar situation to that seen on the rocky shore where wave damage and continual trampling prevent settlement and recovery.

Other abrasion pathways

Collision of objects with the bed, such as wave driven logs (or similar flotsam), is known to cause removal of patches of mussels from mussel beds (Seed & Suchanek 1992; Holt *et al* 1998). When patches occur in mussel beds a good recruitment could result in a rapid recovery (Tyler-Walters 2008) or the patch may increase in size through weakening of the byssus threads of the remaining mussels leaving them vulnerable to erosion from storm damage (Denny 1987). Damage in areas of high wave exposure is likely to result in increased erosion and a patchy distribution although recruitment may be high. In sheltered areas damage may take a lot longer due to limited larval supply, although the frequency of destruction through wave driven logs would be less than in high wave exposure. Similar effects could be observed through the grounding of a vessel, the dropping of an anchor or the laying of a cable, although the scale of damage clearly differs.

Shifting sand is known to limit the range of *Mytilus edulis* through burial and abrasion (Daly & Mathieson 1977) (see section 4.5.5).

Fisheries and shellfisheries

Various fishing methods also result in abrasion of the mussel beds. Bait collection through raking will cause surface abrasion and the removal of patches of mussel resulting in the damage and recovery times described above. Holt *et al* (1998) reported that hand collection, or using simple hand tools occurs in small artisanal fisheries. They suggested that moderate levels of collection by experienced fishermen may not adversely affect the biodiversity of the bed. But they also noted that even artisanal hand fisheries can deplete the mussel biomass on accessible beds in the absence of adequate recruitment of mussels.

Smith and Murray (2005) observed a significant decrease in mussel mass (g/m^2), density (no./m^2), percentage cover and mean shell length due to low-intensity simulated bait-removal treatments (2 mussels/month) for 12 months (Smith & Murray 2005). They also stated that the initial effects of removal were 'overshadowed' by loss of additional mussels during time periods between treatments, probably due to the indirect effect of weakening of byssal threads attachments between the mussel leaving them more susceptible to wave action (Smith & Murray 2005). The low-intensity simulated bait-removal treatments had reduced percentage cover by 57.5% at the end of the 12 month experimental period. Smith and Murray (2005) suggested that the losses occurred from collection and trampling are far greater than those that occur by natural causes. This conclusion was reached due to significant results being displayed for human impact despite the experiment taking place during a time of high natural disturbance from El Niño–Southern Oscillation (ENSO).

Sensitivity assessment

Based on the available evidence it is concluded that all mussel biotopes are sensitive to abrasion and that **resistance** is **'Low'** (loss of 25-75% of bed within direct impact footprint), **resilience** is assessed as **'Medium'**, resulting in a **sensitivity** of **'Medium'.** This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as '**Medium'.**

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'Medium' – based on directly applicable evidence from USA and limited studies in UK.
Concordance is 'Medium' – studies agree on direction but vary on magnitude, as the effects vary with location and between studies.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

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

ICG-C pressure description
The disturbance of sediments where there is limited or no loss of substratum from the system. This pressure is associated with activities such as anchoring, taking of sediment/geological cores, cone penetration tests, cable burial (ploughing or jetting), propeller wash from vessels, certain fishing activities, e.g. scallop dredging, beam trawling. Agitation dredging, where sediments are deliberately disturbed by and 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 sea bed surface layers (typically up to 50cm depth). Activities associated with abrasion can cover relatively large spatial areas and include: fishing with towed demersal trawls (fish and shellfish); bio-prospecting such as harvesting of biogenic features such as maerl beds where, after extraction, conditions for recolonisation remain suitable or relatively localised activities including: seaweed harvesting, recreation, potting, aquaculture. Change from gravel to silt substratum would adversely affect herring spawning grounds.

Pressure benchmark
Structural damage to seabed sub-surface.

Evidence description
The blue mussel *Mytilus edulis* is a major fishery in Europe, together with the more southern species *M. galloprovincialis*. *M. edulis* is cultivated and farmed around the UK coasts, especially in the Wash, Morecambe Bay, Menai Straits, and west coast of Scotland (Smaal 2002). However, the biotopes in question would be considered to be wild beds, and wild fisheries are more restricted due to problems of sanitary quality, purification costs and potential over-exploitation (Holt *et al* 1998; Smaal 2002).

Mytilus edulis lives on the surface of the seabed held in one place by byssus threads that either attach to the substratum or to other mussels in the bed. Activities resulting in penetration and disturbance can either directly affect the mussel by crushing or removal, or indirectly affect them by the weakening or breaking of their byssus threads making them vulnerable to displacement (Denny 1987) where they are unlikely to survive (Dare 1976). Where mussels are removed the associated fauna and flora will also be removed. In addition, abrasion and sub-surface damage attracts mobile scavengers and predators including fish, crabs, and starfish to feed on exposed, dead and damaged individuals and discards (Kaiser & Spencer 1994; Ramsay *et al* 1998; Groenewold & Fonds 2000; Bergmann *et al* 2002). This effect could increase predation pressure on surviving damaged and intact *M. edulis*.

Mussel dredging is the main form of activity that results in penetration around mussel beds. Holt *et al* (1998) noted that several thousand tonnes of mussels were fished in the Wash by dredgers in good years. Dredging will remove the substratum along with the mussels and their associated flora and fauna. Temporary re-suspension of sediment also occurs with mussel dredging (Holt *et al* 1998) in volumes of 1470g/m^2 (Riemann & Hoffmann 1991), which could potentially result in localised smothering (see section 4.3.5). Dredging is also likely to increase the vulnerability of the remaining mussels to storm damage through the weakening of byssal attachment and creating patches in the bed (Denny 1987).

The Scottish MPA Project Fisheries Management Guidance (JNCC 2013a) suggests that scallop dredges and other demersal towed gear is also likely to result in the removal of a proportion of the bed along with its associated fauna and flora. The same report suggested that potting and other demersal static gear would have a lower impact than mobile gear. There is no evidence for the impacts of hydraulic dredging on mussels but Hall *et al* (1990) observed that when using hydraulic dredging for *Ensis sp.* the immediate affects were a reduction in the number of target species and many macrofaunal species. However, after 40 days the effect of the fishing gear could no longer be seen.

Holt *et al* (1998) noted that natural 'wild' beds are susceptible to over-exploitation, especially in some embayments and that over-exploitation can reduce recruitment. Holt *et al* (1998) also point out that the source areas for recruitment to beds is unknown and the relationship between stock and recruitment poorly understood. This statement is consistent with the sporadic and unpredictable nature of recruitment and recovery in mussel beds (Seed & Suchanek 1992) (see section 3.2).

Sensitivity assessment

The activities that penetrate the seabed could result in removal of part of a bed and its associated fauna and flora. Therefore, based on the available evidence it is concluded that all sedimentary mussel biotopes are sensitive to 'penetration and/or disturbance of the seabed'.

Therefore, **resistance** is assessed as '**Low'** (loss of 25-75% of bed within direct footprint), **resilience** is assessed as **'Medium'** (see section 3), and **sensitivity** as '**Medium'**. However the infralittoral rock biotope is unlikely to be affected by penetrative gear or activities, by definition, and is probably 'Not exposed' but is susceptible to 'abrasion' (see section 4.3.1). The sensitivity of each biotope is shown below in Table 4.6.

The **sensitivity** score for each of the **HPI, OSPAR and PMF** blue mussel bed definitions was recorded as **'Medium'**, because one or more biotope within each definition was assessed as 'Medium' sensitivity to against this pressure.

Resistance confidence

Quality of evidence is 'Medium' – based on inference from grey and peer reviewed evidence.
Applicability is 'Medium' – based on applicable evidence on similar pressures from UK and Europe.
Concordance is 'Medium' – studies agree on direction but vary on magnitude.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

Table 4.6. Sensitivity score of individual biotopes within each habitat definition to the penetration pressure (NX = Not exposed).

EUNIS Code	Biotope	PMF	HPI	OSPAR
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	**Medium**	**Medium**	

A2.721	*Mytilus edulis* beds on littoral sediments	**Medium**	**Medium**	
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	**Medium**	**Medium**	**Medium**
A2.7212	*Mytilus edulis* beds on littoral sand	**Medium**	**Medium**	**Medium**
A2.7213	*Mytilus edulis* beds on littoral mud	**Medium**	**Medium**	
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	**NX**	**NX**	
A5.625	*Mytilus edulis* beds on sublittoral sediment	**Medium**	**Medium**	

4.3.3 Changes in suspended solids (water clarity)

ICG-C pressure description
Changes in water clarity from sediment and organic particulate matter concentrations. It is related to activities disturbing sediment and/or organic particulate matter and mobilising it into the water column. 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, 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. This pressure also relates to changes in turbidity from suspended solids of organic origin (as such it excludes sediments - see the "changes in suspended sediment" pressure type). Salinity, turbulence, pH and temperature may result in flocculation of suspended organic matter. Anthropogenic sources mostly short lived and over relatively small spatial extents.

Pressure benchmark
A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to turbid for one year (see Table 4.7).

Table 4.7. Water turbidity ranks based on mean concentration of suspended particulate matter mg/l)

Water Turbidity	Definition
>300	Very Turbid
100-300	Medium Turbidity
10-100	Intermediate
<10	Clear

Evidence description
Mytilus edulis does not rely on light penetration for photosynthesis. In addition visual perception is limited and the species does not rely on sight to locate food or other resources. An indirect effect of increased turbidity and reduced light penetration may be reduced phytoplankton productivity which could reduce the food availability for *M. edulis* (Tyler-Walters 2008). However, as *M. edulis* uses a variety of food sources and food is brought in from other areas with currents and tides, the effect is likely to be minimal. This species and the biotopes it forms are therefore not sensitive to changes in water clarity that refer to light penetration.

M. edulis are often found in areas with high levels of turbidity. For example, the average suspended particulate matter (SPM) concentration at Hastings Shingle Bank was 15 -20mg/l in June 2005, reaching 50mg/l in windier (force 4) conditions, although a concentration of 200mg/l was recorded at this site during gales (Last *et al* 2011).

Winter (1972) (cited by Moore 1977) recorded 75% mortality of *M. edulis* in concentrations of 1.84-7.36mg/l when food was also available. However, a relatively small increase in SPM concentration e.g. from 10mg/l to 90mg/l was found to increase growth rates (Hawkins *et al* 1996). Concentrations above 250mg/l have been shown to impair the growth of filter-feeding organisms (Essink 1999). But Purchon (1937) found that concentrations of particulates as high a 440mg/l did not affect *M. edulis* and that mortality was only occurred when mud was added to the experiment bringing the concentrations up to 1220mg/l. The reason for some of the discrepancy between studies may be due to the volume of water used in the experiment. Loosanoff (1962) found that in small quantities of turbid water (due to particulates) the mussel can filter out all of the particulates within a few minutes whereas in volumes >50 gallons per individual the mussel becomes exhausted before the turbidity has been significantly lowered, causing it to close its shell and die.

It may be possible for *Mytilus edulis* to adapt to a permanent increase in SPM by decreasing their gill size and increasing their palp size in areas of high turbidity (Theisen 1982; Essink 1999). In areas of variable SPM it is likely that the gill size would remain the same but the palp would adapt (Essink 1999). Whilst the ability to adapt may prevent immediate declines in health, the energetic costs of these adaptations may result in reduced fitness; the extent of which is still to be established.

Mytilus edulis uses the circadian clock to determine the opening of the shell gape in nocturnal gape cycles (Ameyaw-Akumfi & Naylor 1987). Last *et al* (2011) investigated the effects on increased SPM concentrations on both the gape pattern and mortality in order to establish the effect that aggregate dredging will have on *M. edulis* and other benthic invertebrates. Therefore they tested concentrations similar to those expected within a few hundred meters of an aggregate extraction site. The highest concentration tested using a *p*VORT (paddle VOrtex Resuspension Tanks) was ~71mg/l. They showed that there is a significant reduction of the strength of the nocturnal gape cycle at high suspended sediment loads as well as a change in the gape period. The effects of these changes are not fully known but as it is likely that the gape pattern is a strategy to avoid diurnal predators the change may result in an increased risk of predation. On the other hand the increased turbidity may reduce predation from visual predators such as fish and birds (Essink 1999). After continued measurements of the gape cycle for 4 days post treatment, Last *et al* (2011) observed that the cycle took longer than this to recover from the cycle disruption. Further study is required to determine the length of time required for recovery of this behavioural response (Last *et al* 2011).

Based on a comprehensive literature review, Moore (1977) concluded that *M. edulis* displayed a higher tolerance to high SPM concentrations than many other bivalves although the upper limit of this tolerance was not certain. He also hypothesised that the ability of the mussel to clean its shell in such conditions played a vital role in its success along with its pseudofaecal expulsion.

A reduction in SPM concentrations may be caused by the erecting of dams and hydroelectric power stations (Moore 1977), which could leave subtidal mussel beds more vulnerable to visual predators such as birds and fish. The recovery time from increased predation pressures would depend on the duration of the reduced turbidity. If reduced SPM concentration is also linked with a reduction of suspended organic matter then it could be assumed that the mussel fitness would be negatively affected by a reduction in food supply. However, as active filter feeders they are no dependent on water flow to supply food.

Sensitivity assessment

Evidence indicates that *M. edulis* and hence blue mussel beds can tolerate a broad range of suspended solids. The benchmark for this pressure refers to a change in turbidity of one rank on the Water Framework Directive (WFD) scale. Mussel beds form in relatively clear waters of open coasts and wave exposed shores and on sediments in sheltered coast (where turbulent water flow over the mussel beds could resuspend sediments locally) and in turbid bays and estuaries. Therefore, is unlikely that a change in turbidity by of one rank (e.g. from 300 to 100mg/l or <10 to 100mg/l) will significantly affect the mussel bed.

Resistance to this pressure is therefore assessed as **‘High. Resilience** is assessed as **‘High’** (no impact to recover from), and **sensitivity** is therefore **'Not sensitive'**. This assessment was considered to apply to all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was assessed as **‘Not sensitive’.**

Resistance confidence

Quality of evidence is ‘High’ – based on peer reviewed evidence.
Applicability is ‘High’ – based on directly applicable evidence in UK and other areas.
Concordance is ‘Medium’ – studies agree on direction but vary on magnitude.

Resilience confidence

Quality of evidence is ‘High’ – based on no impact to recover from.
Applicability is ‘High’ – based on no impact to recover from.
Concordance is ‘High’ – based on no impact to recover from.

4.3.4 Habitat structure changes - removal of substratum (extraction)

ICG-C pressure description
Unlike the "physical change" pressure type where there is a permanent change in sea bed type (e.g. sand to gravel, sediment to a hard artificial substratum) the "habitat structure change" pressure type relates to temporary and/or reversible change, e.g. from marine mineral extraction where a proportion of seabed sands or gravels are removed but a residual layer of seabed is similar to the pre-dredge structure and as such biological communities could re-colonise; navigation dredging to maintain channels where the silts or sands removed are replaced by non-anthropogenic mechanisms so the sediment typology is not changed.

Pressure benchmark
Extraction of sediment to 30cm.

Evidence description
The process of extraction will remove the entire mussel bed and the associated community; therefore a **resistance** of **‘None’** is recorded. As a result, **resilience** is assessed as **‘Low’,** and **sensitivity** as **‘High’.** The infralittoral rock biotope (A3.361) is, by definition, ‘**Not Exposed’** to this pressure (removal of sediment) (Table 4.8).

The **sensitivity** score for each of the **HPI, OSPAR and PMF** blue mussel bed definitions was recorded as **‘High’**, because one or more biotope within each definition was assessed as ‘High’ sensitivity to against this pressure.

Resistance confidence

Quality of evidence is ‘High’ – based the effect of pressure.
Applicability is ‘High’ – based the effect of pressure.
Concordance is ‘High’ – based the effect of pressure.

Resilience confidence

Quality of evidence is ‘High’ – based on considerable peer reviewed evidence.
Applicability is ‘Low’ - based on recovery from natural events and other pressures.
Concordance is ‘Medium’ – based on variation in recovery rates reported in the literature.

Table 4.8. Sensitivity score of individual biotopes within each habitat definition to habitat extraction (NX = not exposed).

EUNIS Code	Biotope	PMF	HPI	OSPAR
A2.212	*Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment	High	High	
A2.721	*Mytilus edulis* beds on littoral sediments	High	High	
A2.7211	*Mytilus edulis* beds on littoral mixed substrata	High	High	High
A2.7212	*Mytilus edulis* beds on littoral sand	High	High	High
A2.7213	*Mytilus edulis* beds on littoral mud	High	High	
A3.361	*Mytilus edulis* beds on reduced salinity infralittoral rock	NX	NX	
A5.625	*Mytilus edulis* beds on sublittoral sediment	High	High	

4.3.5 Siltation rate changes, including smothering (depth of vertical sediment overburden)

ICG-C pressure description
When the natural rates of siltation are altered (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, navigation dredging, disposal at sea, marine mineral extraction, cable and pipeline laying and various construction activities. It can result in short lived sediment concentration gradients and the accumulation of sediments on the sea floor. This accumulation of sediments is synonymous with "light" smothering, which relates to the depth of vertical overburden.

“Light” smothering relates to the deposition of layers of sediment on the seabed. It is associated with activities such as sea disposal of dredged materials where sediments are deliberately deposited on the sea bed. For “light” smothering most benthic biota may be able to adapt, i.e. vertically migrate through the deposited sediment.

“Heavy” smothering also relates to the deposition of layers of sediment on the seabed but is associated with activities such as sea disposal of dredged materials where sediments are deliberately deposited on the sea bed. This accumulation of sediments relates to the depth of vertical overburden where the sediment type of the existing and deposited sediment has similar physical characteristics because, although most species of marine biota are unable to adapt, e.g. sessile organisms unable to make their way to the surface, a similar biota could, with time, re-establish. If the sediments were physically different this would fall under L2.

Pressure benchmark
Up to 30cm of fine material added to the seabed in a single event.

Evidence description
The main human activity that increases sedimentation is dredging and the dumping of dredged sediments in estuarine and coastal waters. Aggregate dredging and fishing gear can cause localised sedimentation and smothering. However, changes in water flow can cause localised smothering within mussel beds (Widdows *et al* 2002), and storms may move large volumes of sediment and smother entire mussel beds (Dare 1976).

Mytilus edulis occurs in areas of high suspended particulate matter (SPM) and therefore a level of siltation is expected from the settling of SPM. In addition, the high rate of faecal and pseudofaecal matter production by the mussels naturally results in siltation of the seabed, often resulting in the formation of large mounds beneath the mussel bed. For example, at Morecambe Bay an accumulation of mussel-mud (faeces, pseudofaeces and washed sand) of 0.4-0.5m between May 1968 and September 1971 resulted in the mortality of young mussels (Daly & Mathieson 1977). In order to survive the mussels needed to keep moving upwards to stay on the surface. Many individuals did not make it to the surface and were smothered by the accumulation of mussel-mud (Daly and Mathieson 1977), so that whilst *M. edulis* does have the capacity to vertically migrate through sediment some individuals will not survive.

Sand burial has been shown to determine the lower limit of *M. edulis* beds (Daly & Mathieson 1977a). Burial of *M. edulis* beds by large scale movements of sand, and resultant mortalities have been reported from Morecambe Bay, the Cumbrian coast and Solway Firth (Holt *et al* 1998). Essink (1999) recorded fatal burial depths of 1-2cm for *M. edulis* and suggested that they had a low tolerance of sedimentation based on investigations by R.Bijkerk (cited by Essink 1999). Essink (1999) suggested that deposition of sediment (mud or sand) on shallow mussel beds should be avoided. However, Widdows *et al* (2002) noted that mussels buried by 6cm of sandy sediment (caused by resuspension of sediment due to turbulent flow across the bed) were able to move to the surface within one day. Conversely, Condie (2009) (cited by Last *et al* 2011) reported that *M. edulis* was tolerant of repeated burial events.

Last *et al* (2011) carried out burial experiments on *M. edulis* in pVORTs. They used a range of burial depths and sediment fractions and temperatures. It was found that individual mussels were able to survive burial in depths of 2, 5 and 7cm for over 32 days although the deeper and longer the mussels were buried the higher the mortality. Only 16% of buried mussels died after 16 days compared to almost 50% mortality at 32 days. Mortality also increased sharply with a decrease in particle size and with increases in temperature from 8.0 and 14.5 to 20°C. The ability of a proportion of individuals to emerge from burial was again demonstrated with approximately one quarter of the individuals buried at 2cm resurfacing. However, at depths of 5cm and 7cm no emergence was recorded (Last *et al* 2011). The lower mortality when buried in coarse sands may be related to the greater number of individuals who were able to emerge in these conditions and emergence was to be significant for survival.

It is unclear whether the same results would be recorded when mussels are joined by byssal threads or whether this would have an impact on survival (Last *et al* 2011), although Daly and Mathieson (1977) recorded loose attachments between juvenile mussels during a burial event and some of these were able to surface. It was not clear whether the same ability would be shown by adult mussels in a more densely packed bed.

Sensitivity assessment

Overburden by 30cm of fine material (see benchmark) in a single incident could result in significant mortality in blue mussel beds due to the limited ability of *M. edulis* to emerge from sediment deeper than 2cm (Last *et al* 2011; Essink 1999; Daly & Matthieson 1977) and the increased mussel mortality with depth and reduced particle size observed by Last *et al*

(2011). Survival will be higher in winter months when temperatures are lower and physiological demands are decreased. However, mortality will depend on the duration of smothering.

Mortality is likely to be significant in wave sheltered areas, devoid of tidal streams, where the smothering sediment remains for prolonged periods (e.g. more than 16 days). Therefore, **resistance** has been assessed as **'Low'** (significant mortality, loss of 25-75% of population abundance, or extent) for the littoral sediment biotopes (A2.721) and A2.212. Mortality will be limited, and possibly avoided, where the smothering sediment is removed due to wave action or tidal streams, depending on how long the sediment remains over the individual mussels. Therefore, a precautionary **resistance** has been assessed as **'Medium'** for biotopes A3.361 and A5.625. **Resilience** is assessed as **'Medium'** (see section 3.4).

The resultant **sensitivity** is **'Medium'** for all biotopes and, hence, each of the **HPI, OSPAR and PMF** blue mussel bed definitions are assessed as **'Medium' sensitivity'.**

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based the effect of pressure.
Concordance is 'Medium' – based on agreement in direction but not magnitude.

Resilience confidence

Quality of evidence is 'High' – based on considerable peer reviewed evidence.
Applicability is 'Low' - based on recovery from natural events and other pressures.
Concordance is 'Medium' – based on variation in recovery rates reported in the literature.

4.4 Physical loss (permanent change)

4.4.1 Physical change (to another seabed type)

ICG-C pressure description
The permanent change of one marine habitat type to another marine habitat type, through the change in substratum, including to artificial (e.g. concrete). This therefore involves the permanent loss of one marine habitat type but has an equal creation of a different marine habitat type. Associated activities include the installation of infrastructure (e.g. surface of platforms or wind farm foundations, marinas, coastal defences, pipelines and cables), the placement of scour protection where soft sediment habitats are replaced by hard/coarse substratum habitats, removal of coarse substratum (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 i.e. mussel beds. Protection of pipes and cables using rock dumping and mattressing techniques. Placement of cuttings piles from oil and gas activities could fit this pressure type, however, there may be an additional pressures, e.g. "pollution and other chemical changes" theme. This pressure excludes navigation dredging where the depth of sediment is changes locally but the sediment typology is not changed.

Pressure benchmark
Change in 1 Folk class for 2 years.

Evidence description
Mytilus edulis can be found on a wide range of substrata including artificial substratum (e.g. metal, wood, concrete), bedrock, biogenic reef, caves, crevices/fissures, large to very large boulders, mixed, muddy gravel, muddy sand, rock pools, sandy mud, small boulders, under

boulders (Tyler-Walters 2008). The introduction of artificial hard substratum is not considered at the pressure benchmark level (which refers to changes in sedimentary classification). However, it is noted that *M. edulis* can colonise artificial structures. An increase in the availability of hard substratum may be beneficial in areas where sedimentary habitats were previously unsuitable for colonisation e.g. coarse, mobile sediments. It should also be noted that differences in diversity and other structural characteristics of assemblages between natural and artificial substratum have been observed suggesting that there is not a direct, compensatory effect.

Mussels themselves will often cause a change in substrata by the deposition of large quantities of 'mussel-mud' composed of faecal matter and pseudofaeces (Dare 1976) particularly in areas of low water movement. A change from rock to sand in an area of high water flow would increase the mussels' vulnerability to dislodgement and scour (Widdows *et al* 2002) and potentially smothering as sand smothering has been show to set the lower limit of *Mytilus* beds in some areas (Daly & Mathieson 1977).

Sensitivity assessment

The pressure benchmark refers to the simplified Folk classification developed by Long (2006) and the UK Marine Habitat Classification Littoral and Sublittoral Sediment Matrices (Connor *et al* 2004).

In most instances the pathway (human activity) by which the substratum is changed would remove or smother mussels. However, these effects are addressed under the 'hydrological change' (section 4.2), 'abrasion' (section 4.3.1), 'penetration and disturbance' (section 4.3.2) or 'smothering' (section 4.3.5) pressures above. The natural modification of the sediment due to build-up of mussel-mud (see section 4.3.5) could result in change of sediment type from mixed and sand dominated, to anoxic mud, depending on location and hydrography.

In addition, a change in sediment type would also change the biotope definition. That is, a change from mud to sand would change the biotope from A2.7213 to A2.7212. Technically this change could be viewed as loss of the biotope and, hence, high sensitivity. However, this has not been taken into account in the sensitivity assessment, as long as a blue mussel bed biotope remains. This pressure at the benchmark is not considered applicable to *M. edulis* biotopes that occur on rock (A3.361), which are therefore considered **'Not exposed'**.

The biotope A2.721 encompasses three biotopes found on mud, sand and mixed sediment. These biotopes encompass the full variety of sediments ranging from mud and sand to pebble, cobbles and medium boulders; although gravel is not mentioned (Connor *et al* 2004). This biotope is therefore considered to have **'High' resistance** and subsequently **'High recovery** and **'Not sensitive** to a change in sediment type of 1 Folk class as a change between mixed sediments, mud and sandy mud and sand and muddy sand would not adversely affect the biotopes. Similarly, the rationale for this assessment also applies to the biotope A5.625, which Connor *et al* (2004) describe as the sublittoral extension of the A2.721 biotope.

The biotope A2.212 is found on mixed sediments (pebbles, gravel, sand and shell debris with mud) at the top of the shore (Connor *et al* 2004). Connor *et al* (2004) note that its classification and description are uncertain. However, it could probably form on most sediment types and is assessed a **'Not sensitive'** under the same rationale as the other sedimentary biotopes, although confidence in this assessment is based purely on expert judgment and may require revision if further evidence becomes available.

Therefore, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was considered to be **'Not sensitive'**.

Resistance confidence

Quality of evidence is ‘Low’ – based on expert judgment and interpretation of the UK Marine Habitat Classification (Connor *et al* 2004).
Applicability is ‘Not assessed’ – based on expert judgement.
Concordance is ‘Not assessed’ – based on expert judgement.

Resilience confidence

Quality of evidence is ‘High’ – based on no impact to recover from.
Applicability is ‘High’ – based on no impact to recover from.
Concordance is ‘High’ – based on no impact to recover from.

4.4.2 Physical loss (to land or freshwater habitat)

ICG-C Pressure description
Permanent loss of marine habitats. Associated activities are land claim, new coastal defences that encroach on and move the Mean High Water Springs mark seawards, the footprint of a wind turbine on the seabed, dredging if it alters the position of the halocline. This excludes changes from one marine habitat type to another marine habitat type.

Pressure benchmark
Permanent loss of existing saline habitat.

Sensitivity assessment

All marine habitats and benthic species are considered to have a **resistance** of **‘None’** to this pressure and to be unable to recover from a permanent loss of habitat (**resilience is ‘Very Low’). Sensitivity** within the direct spatial footprint of this pressure is therefore **‘High’.** Although no specific evidence is described **confidence** in this assessment is **‘High’**, due to the incontrovertible nature of this pressure. Adjacent habitats and species populations may be indirectly affected where meta-population dynamics and trophic networks are disrupted and where the flow of resources e.g. sediments, prey items, loss of nursery habitat *etc*. is altered.

Therefore, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was considered to be **‘High’ sensitivity**.

4.5 Pollution and other chemical changes

4.5.1 De-oxygenation

ICG-C Pressure description
Any de-oxygenation that is not directly associated with nutrient or organic enrichment. The lowering, temporarily or more permanently, of oxygen levels in the water or substratum due to anthropogenic causes (some areas may naturally be deoxygenated due to stagnation of water masses, e.g. inner basins of fjords). This is typically associated with nutrient and organic enrichment, but it can also derive from the release of ballast water or other stagnant waters (where organic or nutrient enrichment may be absent). Ballast waters may be deliberately deoxygenated via treatment with inert gases to kill non-indigenous species.

Pressure benchmark
Compliance with WFD criteria for good status.

Evidence description
Decreased oxygen levels may be caused by sedimentation, temperature and salinity stratification, eutrophication, and the death of algal blooms. In order to comply with the Water Framework Directive standards (UKTAG 2008) for transitional and coastal waters, oxygen concentration should be greater than 4.5 to 5.7mg/l (at a salinity of 35psu) for 95% of the time.

Mytilus edulis is regarded as euryoxic, tolerant of a wide range of oxygen concentrations including zero (Zandee *et al* 1986; Wang & Widdows 1991; Gosling 1992; Zwaan de & Mathieu 1992; Diaz & Rosenberg 1995; Gray *et al* 2002). Diaz and Rosenberg (1995) suggest it is resistant to severe hypoxia.

Adult mytilids exhibited high tolerance of anoxia, e.g. Theede *et al* (1969) reported LD_{50} of 35 days for *M. edulis* exposed to 0.21mg/l O_2 at 10°C, which was reduced to 25 days with the addition of sulphide (50mg/l $Na_2S.9H_2O$). Jorgensen (1980) observed, by diving, the effects of hypoxia (0.2 -1mg/l) on benthic macrofauna in marine areas in Sweden over a 3-4 week period. Mussels were observed to close their shell valves in response to hypoxia and survived for 1-2 weeks before dying (Cole *et al* 1999; Jorgensen 1980).

M. edulis is capable of anaerobic metabolism. In aerial exposure (emersion) the mussel closes its valves, resulting in a low rate of oxygen exchange and consumption, and conservation of energy (Widdows *et al* 1979a; Zwaan de & Mathieu 1992).

All life stages show high levels of tolerance to low oxygen levels. *M. edulis* larvae, for example, are tolerant down to 1.0ml/l, and although the growth of late stage larvae is depressed in hypoxic condition, the settlement behaviour does not seem to be affected (Diaz & Rosenberg 1995). Based on the available evidence *M. edulis* are considered to be resistant to periods of hypoxia and anoxia although sub-lethal effects on feeding and growth may be expected.

Sensitivity assessment

Mytilus edulis is considered to be 'Not Sensitive' to oxygen levels that comply with the requirements for good status for transitional and coastal water bodies (UKTAG 2014). **Resistance** is therefore assessed as **'High'** and resilience as **'High'** (no effect to recover from), resulting in a **sensitivity** of **'Not sensitive'**. Confidence in this assessment is 'High' by definition of the pressure benchmark.

Therefore, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was considered to be **'Not sensitive'**.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on directly applicable evidence on the effects of the pressure.
Concordance is 'High' – studies agree on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' – based on no impact to recover from.
Applicability is 'High' – based on no impact to recover from.
Concordance is 'High' – based on no impact to recover from.

4.5.2 Nutrient enrichment

ICG-C Pressure description
Increased levels of the elements nitrogen, phosphorus, silicon (and iron) in the marine environment compared to background concentrations. Nutrients can enter marine waters by natural processes (e.g. decomposition of detritus, riverine, direct and atmospheric inputs) or anthropogenic sources (e.g. waste water runoff, terrestrial/agricultural runoff, sewage discharges, aquaculture, and atmospheric deposition). Nutrients can also enter marine regions from 'upstream' locations, e.g. via tidal currents to induce enrichment in the receiving area. Nutrient enrichment may lead to eutrophication (see also organic enrichment). Adverse environmental effects include deoxygenation, algal blooms, changes in community structure of benthos and macrophytes.

Pressure benchmark
Compliance with WFD criteria for good status.

Evidence description
This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The benchmark is set at compliance with WFD criteria for good status, based on nitrogen concentration (UKTAG 2014). No information on 'good status' and associated benthic communities was found.

Nutrient enrichment may impact mussel beds by altering the biomass of phytoplankton and macroalgae. At low levels, nutrient enrichment may stimulate the growth of phytoplankton used as food - a potential beneficial effect. In the Wadden Sea, where fishing had caused the destruction of the local population of *Sabellaria spinulosa*, *Mytilus edulis* was able to colonise, partly because of the increase in coastal eutrophication (Maddock 2008). Conversely, Dinesen *et al* (2011) observed that a reduction in nutrient loading to comply with the WFD resulted in a decrease of mussel biomass in estuaries.

High levels of enrichment may stimulate algal blooms and macroalgal growth. The growth of macrophytes on the mussel beds may result in increased drag on the mussel bed and hence increase susceptibility to damage from wave action and/or storms (see section 4.2.5). Algal blooms may die off suddenly, causing deoxygenation (section 4.5.1) where the algae decompose on the seabed. The thresholds at which these blooms occur depend on site-specific conditions and be mitigated by the degree of mixing and tidal exchange.

Some algae have been shown to negatively affect *M. edulis* when present in high concentrations. For example, blooms of the algae *Phaeocystis sp.*, have been observed to block the mussels gills when present in high concentrations reducing clearing rates, and at high levels they caused a complete cessation of clearance (Smaal & Twisk 1997). Blockage of the gills is also likely to reduce ingestion rates, prevent growth and cause reproductive failure (Holt *et al* 1998). Other species known to negatively impact *M. edulis* are *Gyrodinium aureolum* (Tangen 1977; Widdows *et al* 1979b) and non-flagellated chrysophycean alga (Tracey 1988). The accumulation of toxins from algal blooms has also been linked to out-breaks of paralytic shellfish poisoning resulting in the closure of shell fish beds (Shumway 1990).

Sensitivity assessment

Mytilus edulis beds are considered to be not sensitive to nutrient enrichment at levels that comply with the requirements for good status for transitional and coastal water bodies (UKTAG 2014). **Resistance** is therefore assessed as **'High'** and **resilience** as **'High'** (no effect to recover from) resulting in a **sensitivity** of **'Not sensitive'**. Therefore, each of the **HPI, OSPAR and PMF** blue mussel bed definitions was considered to be **'Not sensitive**.

Resistance confidence

Quality of evidence is 'High' – based on the nature of the benchmark.
Applicability is 'High' – based on the nature of the benchmark.
Concordance is 'High' – based on the nature of the benchmark.

Resilience confidence

Quality of evidence is 'High' – as there is no effect to recover from.
Applicability is 'High' – as there is no effect to recover from.
Concordance is 'High' – as there is no effect to recover from.

4.5.3 Organic enrichment

ICG-C Pressure description
Resulting from the degraded remains of dead biota and microbiota (land and sea); faecal matter from marine animals; flocculated colloidal organic matter and the degraded remains of: sewage material, domestic wastes, industrial wastes *etc*. Organic matter can enter marine waters from sewage discharges, aquaculture or terrestrial/agricultural runoff. Black carbon comes from the products of incomplete combustion (PIC) of fossil fuels and vegetation. Organic enrichment may lead to eutrophication (see also nutrient enrichment). Adverse environmental effects include deoxygenation, algal blooms, changes in community structure of benthos and macrophytes.

Pressure benchmark
A deposit of 100gC/m^2/yr.

Evidence description
Organic enrichment can result from inputs of additional organic matter. Organic enrichment may lead to eutrophication with adverse environmental effects including deoxygenation, algal blooms and changes in community structure (see also section 4.5.2 on 'nutrient enrichment' and section 4.5.1 on 'de-oxygenation).

It has been shown that regardless of the concentration of organic matter *Mytilus edulis* will maintain its feeding rate by compensating with changes to filtration rate, clearance rates, production of pseudofaeces and absorption efficiencies (Tracey 1988; Bayne *et al* 1993; Hawkins *et al* 1996). A number of studies have highlighted the ability of *M. edulis* to utilise the increased volume of organic material available at locations around salmon farms. Reid *et al* (2010) noted that *M. edulis* could absorb organic waste products from the salmon farm with great efficiency. Increased shell length, wet meat weight, and condition index were shown at locations within 200m from a farm in the Bay of Fundy allowing a reduced time to market (Lander *et al* 2012).

M. edulis were also often recorded in areas around sewage outflows (Akaishi *et al* 2007; Lindahl & Kollberg 2008; Nenonen *et al* 2008; Giltrap *et al* 2013) suggesting that they display a high tolerance to the increase in organic material that would occur in these areas.

It should be noted that biotopes occurring in tide swept or wave exposed areas e.g. biotope A3.361 are less likely to experience the effects of organic enrichment as the organic matter will be rapidly removed.

Sensitivity assessment

Based on the observation of *M. edulis* thriving in areas of increased organic matter (Lander *et al* 2012, Reid *et al* 2010), it was assumed that *M. edulis* had a **'High' resistance** to increased organic matter at the pressure benchmark. **Resilience** is therefore assessed as **'High'** (no effect to recover from). Therefore, each of the **HPI, OSPAR and** PMF blue mussel bed definitions was considered **'Not sensitive**.

Resistance confidence

Quality of evidence is 'High' – based peer reviewed evidence.
Applicability is 'High' – based on the directly applicable evidence.
Concordance is 'High' – based on evidence that agreed on both magnitude and direction of the effect.

Resilience confidence

Quality of evidence is 'High' – as there is no effect to recover from.
Applicability is 'High' – as there is no effect to recover from.
Concordance is 'High' – as there is no effect to recover from.

5 Overview of information gaps and confidence in assessments

The blue mussel *Mytilus edulis* is common, abundant, easy to rear and maintain in the laboratory. Blue mussel beds are important marine habitats for biodiversity, wildlife and wild fowl and of commercial importance themselves. Therefore, *M. edulis* and its habitats are well studied. As a result, evidence was available for all pressures, except litter, electromagnetic fields and radionuclide contamination. Evidence on the effects of 'litter' is still incomplete and no information on its effects at the population level is known but it is likely to be more significant as research continues. Similarly, the effects of electromagnetic fields on invertebrates are under-researched. Mussels are known to accumulate radionuclides (Tyler-Walters 2008) but any effects on the population are unknown.

The considerable quantity of information available meant that the majority of the confidence assessments for quality of evidence were 'High' but confidence was reduced by the applicability of the evidence to the benchmarks and, occasionally, the degree of agreement between studies. For example, resilience is based on excellent studies of recovery in the field but the values of recovery rate vary considerably depending on the local habitat, availability of recruits and sporadic nature of recruitment and survivability in bivalves, so that rates vary between days, years and even decades.

Some benchmarks required expert judgement to compare with the available evidence. Changes in wave exposure proved particularly difficult. Most of the evidence discussed wave exposure in general, unspecified, terms, while the UK Marine Habitat Classification (Connor *et al* 2004) uses clearly defined descriptors of wave exposure to separate out biotope, but neither descriptors of wave exposure can be easily compared with changes in wave height. Similarly, where inference was made from the habitat preferences described by Connor *et al* (2004), e.g. for changes in sediment type, a 'Low' confidence was given.

A 'precautionary approach' was taken throughout, whereby the authors were careful to assess sensitivity strictly based on the evidence presented and/or combined with expert judgement, but that, where resistance, resilience or sensitivity were considered borderline, the worst case scenario was chosen, and the lowest confidence reported.

6 Comparison with MB0102 sensitivity assessments

Twenty pressures were assessed in the evidence review – this report. The sensitivity ranks assessed by this project and the previous MB0102 project are compared in Table 6.1. The evidence review assessment supported eleven of the existing MB0102 assessments.

Table 6.1. Comparison of sensitivities between this report and MB0102 (Tillin *et al* 2010). Sensitivity scores are shown in each box; resistance and resilience separated by (/). The range of sensitivities across the component biotopes is indicated by (-). Scores are abbreviated as follows: High (H), Medium (M), Low (L), Very low (VL), None (N), Not sensitive (NS), No evidence (NE) and Not assessed (NA).

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
Biological pressures	Genetic modification & translocation of indigenous species	NA	NE	NE	NE	MB0102 considered only commercially farmed species and did not assess this pressure.
	Introduction of microbial pathogen	NS	M (M/M)	M (M/M)	M (M/M)	MB0102 considered blue mussel beds to be Not sensitive' to this pressure, and excluded further assessment.
	Introduction or spread of non-indigenous species (NIS)	M (M/M)	H (M-N/M-VL)	H (M-N/M-VL)	H (M-N/M-VL)	MB0102 assessment based on expert workshops and suggested ability of mussels to adapt to competition, but with 'Low confidence. This review examined the sensitivity to range of NIS, hence range in resistance/resilience scores, but based on direct evidence.
	Removal of non-target species	M (M/M)	NS (H/H)	NS (H/H)	NS (H/H)	The basis of the MB0102 assessment is not clear; it may have been based on the sensitivity of beds to physical disturbance rather than the removal of associated species. The pressure benchmark may therefore be different to that used by this evidence review.
	Removal of target species	M (M/M)	M (L/M)	M (L/M)	M (L/M)	MB0102 assessment supported by evidence review approach but differ in resistance assessment.
Hydrological changes (inshore/local)	Emergence regime changes - local	M	M (M/M)	M (M/M)	M (M/M)	MB0102 assessment was based on MarLIN evidence, not resistance/resilience, and given low confidence. The MB0102 assessment agrees with this evidence review.
	Salinity changes - local	NS-L	NS (H/H)	NS (H/H)	NS (H/H)	MB0102 and this evidence review agree. The 'Low' score reported in MB102 was based on MarLIN as a precaution, but MarLIN sensitivity scales differ from those used in MB0102/this report.

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
	Temperature changes - local	L	NS (H/H)	NS (H/H)	NS (H/H)	The 'Low' score reported in MB0102 was based on MarLIN. This evidence review score is based on similar evidence but a different sensitivity scale.
	Water flow (tidal current) changes - local, including sediment transport considerations	NS	M (M/M)	M (M/M)	M (M/M)	MB0102 workshops scored Not sensitive as mussels are found in high flow rates but with low confidence. This evidence review examined direct evidence, and noted a range of sensitivities between biotopes of Not sensitive to Medium, and hence an overall sensitivity of Medium.
	Wave exposure changes - local	M	M (L-M/M)	M (L-M/M)	M (L-M/M)	MB0102 score was based on MarLIN. This review noted that resistance could vary between rock and sediment, but overall sensitivity was Medium.
Physical damage (reversible change)	Abrasion /disturbance of the substratum on the surface of the seabed	M (N/M)	M (L/M)	M (L/M)	M (L/M)	MB0102 agrees with this evidence review, the difference in resistance lies in judgment of likely degree of impact, i.e. complete vs. significant damage.
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	M (N/M)	M (L/M)	M (L/M)	M (L/M)	MB0102 agrees with this evidence review, the difference in resistance lies in judgment of likely degree of impact, i.e. complete vs. significant damage.
	Changes in suspended solids (water clarity)	NS-L	NS (H/H)	NS (H/H)	NS (H/H)	MB0102 score of Low was based on MarLIN (which uses a different sensitivity scale), while Not sensitive was based on expert workshops. This evidence review agrees with the latter.
	Habitat structure changes - removal of substratum (extraction)	M (N/M)	H (N/L)	H (N/L)	H (N/L)	MB0102 based on expert workshop. MB0102 and this evidence review agree on likely damage from pressure (resistance) but disagree on resilience. This review was more precautionary.
	Siltation rate changes, including smothering (depth of vertical sediment overburden)	H (N/L)	M (L-M/M)	M (L-M/M)	M (L-M/M)	MB0102 based on expert workshop and uncertainty over recovery rates. This evidence review concluded that damage and recovery dependent on duration of smothering, hence hydrology, and varied between biotopes.

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
Physical loss (permanent change)	Physical change (to another seabed type)	M (L/M)	NS (H/H)	NS (H/H)	NS (H/H)	MB0102 assessment is based upon expert judgment. It is unclear but the assessment may have been based on the sensitivity of beds to physical disturbance, rather than this pressure alone.
	Physical loss (to land or freshwater habitat)	H (N/VL)	H (N/VL)	H (N/VL)	H (N/VL)	The resistance scores developed by the MB0102 workshops were supported by the evidence review.
Pollution and other chemical changes.	De-oxygenation	NS	NS (H/H)	NS (H/H)	NS (H/H)	MB102 assumed compliance with WFD quality standard, so default was not sensitive. This evidence review agreed, by definition.
	Nutrient enrichment	NS	NS (H/H)	NS (H/H)	NS (H/H)	MB102 assumed compliance with WFD quality standard, so default was not sensitive. This evidence review agreed, by definition.
	Organic enrichment	NS (H/H)	NS (H/H)	NS (H/H)	NS (H/H)	MB0102 based on expert workshop. This evidence review agrees based on available evidence.

Two of the sensitivity scores assigned by project MB0102 were expressed as a range due to differences in assessments developed by the two expert workshops and other sources including assessments from MarLIN (where the pressure benchmarks were the same) and those provided by expert reviewers.

In two cases, the differences were probably due to interpretation ('physical change to another seabed type' and 'removal of non-target species') where the effects of the pressure were not distinguished from the physical disturbance rather than ecological effects.

In several cases ('introduction of microbial pathogens', 'removal of non-target species', 'water flow changes', and 'siltation rate changes including smothering') the difference in scores was probably due to the more extensive and more detailed review of evidence undertaken in this report, or differences between the likely effects of 'non-indigenous species'. The difference in sensitivity scores between MB0102 and this review for 'habitat extraction' was based on a more precautionary assessment of resilience used in this report.

7 Application of sensitivity assessments – assumptions and limitations

The assumptions inherent in, and limitations in application of, the sensitivity assessment methodology (Tillin *et al* 2001) as modified in this report, are outlined below and explained in detail in Appendix 4.

- The sensitivity assessments are generic and **NOT site specific**. They are based on the likely effects of a pressure on a 'hypothetical' population in the middle of its 'environmental range'[6].

- Sensitivity assessments are **NOT absolute values but are relative** to the magnitude, extent, duration and frequency of the pressure effecting the species or community and habitat in question; thus the assessment scores are very dependent on the pressure benchmark levels used.

- Sensitivity assessment takes account of both resistance and resilience (recovery). Recovery pre-supposes that the pressure has been alleviated but this will generally only be the case where management measures are implemented.

- The assessments are based on the magnitude and duration of pressures (where specified) but do not take account of spatial or temporal scale.

- The significance of impacts arising from pressures also needs to take account of the scale of the features.

- There are limitations of the scientific evidence on the biology of features and their responses to environmental pressures on which the sensitivity assessments have been based.

Recovery is assumed to have occurred if a species population and/or habitat returns to a state that existed prior to the impact of a given pressure, not to some hypothetical pristine condition. Furthermore, we have assumed recovery to a 'recognisable' habitat or similar population of species, rather than presume recovery of all species in the community and/or total recovery to prior biodiversity.

It follows from the above, that the sensitivity assessments presented are general assessments that indicate the **likely effects of a given pressure** (likely to arise from one or more activities) on species or habitats of conservation concern. They need to be **interpreted within each region (or site)** against the range of activities that occur within that region (or site) and the habitats and species present within its waters.

It should also be noted that the evidence provided, and the nature of the species and habitat features will **need interpretation by experienced marine biologists**.

In particular, interpretation of any specific pressure should pay careful attention to:

- the benchmarks used;

- the resistance, resilience and sensitivity assessments listed;

[6] Where 'environmental range' indicates the range of 'conditions' in which the species or community occurs and includes habitat preferences, physic-chemical preferences and, hence, geographic range.

- the evidence provided to support each assessment; and
- the confidence attributed to that assessment based on the evidence.

It is important to remember that benchmarks are used as part of the assessment process. While they are indicative of levels of pressure associated with certain activities they are **not deterministic**, i.e. if an activity results in a pressure lower than that used in the benchmark this does not mean that it will have no impact. **A separate assessment will be required**.

Similarly, all assessments are made based 'on the level of the benchmark'. Therefore, a **score of 'not sensitive' does not mean that no impact is possible** from a particular 'pressure vs. feature' combination, only that a limited impact was judged to be likely at the specified level of the benchmark.

A further limitation of the methodology is that it is only able to assess single pressures and does not consider the cumulative risks associated with multiple pressures of the same type (e.g. anchoring and beam trawling in the same area which both caused abrasion) or different types of pressure at a single location (e.g. the combined effects of siltation, abrasion, synthetic and non-synthetic substance contamination and underwater noise). When considering multiple pressures of the same or different types at a given location, a judgment will need to be made on the extent to which those pressures might act synergistically, independently or antagonistically.

8 Conclusion

The aim of this project was the development of sensitivity assessments of blue mussel (*Mytilus edulis*) beds for a range of human induced pressures using the sensitivity assessment methodology developed by Project MB0102 (Tillin *et al* 2010). This project looked in particular at differences in sensitivity between three mussel bed definitions given by HPI, PMF and OSPAR.

A total of 20 pressures falling in five categories - biological, hydrological, physical damage, physical loss, and pollution and other chemical changes - were assessed in this report. The review examined seven blue mussel bed biotopes found on littoral sediment and sublittoral rock and sediment. The assessments were based on the sensitivity of *M. edulis* rather than associated species, as *M. edulis* was considered the most important characteristic species in blue mussel beds.

To develop each sensitivity assessment, the resistance and resilience of the key elements are assessed against the pressure benchmark using the available evidence gathered in this review. The benchmarks were designed to provide a ‘standard’ level of pressure against which to assess sensitivity. Blue mussel beds were highly sensitive to a few human activities:

- introduction or spread of non-indigenous species (NIS);
- habitat structure changes - removal of substratum (extraction); and
- physical loss (to land or freshwater habitat).

Physical loss of habitat and removal of substratum are particularly damaging pressures, while the sensitivity of blue mussel beds to non-indigenous species depended on the species assessed. *Crepidula fornicata* and *Crassostrea gigas* both had the potential to out-compete and replace mussel beds, so resulted in a high sensitivity assessment.

Mytilus spp. populations are considered to have a strong ability to recover from environmental disturbance. A good annual recruitment may allow a bed to recover rapidly, though this cannot always be expected due to the sporadic nature of *M. edulis* recruitment. Therefore, blue mussel beds were considered to have a 'Medium' resilience (recovery within 2-10 years). As a result, even where the removal or loss of proportion of a mussel bed was expected due to a pressure, a sensitivity of 'Medium' was reported. Hence, most of the sensitivities reported were 'Medium'. It was noted, however, that the recovery rates of blue mussel beds were reported to be anywhere between two years to several decades.

In addition, *M. edulis* is considered very tolerant of a range of physical and chemical conditions. As a result, blue mussel beds were considered to be 'Not sensitive' to changes in temperature, salinity, de-oxygenation, nutrient and organic enrichment, and substratum type, at the benchmark level of pressure.

The report found that no distinct differences in overall sensitivity exist between the HPI, PMF and OSPAR definitions. Individual biotopes do however have different sensitivities to pressures, and the OSPAR definition only includes blue mussel beds on sediment. These differences were determined by the position of the habitat on the shore and the sediment type. For example, the infralittoral rock biotope (A3.361) was unlikely to be exposed to pressures that affect sediments. However in the case of increased water flow, mixed sediment biotopes were considered more stable and ‘Not sensitive’ (at the benchmark level) while the remaining biotopes were likely to be affected.

Using a clearly documented, evidence based approach to create sensitivity assessments allows the assessment basis and any subsequent decision making or management plans to be readily communicated, transparent and justifiable. The assessments can be replicated and updated where new evidence becomes available ensuring the longevity of the sensitivity assessment tool. For every pressure where sensitivity was previously assessed as a range of scores in MB0102, the assessments made by the evidence review have supported one of the MB0102 assessments. The evidence review has reduced the uncertainty around the MB0102 assessments by a more detailed assessment of available evidence.

Finally, as blue mussel bed habitats also contribute to ecosystem function and the delivery of ecosystem services, understanding the sensitivity of these biotopes may also support assessment and management in regard to these.

Whatever objective measures are applied to data to assess sensitivity, the final sensitivity assessment is indicative. The evidence, the benchmarks, the confidence in the assessments and the limitations of the process, require a sense-check by experienced marine ecologists before the outcome is used in management decisions.

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Acronym List

JNCC - Joint Nature Conservation Committee

PMF - Priority Marine Feature

HPI - Habitat of Principle Importance

OSPAR - Oslo and Paris Commission

ICG-C - Intercessional Correspondence Group on Cumulative Effects

NMBL - National Marine Biological Library

ASFA - Aquatic Sciences and Fisheries Abstracts

EUNIS - European Union Nature Information System

MCZ - Marine Conservation Zone

NIS - Non-indigenous Species

MLW - Mean Low Water

MHW - Mean High Water

Appendix 1 - Sensitivity assessment methodology

Introduction

The UK Review of Marine Nature Conservation (Defra 2004) defined sensitivity as 'dependent on the intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery'. Sensitivity can therefore be understood as a measure of the likelihood of change when a pressure is applied to a feature (receptor) and is a function of the ability of the feature to tolerate or resist change (resistance) and its ability to recover from impact (resilience). The concepts of resistance and resilience are widely used in this way to assess sensitivity.

As part of the process of establishing a UK network of marine protected areas (MPAs), Defra led on a piece of work designed to assess the sensitivity of certain marine features, considered to be of conservation interest, against physical, chemical and biological pressures resulting from human activities (Tillin *et al* 2010). The approach was adapted from a number of approaches in particular; Holling (1973); MarLIN (Hiscock & Tyler-Walters 2006; Tyler-Walters *et al* 2009); OSPAR Texel-Faial Criteria (OSPAR 2003); the CCW 'Beaumaris approach' (Hall *et al* 2008); Robinson *et al* (2008) and the Review of Marine Nature Conservation (Laffoley *et al* 2000).

- The OSPAR commission used these concepts to evaluate sensitivity as part of the criteria used to identify 'threatened and declining' species and habitats within the OSPAR region - the Texel-Faial criteria (OSPAR 2003). A species is defined as very sensitive when it is easily adversely affected by human activity (low resistance) and/or it has low resilience (recovery is only achieved after a prolonged period, if at all). Highly sensitive species are those with both low resistance and resilience.

- The Marine Life Information Network (MarLIN) developed an approach to sensitivity assessment based on species tolerance and ability to recover from pressures (Hiscock & Tyler-Walters 2006; Tyler-Walters *et al* 2009). Based on this methodology detailed assessments are available on-line[7] for a number of biotopes and species.

- The Countryside Council for Wales (CCW) developed the Beaumaris approach (Hall *et al* 2008) that focused on the sensitivity of benthic habitats to fishing activities around the Welsh coast and coastal waters. They compared the severity of a fishing event at four levels of intensity against the rate of habitat recovery to derive a habitat sensitivity score (high, medium or low). The study assessed 30 habitat categories to the intensity of the disturbance and the spatial footprint of the disturbance (which were used together to assess the severity of the disturbance event) and the rate of recovery from the disturbance.

- Robinson *et al* (2008) developed an assessment methodology which was used for OSPAR and Charting Progress II. This assessment was based on expert-judgement and follows the DPSIR (Drivers-Pressures-State-Impacts-Responses) framework.

The Tillin *et al* (2010) methodology was modified by Tillin & Hull (2012-2013), who introduced a detailed evaluation and audit trail of evidence on which to base the sensitivity assessments.

To facilitate the assessment of features, pressure definitions and benchmarks were established. Pressure definitions and associated benchmarks were supplied by JNCC for

[7] Available on-line at www.marlin.ac.uk

each of the pressures that were to be assessed (Appendix 2). The pressure descriptions used in this report were created by the Intercessional Correspondence Group on Cumulative Effects (ICG-C). The benchmarks were taken from Tillin *et al* (2010) and applied to the relevant ICG-C pressure (Appendix 2).

Sensitivity assessment

The sensitivity assessment method used (Tillin *et al* 2010; Tillin and Hull 2012-2013) involves the following stages.

A. Defining the key elements of the feature to be assessed (in terms of life history, and ecology of the key and characterising species).
B. Assessing feature resistance (tolerance) to a defined intensity of pressure (the benchmark).
C. Assessing the resilience (recovery) of the feature to a defined intensity of pressure (the benchmark).
D. The combination of resistance and resilience to derive an overall sensitivity score.
E. Assess level of confidence in the sensitivity assessment.
F. Written audit trail.

A) Defining the key elements of the feature

When assessing habitats/biotopes the key elements of the feature that the sensitivity assessment will consider must be selected at the outset.

B and C) Assessing feature resistance (tolerance) and resilience to a defined intensity of pressure (the benchmark)

To develop each sensitivity assessment, the resistance and resilience of the key elements are assessed against the pressure benchmark using the available evidence. The benchmarks are designed to provide a ‘standard’ level of pressure against which to assess sensitivity.

The assessment scales used for resistance (tolerance) and resilience (recovery) are given in Table 10.1and Table 10.2 respectively.

‘Full recovery’ is envisaged as a return to the state that existed prior to impact. However, this does not necessarily mean that every component species or other key elements of the habitat have returned to its prior condition, abundance or extent but that the relevant functional components are present and the habitat is structurally and functionally recognisable as the initial habitat of interest.

D) The combination of resistance and resilience to derive an overall sensitivity score

The resistance and resilience scores can be combined, as follows, to give an overall sensitivity score as shown in Table 10.3.

Table 10.1. Assessment scale for resistance (tolerance) to a defined intensity of pressure.

Resistance (Tolerance)	Description
None	Key functional, structural, characterising species severely decline and/or physico-chemical parameters are also affected e.g. removal of habitats causing change in habitats type. A severe decline/reduction relates to the loss of 75% of the extent, density or abundance of the selected species or habitat element e.g. loss of 75% substratum (where this can be sensibly applied).
Low	Significant mortality of key and characterising species with some effects on physico-chemical character of habitat. A significant decline/reduction relates to the loss of 25-75% of the extent, density, or abundance of the selected species or habitat element e.g. loss of 25-75% of substratum.
Medium	Some mortality of species (can be significant where these are not keystone structural/functional and characterising species) without change to habitats relates to the loss <25% of the species or element.
High	No significant effects to the physico-chemical character of habitat and no effect on population viability of key/characterising species but may affect feeding, respiration and reproduction rates.

Table 10.2. Assessment scale for resilience (recovery).

Resilience (Recovery)	Description
Very Low	Negligible or prolonged recovery possible; at least 25 years to recover structure and function
Low	Full recovery within 10-25 years
Medium	Full recovery within 2-10 years
High	Full recovery within 2 years

Table 10.3. Combining resistance and resilience scores to categorise sensitivity.

	Resistance			
Resilience	**None**	**Low**	**Medium**	**High**
Very Low	High	High	Medium	Low
Low	High	High	Medium	Low
Medium	Medium	Medium	Medium	Low
High	Medium	Low	Low	Not sensitive

The following options can also be used for pressures where an assessment is not possible or not felt to be applicable (this is documented and justified in each instance):

No exposure - where there will be no exposure to a particular pressure, for example, deep mud habitats are not exposed to changes in emersion.

Not assessed (NA) – where the evidence base is not considered to be developed enough for assessments to be made of sensitivity

No evidence (NE) - unable to assess the specific feature/pressure combination based on knowledge and unable to locate information regarding the feature on which to base decisions. This can be the case for species with distributions limited to a few locations (sometimes only one), so that even basic tolerances could not be inferred. An assessment of ‘No Evidence’ should not be taken to mean that there is no information available for features.

E) Confidence Assessments

Confidence scores are assigned to the individual assessments for resistance (tolerance) and resilience (recovery) in the pro-forma in accordance with the criteria in Table 10.4. The confidence assessment categories for resistance (tolerance) and resilience (recovery) are combined to give an overall confidence score for the confidence category (i.e. quality of information sources, applicability of evidence and degree of concordance) for each individual feature/pressure assessment, using Table 10.5.

Table 10.4. Confidence assessment categories for evidence.

Confidence Level	Quality of Information Sources	Applicability of evidence	Degree of Concordance
High	High – based on peer reviewed papers (observational or experimental) or grey literature reports by established agencies (give number) on the feature.	High - assessment based on the same pressures acting on the same type of feature in the UK.	High -agree on the direction and magnitude of impact.
Medium	Medium - based on some peer reviewed papers but relies heavily on grey literature or expert judgement on feature or similar features.	Medium - assessment based on similar pressures on the feature in other areas.	Medium - agree on direction but not magnitude.
Low	Low - based on expert judgement.	Low - assessment based on proxies for pressures e.g. natural disturbance events.	Low - do not agree on concordance or magnitude.

Table 10.5. Combined confidence assessments (Based on Quality of Information Assessment only).

	Resistance confidence score		
Resilience confidence score	**Low**	**Medium**	**High**
Low	Low	Low	Low
Medium	Low	Medium	Medium
High	Low	Medium	High

F) Written Audit Trail

So that the basis of the sensitivity assessment is transparent and repeatable the evidence base and justification for the sensitivity assessments is recorded. A complete and accurate account of the evidence that was used to make the assessments is presented for each sensitivity assessment in the form of the literature review and a sensitivity ‘pro-forma’ that records a summary of the assessment, the sensitivity scores and the confidence levels.

Appendix 2 - List of pressures and their associated descriptions and benchmarks

Pressures and Definitions taken from the Intercessional Correspondence Group on Cumulative Effects – Amended 25th March 2011 (OSPAR 2011). Benchmarks taken from Tillin *et al* (2010).

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Biological pressures	Genetic modification and translocation of indigenous species	Genetic modification can be either deliberate (e.g. introduction of farmed individuals to the wild, GM food production) or a by-product of other activities (e.g. mutations associated with radionuclide contamination). Former related to escapees or deliberate releases e.g. cultivated species such as farmed salmon, oysters, and scallops if GM practices employed. Scale of pressure compounded if GM species "captured" and translocated in ballast water. Mutated organisms from the latter could be transferred on ships hulls, in ballast water, with imports for aquaculture, aquaria, and live bait, species traded as live seafood or 'natural' migration.	Translocation outside of a geographic areas; introduction of hatchery – reared juveniles outside of geographic area from which adult stick derives
Biological pressures	Introduction of microbial pathogens	Untreated or insufficiently treated effluent discharges and run-off from terrestrial sources and vessels. It may also be a consequence of ballast water releases. In mussel or shellfisheries where seed stock is imported, 'infected' seed could be introduced, or it could be from accidental releases of effluvia. Escapees, e.g. farmed salmon could be infected and spread pathogens in the indigenous populations. Aquaculture could release contaminated faecal matter, from which pathogens could enter the food chain.	The introduction of microbial pathogens Bonamia and *Marteilia refringens* to an area where they are currently not present
Biological pressures	Introduction or spread of non-indigenous species (NIS)	The direct or indirect introduction of non-indigenous species, e.g. Chinese mitten crabs, slipper limpets, Pacific oyster and their subsequent spreading and out-competing of native species. Ballast water, hull fouling, stepping stone effects (e.g. offshore wind farms) may facilitate the spread of such species. This pressure could be associated with aquaculture, mussel or shellfishery activities due to imported seed stock imported or from accidental releases.	A significant pathway exists for introduction of one or more invasive non-indigenous species (NIS) (e.g. aquaculture of NIS, untreated ballast water exchange, local port, terminal harbour or marina); creation of new colonisation space >1ha
Biological pressures	Removal of non-target species	By-catch associated with all fishing activities. The physical effects of fishing gear on sea bed communities are addressed by the "abrasion" pressure type (D2) so B6 addresses the direct removal of individuals associated with fishing/ harvesting. Ecological consequences include food web dependencies, population dynamics of fish, marine mammals, turtles and sea birds (including survival threats in extreme cases, e.g. harbour porpoise	Removal of features through pursuit of a target fishery at a commercial scale

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
		in Central and Eastern Baltic).	
Biological pressures	Removal of target species	The commercial exploitation of fish and shellfish stocks, including smaller scale harvesting, angling and scientific sampling. The physical effects of fishing gear on sea bed communities are addressed by the "abrasion" pressure type D2, so B5 addresses the direct removal / harvesting of biota. Ecological consequences include the sustainability of stocks, impacting energy flows through food webs and the size and age composition within fish stocks.	Removal of target species that are features of conservation importance or sub-features of habitats of conservation importance at a commercial scale
Biological pressures	Visual disturbance	The disturbance of biota by anthropogenic activities, e.g. increased vessel movements, such as during construction phases for new infrastructure (bridges, cranes, port buildings *etc*.), increased personnel movements, increased tourism, increased vehicular movements on shore *etc*. disturbing bird roosting areas, seal haul out areas *etc*.	None proposed
Hydrological changes (inshore /local)	Emergence regime changes - local, including tidal level change considerations	Changes in water levels reducing the intertidal zone (and the associated/dependant habitats). The pressure relates to changes in both the spatial area and duration that intertidal species are immersed and exposed during tidal cycles (the percentage of immersion is dependent on the position or height on the shore relative to the tide). The spatial and temporal extent of the pressure will be dependent on the causal activities but can be delineated. This relates to anthropogenic causes that may directly influence the temporal and spatial extent of tidal immersion, e.g. upstream and downstream of a tidal barrage the emergence would be respectively reduced and increased, beach re-profiling could change gradients and therefore exposure times, capital dredging may change the natural tidal range, managed realignment, saltmarsh creation. Such alteration may be of importance in estuaries because of their influence on tidal flushing and potential wave propagation. Changes in tidal flushing can change the sediment dynamics and may lead to changing patterns of deposition and erosion. Changes in tidal levels will only affect the emergence regime in areas that are inundated for only part of the time. The effects that tidal level changes may have on sediment transport are not restricted to these areas, so a very large construction could significantly affect the tidal level at a deep site without changing the emergence regime. Such a change could still have a serious impact. This excludes pressure from sea level rise which is considered under the climate change pressures.	Intertidal species (and habitats not uniquely defined by intertidal zone): A 1 hour change in the time covered or not covered by the sea for a period of 1 year. Habitats and landscapes defined by intertidal zone: An increase in relative sea level or decrease in high water level of 1mm for one year over a shoreline length >1km

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Hydrological changes (inshore/local)	Salinity changes - local	Events or activities increasing or decreasing local salinity. This relates to anthropogenic sources/causes that have the potential to be controlled, e.g. freshwater discharges from pipelines that reduce salinity, or brine discharges from salt caverns washings that may increase salinity. This could also include hydro-morphological modification, e.g. capital navigation dredging if this alters the halocline, or erection of barrages or weirs that alter freshwater/seawater flow/exchange rates. The pressure may be temporally and spatially delineated derived from the causal event/activity and local environment.	Increase from 35 to 38 units for one year. Decrease in Salinity by 4-10 units a year
Hydrological changes (inshore/local)	Temperature changes - local	Events or activities increasing or decreasing local water temperature. This is most likely from thermal discharges, e.g. the release of cooling waters from power stations. This could also relate to temperature changes in the vicinity of operational sub-sea power cables. This pressure only applies within the thermal plume generated by the pressure source. It excludes temperature changes from global warming which will be at a regional scale (and as such are addressed under the climate change pressures).	A 5°C change in temp for one month period, or 2°C for one year
Hydrological changes (inshore/local)	Water flow (tidal current) changes - local, including sediment transport considerations	Changes in water movement associated with tidal streams (the rise and fall of the tide, riverine flows), prevailing winds and ocean currents. The pressure is therefore associated with activities that have the potential to modify hydrological energy flows, e.g. Tidal energy generation devices remove (convert) energy and such pressures could be manifested leeward of the device, capital dredging may deepen and widen a channel and therefore decrease the water flow, canalisation and/or structures may alter flow speed and direction; managed realignment (e.g. Wallasea, England). The pressure will be spatially delineated. The pressure extremes are a shift from a high to a low energy environment (or vice versa). The biota associated with these extremes will be markedly different as will the substratum, sediment supply/transport and associated seabed elevation changes. The potential exists for profound changes (e.g. coastal erosion/deposition) to occur at long distances from the construction itself if an important sediment transport pathway was disrupted. As such these pressures could have multiple and complex impacts associated with them.	A change in peak mean spring tide flow speed of between 0.1m/s to 0.2m/s over an areas > 1km2 or 50% if width of water body for more than 1 year
Hydrological changes (inshore/local)	Wave exposure changes - local	Local changes in wave length, height and frequency. Exposure on an open shore is dependent upon the distance of open seawater over which wind may blow to generate waves (the fetch) and the strength and incidence of winds. Anthropogenic sources of this pressure include artificial reefs, breakwaters, barrages, wrecks that can directly influence wave action or activities that may locally affect the incidence of winds, e.g. a dense network of wind turbines may have the potential to influence wave exposure, depending upon their location relative to the coastline.	A change in nearshore significant wave height >3% but <5%

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Other physical pressures	Barrier to species movement	The physical obstruction of species movements and including local movements (within and between roosting, breeding, feeding areas) and regional/global migrations (e.g. birds, eels, salmon, whales). Both include up-river movements (where tidal barrages and devices or dams could obstruct movements) or movements across open waters (offshore wind farm, wave or tidal device arrays, mariculture infrastructure or fixed fishing gears). Species affected are mostly birds, fish, and mammals.	10% change in tidal excursion, or temporary barrier to species movement over ≥50% of water body width
Other physical pressures	Death or injury by collision	Injury or mortality from collisions of biota with both static and/or moving structures. Examples include: Collision with rigs (e.g. birds) or screens in intake pipes (e.g. fish at power stations) (static) or collisions with wind turbine blades, fish and mammal collisions with tidal devices and shipping (moving). Activities increasing number of vessels transiting areas, e.g. new port development or construction works will influence the scale and intensity of this pressure.	0.1% of tidal volume on average tide, passing through artificial structure
Other physical pressures	Electromagnetic changes	Localised electric and magnetic fields associated with operational power cables and telecommunication cables (if equipped with power relays). Such cables may generate electric and magnetic fields that could alter behaviour and migration patterns of sensitive species (e.g. sharks and rays).	Local electric field of 1V m-1. Local magnetic field of 10µT
Other physical pressures	Introduction of light	Direct inputs of light from anthropogenic activities, i.e. lighting on structures during construction or operation to allow 24 hour working; new tourist facilities, e.g. promenade or pier lighting, lighting on oil and gas facilities *etc*. Ecological effects may be the diversion of bird species from migration routes if they are disorientated by or attracted to the lights. It is also possible that continuous lighting may lead to increased algal growth.	None proposed
Other physical pressures	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 *etc*. and their degraded components, e.g. microplastic particles. Ecological effects can be physical (smothering), biological (ingestion, including uptake of microplastics; entangling; physical damage; accumulation of chemicals) and/or chemical (leaching, contamination).	None proposed
Other physical pressures	Underwater noise changes	Increases over and above background noise levels (consisting of environmental noise (ambient) and incidental man-made/anthropogenic noise (apparent)) at a particular location. Species known to be affected are marine mammals and fish. The theoretical zones of noise influence (Richardson *et al* 1995) are temporary or permanent hearing loss, discomfort and injury; response; masking and detection. In extreme cases noise pressures may lead to death. The physical or behavioural effects are dependent on a number of variables, including the sound pressure, loudness, sound exposure level and frequency. High amplitude low and mid-frequency impulsive sounds and low frequency continuous sound are of greatest concern for effects on marine mammals	MSFD indicator levels (SEL or peak SPL) exceeded for 20% of days in calendar year within site

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
		and fish. Some species may be responsive to the associated particle motion rather than the usual concept of noise. Noise propagation can be over large distances (tens of kilometres) but transmission losses can be attributable to factors such as water depth and sea bed topography. Noise levels associated with construction activities, such as pile-driving, are typically significantly greater than operational phases (i.e. shipping, operation of a wind farm).	
Physical damage (Reversible Change)	Abrasion/disturbance of the substratum on the surface of the seabed	The disturbance of sediments where there is limited or no loss of substratum from the system. This pressure is associated with activities such as anchoring, taking of sediment/geological cores, cone penetration tests, cable burial (ploughing or jetting), propeller wash from vessels, certain fishing activities, e.g. scallop dredging, beam trawling. Agitation dredging, where sediments are deliberately disturbed by and 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 sea bed surface layers (typically up to 50cm depth). Activities associated with abrasion can cover relatively large spatial areas and include: fishing with towed demersal trawls (fish and shellfish); bio-prospecting such as harvesting of biogenic features such as maerl beds where, after extraction, conditions for recolonisation remain suitable or relatively localised activities including: seaweed harvesting, recreation, potting, aquaculture. Change from gravel to silt substratum would adversely affect herring spawning grounds.	Damage to seabed surface features
Physical damage (Reversible Change)	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion		Structural damage to seabed sub-surface
Physical damage (Reversible Change)	Changes in suspended solids (water clarity)	Changes in water clarity from sediment and organic particulate matter concentrations. It is related to activities disturbing sediment and/or organic particulate matter and mobilising it into the water column. 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, 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. This pressure also relates to changes in turbidity from suspended solids of organic origin (as such it excludes sediments - see the "changes in suspended sediment" pressure type). Salinity, turbulence, pH and temperature may result in flocculation of suspended organic matter. Anthropogenic sources mostly short lived and over relatively small spatial extents.	A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to turbid for one year

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Physical damage (Reversible Change)	Habitat structure changes - removal of substratum (extraction)	Unlike the "physical change" pressure type where there is a permanent change in sea bed type (e.g. sand to gravel, sediment to a hard artificial substratum) the "habitat structure change" pressure type relates to temporary and/or reversible change, e.g. from marine mineral extraction where a proportion of seabed sands or gravels are removed but a residual layer of seabed is similar to the pre-dredge structure and as such biological communities could re-colonise; navigation dredging to maintain channels where the silts or sands removed are replaced by non-anthropogenic mechanisms so the sediment typology is not changed.	Extraction of sediment to 30cm
Physical damage (Reversible Change)	Siltation rate changes, including smothering (depth of vertical sediment overburden)	When the natural rates of siltation are altered (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, navigation dredging, and disposal at sea, marine mineral extraction, cable and pipeline laying and various construction activities. It can result in short lived sediment concentration gradients and the accumulation of sediments on the sea floor. This accumulation of sediments is synonymous with "light" smothering, which relates to the depth of vertical overburden. “Light” smothering relates to the deposition of layers of sediment on the seabed. It is associated with activities such as sea disposal of dredged materials where sediments are deliberately deposited on the sea bed. For “light” smothering most benthic biota may be able to adapt, i.e. vertically migrate through the deposited sediment. “Heavy” smothering also relates to the deposition of layers of sediment on the seabed but is associated with activities such as sea disposal of dredged materials where sediments are deliberately deposited on the sea bed. This accumulation of sediments relates to the depth of vertical overburden where the sediment type of the existing and deposited sediment has similar physical characteristics because, although most species of marine biota are unable to adapt, e.g. sessile organisms unable to make their way to the surface, a similar biota could, with time, re-establish. If the sediments were physically different this would fall under L2. Eleftheriou and McIntyre, 2005 describe that the majority of animals will inhabit the top 5-10cm in open waters and the top 15cm in intertidal areas. The depth of sediment overburden that benthic biota can tolerate is both trophic group and particle size/sediment type dependant (Bolam, 2010). Recovery from burial can occur from: - planktonic recruitment of larvae - lateral migration of juveniles/adults - vertical migration (see Chandrasekara & Frid 1998; Bolam *et al* 2003, Bolam & Whomersley 2005). Spatial scale, timing, rate and depth of placement all contribute the relative importance of these three recovery mechanisms (Bolam *et al* 2006).	up to 30cm of fine material added to the seabed in a single event

Pressure theme	**ICG-C Pressure**	**ICG-C description**	**MB0102 benchmark**
		As such the terms “light” and “heavy” smothering are relative and therefore difficult to define in general terms. Bolam (2010) cites various examples: - *H. ulvae* maximum overburden 5cm (Chandrasekara & Frid 1998) - *H. ulvae* maximum overburden 20cm mud or 9cm sand (Bijerk 1988) - S. shrubsolii maximum overburden 6cm (Saila *et al* 1972, cited by Hall 1994) - *N. succinea* maximum overburden 90cm (Maurer *et al* 1982) - gastropod molluscs maximum overburden 15cm (Roberts *et al* 1998). Bolam (2010) also reported when organic content was low: - *H. ulvae* maximum overburden 16cm - *T, benedii* maximum overburden 6cm - *S. shrubsolii* maximum overburden <6cm - *Tharyx* sp. maximum overburden <6cm	
Physical loss (Permanent Change)	Physical change (to another seabed type)	The permanent change of one marine habitat type to another marine habitat type, through the change in substratum, including to artificial (e.g. concrete). This therefore involves the permanent loss of one marine habitat type but has an equal creation of a different marine habitat type. Associated activities include the installation of infrastructure (e.g. surface of platforms or wind farm foundations, marinas, coastal defences, pipelines and cables), the placement of scour protection where soft sediment habitats are replaced by hard/coarse substratum habitats, removal of coarse substratum (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 i.e. mussel beds. Protection of pipes and cables using rock dumping and mattressing techniques. Placement of cuttings piles from oil and gas activities could fit this pressure type, however, there may be an additional pressures, e.g. "pollution and other chemical changes" theme. This pressure excludes navigation dredging where the depth of sediment is changes locally but the sediment typology is not changed.	Change in 1 folk class for 2 years
Physical loss (Permanent Change)	Physical loss (to land or freshwater habitat)	The permanent loss of marine habitats. Associated activities are land claim, new coastal defences that encroach on and move the Mean High Water Springs mark seawards, the footprint of a wind turbine on the seabed, dredging if it alters the position of the halocline. This excludes changes from one marine habitat type to another marine habitat type.	Permanent loss of existing saline habitat

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Pollution and other chemical changes	De-oxygenation	Any deoxygenation that is not directly associated with nutrient or organic enrichment. The lowering, temporarily or more permanently, of oxygen levels in the water or substratum due to anthropogenic causes (some areas may naturally be deoxygenated due to stagnation of water masses, e.g. inner basins of fjords). This is typically associated with nutrient and organic enrichment, but it can also derive from the release of ballast water or other stagnant waters (where organic or nutrient enrichment may be absent). Ballast waters may be deliberately deoxygenated via treatment with inert gases to kill non-indigenous species.	Compliance with WFD criteria for good status
Pollution and other chemical changes	Hydrocarbon and PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Increases in the levels of these compounds compared with background concentrations. Naturally occurring compounds, complex mixtures of two basic molecular structures: - straight chained aliphatic hydrocarbons (relatively low toxicity and susceptible to degradation) - multiple ringed aromatic hydrocarbons (higher toxicity and more resistant to degradation) These fall into three categories based on source (includes both aliphatics and polyaromatic hydrocarbons): - petroleum hydrocarbons (from natural seeps, oil spills and surface water run-off) - pyrogenic hydrocarbons (from combustion of coal, woods and petroleum) - biogenic hydrocarbons (from plants and animals) Ecological consequences include tainting, some are acutely toxic, carcinomas, growth defects.	Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls
Pollution and other chemical changes	Introduction of other substances (solid, liquid or gas)	The 'systematic or intentional release of liquids, gases ' (from MSFD Annex III Table 2) is being considered e.g. in relation to produced water from the oil industry. It should therefore be considered in parallel with P1, P2 and P3.	None proposed
Pollution and other chemical changes	Nutrient enrichment	Increased levels of the elements nitrogen, phosphorus, silicon (and iron) in the marine environment compared to background concentrations. Nutrients can enter marine waters by natural processes (e.g. decomposition of detritus, riverine, direct and atmospheric inputs) or anthropogenic sources (e.g. waste water runoff, terrestrial/agricultural runoff, sewage discharges, aquaculture, atmospheric deposition). Nutrients can also enter marine regions from ‘upstream’ locations, e.g. via tidal currents to induce enrichment in the receiving area. Nutrient enrichment may lead to eutrophication (see also organic enrichment). Adverse environmental effects include deoxygenation, algal blooms, changes in community structure of benthos and macrophytes.	Compliance with WFD criteria for good status

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
Pollution and other chemical changes	Organic enrichment	Resulting from the degraded remains of dead biota and microbiota (land and sea); faecal matter from marine animals; flocculated colloidal organic matter and the degraded remains of: sewage material, domestic wastes, industrial wastes *etc*. Organic matter can enter marine waters from sewage discharges, aquaculture or terrestrial/agricultural runoff. Black carbon comes from the products of incomplete combustion (PIC) of fossil fuels and vegetation. Organic enrichment may lead to eutrophication (see also nutrient enrichment). Adverse environmental effects include deoxygenation, algal blooms, changes in community structure of benthos and macrophytes.	A deposit of $100gC/m^2/yr$
Pollution and other chemical changes	Radionuclide contamination	Introduction of radionuclide material, raising levels above background concentrations. Such materials can come from nuclear installation discharges, and from land or sea-based operations (e.g. oil platforms, medical sources). The disposal of radioactive material at sea is prohibited unless it fulfils exemption criteria developed by the International Atomic Energy Agency (IAEA), namely that both the following radiological criteria are satisfied: (i) the effective dose expected to be incurred by any member of the public or ship's crew is 10µSv or less in a year; (ii) the collective effective dose to the public or ship's crew is not more than 1 man Sv per annum, then the material is deemed to contain *de minimis* levels of radioactivity and may be disposed at sea pursuant to it fulfilling all the other provisions under the Convention. The individual dose criteria are placed in perspective (i.e. very low), given that the average background dose to the UK population is ~2700µSv/a. Ports and coastal sediments can be affected by the authorised discharge of both current and historical low-level radioactive wastes from coastal nuclear establishments.	An increase in 10µGy/h above background levels
Pollution and other chemical changes	Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC.	Increases in the levels of these compounds compared with background concentrations. Synthesised from a variety of industrial processes and commercial applications. Chlorinated compounds include polychlorinated biphenols (PCBs), dichlor-diphenyl-trichloroethane (DDT) and 2,3,7,8-tetrachlorodibenzo (p)dioxin (2,3,7,8-TCDD) are persistent and often very toxic. Pesticides vary greatly in structure, composition, environmental persistence and toxicity to non-target organisms. Includes: insecticides, herbicides, rodenticides and fungicides. Pharmaceuticals and Personal Care Products originate from veterinary and human applications compiling a variety of products including, over-the-counter medications, fungicides, chemotherapy drugs and animal therapeutics, such as growth hormones. Due to their biologically active nature, high levels of consumption, known combined effects, and their detection in most aquatic environments they have become an emerging concern. Ecological consequences include physiological changes (e.g. growth defects, carcinomas).	Compliance with all AA EQS, conformance with PELs, EACs, ER-Ls

Appendix 3 – Biotope descriptions (EUNIS)

A2.212 – *Mytilus edulis* and *Fabricia sabella* in littoral mixed sediment

Pebbles, gravel, sand and shell debris with mud in sheltered Firths with a strandline of fucoid algae. The fauna is characterised by juvenile mussels *Mytilus edulis*, often in very high numbers. The nemertean worm *Lineus* spp. may be abundant and oligochaetes are common. Polychaetes such as *Pygospio elegans*, *Scoloplos armiger* and *Fabricia sabella* may be present in high densities. *Fabricia sabella* is typically found amongst algal holdfasts and between cobbles on rocky shores. The bivalves *Macoma balthica* and *Cerastoderma edule*, typical of muddy sediments, characterise the community. The validity of this biotope is uncertain, as the only available data, from the Dornoch Firth and the Moray Firth, are poor. Its position within the classification, as a strandline community, is also very uncertain, but there is not enough information available for a better description or classification at this stage. Situation: occurs on sheltered shores of the Dornoch Firth and Moray Firth.

A2.721 – *Mytilus edulis* beds on littoral sediments

Dense aggregations of *Mytilus edulis* on the mid and lower shore, on mixed substrata (mainly cobbles and pebbles on fine sediments), on sand, or on sheltered muddy shores. In high densities the mussels bind the substratum and provide a habitat for many infaunal and epifaunal species. The wrack *Fucus vesiculosus* is often found attached to either the mussels or cobbles and it can be abundant. The mussels are often encrusted with the barnacles *Semibalanus balanoides*, *Elminius modestus* or *Balanus crenatus*. Where boulders are present they can support the limpet *Patella vulgata*. The winkles *Littorina littorea* and *L. saxatilis* and small individuals of the crab *Carcinus maenas* are common amongst the mussels, whilst areas of sediment may contain the lugworm *Arenicola marina*, the sand mason *Lanice conchilega*, the cockle *Cerastoderma edule*, and other infaunal species. The characterising species list shown below is based on data from epifaunal sampling only. Three sub-biotopes are recognised for this biotope, distinguished principally on the basis of the sediment type associated with the mussel beds. The three types of intertidal mussel beds may be part of a continuum on an axis that is most strongly influenced by the amount of pseudofaeces that accumulate amongst the mussels. The differences may not always be directly connected to the underlying substratum on which the mussel bed may have started a long time ago. It should be noted that there are few data available for the muddy (A2.7213) and sandy (A2.7212) subunits, therefore there are no characterising species lists or comparative tables for these two sub-biotopes. Situation: on more exposed, predominantly rocky shores this biotope can be found below a band of ephemeral green seaweeds (unit A2.821). On sheltered, predominantly rocky shores either a *F. vesiculosus* dominated biotope or a biotope dominated by the wrack *Ascophyllum nodosum* (A1.3132; A1.3142) can be found above or the barnacle dominated biotope (A1.1133). On mudflats and sandflats, this biotope may be found alongside *Cerastoderma edule* beds (A2.242) and other A2.2 and A2.3 biotopes. The intertidal A2.721 biotope can extend seamlessly into the subtidal. Temporal variation: the temporal stability of mussel beds can vary a lot. Some beds are permanent, maintained by recruitment of spat in amongst adults. Other beds are ephemeral, an example of which are beds occurring at South America Skear where large amounts of spat settle intermittently on a cobble basement. The mussels rapidly build up mud, and are unable to remain attached to the stable cobbles. They are then liable to be washed away during gales. A second example of ephemeral mussel dominated biotopes occurs when mussel spat ("mussel crumble") settles on the superficial shell of cockle beds, such as is known to occur in the Burry Inlet.

A2.7211 - Mussel beds on littoral mixed substrata

Mid and lower shore mixed substrata (mainly cobbles and pebbles on fine sediments) in a wide range of exposure conditions and with aggregations of the mussel *Mytilus edulis* colonising mainly the sediment between cobbles, though they can extend onto the cobbles themselves. The mussel aggregations can be very dense and support various age classes. In high densities the mussels bind the substratum and provide a habitat for many infaunal and epifaunal species. The wrack *Fucus vesiculosus* is often found attached to either the mussels or the cobbles and it can occur at high abundance. The mussels are also usually encrusted with the barnacles *Semibalanus balanoides*, *Elminius modestus* or *Chthamalus* spp., especially in areas of reduced salinity. The winkles *Littorina littorea* and *L. saxatilis* and small individuals of the crab *Carcinus maenas* are common amongst the mussels, whilst areas of sediment may contain the lugworm *Arenicola marina*, the sand mason *Lanice conchilega* and other infaunal species. Pools are often found within the mussel beds that support algae such as *Chondrus crispus*. Where boulders are present they can support the limpet *Patella vulgata*, the dog whelk *Nucella lapillus* and the anemone *Actinia equina*. *Ostrea edulis* may occur on the lowest part of the shore. There are few infaunal samples for this biotope; hence the characterizing species list below shows only epifauna. Where infaunal samples have been collected for this biotope, they contain a highly diverse range of species including nematodes, *Anaitides mucosa*, *Hediste diversicolor*, *Polydora* spp., *Pygospio elegans*, *Eteone longa*, oligochaetes such as *Tubificoides* spp., *Semibalanus balanoides*, a range of gammarid amphipods, *Corophium volutator*, *Jaera forsmani*, *Crangon crangon*, *Carcinus maenas*, *Hydrobia ulvae* and *Macoma balthica*. Situation: on more exposed, predominantly rocky shores this biotope can be found below a band of ephemeral green seaweeds (unit A2.821). On sheltered, predominantly rocky shores either a *F. vesiculosus* dominated biotope or a biotope dominated by the wrack *Ascophyllum nodosum* (units A1.3132; A1.3142) can be found above or the barnacle dominated biotope (A1.1133). This biotope is also found in lower shore tide-swept areas, such as in the tidal narrows of Scottish sea lochs. Temporal variation: under sheltered conditions, pseudofaeces may build up over time, creating a layer of mud and changing the biotope to unit A2.7213. Where the stability of the mussed bed depends on the mussels being attached to stable cobbles, a build-up of mud from pseudofaeces may prevent this attachment, making the mussel bed unstable and liable to be washed away during storms.

A2.7212 - Mussel beds on littoral sand

This sub-biotope occurs on mid to lower shore sand and muddy sand. Mussels *Mytilus edulis* grow attached to shell debris and live cockles *Cerastoderma edule*, forming patches of mussels on consolidated shell material, and often growing into extensive beds. The mussel valves are usually encrusted with barnacles such as *Elminius modestus* and *Semibalanus balanoides*, and the mussel bed provides a habitat for a range of species including *Littorina littorea*. The sediment infaunal community is usually rich and very similar to that of cockle beds (A2.242), including cockles *Cerastoderma edule*, the Baltic tellin *Macoma balthica*, and a range of burrowing crustaceans and polychaetes typical for A2.242. Further species may be present are the sand mason *Lanice conchilega*, the sand gaper *Mya arenaria*, the peppery furrow shell *Scrobicularia plana*, *Nephtys* spp., and the rag worm *Hediste diversicolor*. Scattered fronds of eelgrass *Zostera noltii* may occur. Situation: this biotope often occurs in large sandy estuaries, or on enclosed shores, alongside other sand and muddy sand biotopes, most notably unit A2.242. It is possible that Lanice beds (unit A2.245) occur lower down on the shore. Temporal variation: where this sub-biotope occurs in very sheltered conditions on muddy sand, it could change to A2.7213 over time as pseudofaeces build up forming a layer of mud. This cannot happen where wave action or tidal streams wash away pseudofaeces and prevent a build-up. In areas where mussel spat ("mussel crumble") settles on the surface shell layer of cockle beds, the mussel cover may be ephemeral, as is the case in the Burry Inlet (south Wales, UK).

A2.7213 - Mussel beds on littoral mud

Dense mussel beds found in sheltered conditions on mud. There is a build-up of pseudofaeces that results in a bed that is very soft to walk on, and sediment which is anoxic to the surface. Pools are often present in the mussel bed but they tend to contain few species. The sediment infauna is very poor as a result of anoxic conditions. The mussel valves are usually clean, without epifaunal growth. Where this biotope occurs naturally, all age classes are found within the mussel bed. This biotope also includes commercially laid mussel beds on soft sediments, which tend to be of uniform age structure. The species diversity of this sub-biotope is a lot lower than that of the other A2.721 sub-units. Situation: occurs on sheltered mudflats, or areas that were previously rocky or cobble fields, but where pseudofaeces have accumulated, leading to the presence of a thick layer of mud. Temporal variation: mussels may settle on areas of cobble or mixed sediment (unit A2.7211), and lead to the build-up of a thick layer of pseudofaeces, changing the biotope to unit A2.7213 over time. The layer of mud can prevent the attachment of mussels to the underlying stable substratum, thus making the mussel bed liable to be washed away during storms. This is known to occur in areas of Morecambe Bay, northern England.

A3.361 - Mussel beds on reduced salinity infralittoral rock

This biotope occurs in shallow, often tide-swept, reduced salinity conditions. Dense beds of the mussel *Mytilus edulis* with the occasional barnacle *Balanus crenatus*. A wide variety of epifaunal colonisers on the mussel valves, including seaweeds, hydroids and bryozoans can be present. Predatory starfish *Asterias rubens* can be very common in this biotope. This biotope generally appears to lack large kelp plants, although transitional examples containing mussels and kelps plants may also occur. More information needed to validate this description. Situation: occurs in tide-swept entrance channels in very enclosed basins of sealochs where the basins are typically of lowered salinity. Also occurs in very sheltered subtidal rock (often vertical) in lagoons.

A5.625 – *Mytilus edulis* bed on sublittoral sediment

Shallow sublittoral mixed sediment, in fully marine coastal habitats or sometimes in variable salinity conditions in the outer regions of estuaries, are characterised by beds of the common mussel *Mytilus edulis*. Other characterizing infaunal species may include the amphipod *Gammarus salinus* and oligochaetes of the genus *Tubificoides*. The polychaetes *Harmothoe* spp., *Kefersteinia cirrata* and *Heteromastus filiformis* are also important. Epifaunal species in addition to the *M. edulis* include the whelks *Nucella lapillus* and *Buccinum undatum*, the common starfish *Asterias rubens* the spider crab *Maja squinado* and the anemone *Urticina felina*. Relatively few records are available for this biotope and it is possible that as more data is accumulated separate estuarine and fully marine sub-biotopes may be described. Further clarification may also be required with regard to the overlap between littoral and sublittoral mussel beds and with regard to mussel beds biotopes on hard substratum.

Appendix 4 - Sensitivity assessments, assumptions and limitations

The assumptions inherent in, and limitations in application of, the sensitivity assessment methodology (Tillin *et al* 2010) as modified in this report, are outlined below.

Key points

Sensitivity assessments need to be applied carefully by trained marine biologists, for the following reasons.

- The sensitivity assessments are generic and NOT site specific. They are based on the likely effects of a pressure on a 'hypothetical' population in the middle of its 'environmental range'[8];

- Sensitivity assessments are NOT absolute values but are relative to the magnitude, extent, duration and frequency of the pressure effecting the species or community and habitat in question; thus the assessment scores are very dependent on the pressure benchmark levels used;

- The assessments are based on the magnitude and duration of pressures (where specified) but do not take account of spatial or temporal scale;

- The significance of impacts arising from pressures also needs to take account of the scale of the features;

- The sensitivity assessment methodology takes account of both resistance and resilience (recovery). Recovery pre-supposes that the pressure has been alleviated but this will generally only be the case where management measures are implemented; and

- There are limitations of the scientific evidence on the biology of features and their responses to environmental pressures on which the sensitivity assessments have been based.

Generic Nature of Assessments

Detailed assessment of environmental impacts is very dependent on the specific local character of the receiving environment and associated environmental features. Generalisation of impact assessments inevitably leads to an assessment of the average condition. This may over- or under-estimate impact risks.

Sensitivity of assessment scores to changes in pressure levels

Sensitivity assessments are not 'absolute' values but 'relative' to the level of the pressure. Assessment of sensitivity is very dependent on the benchmark level of pressure used in the assessment. The benchmarks were designed to represent a likely level of pressure, in relation to the likely range of activities that could cause the pressure. The benchmark provides a 'standard' level of pressure (and hence potential effect) against which the range of species and habitats can then be assessed. The benchmarks are intended to be pragmatic guidance values for sensitivity assessment, to allow comparison of sensitivities between

[8]Where 'environmental range' indicates the range of 'conditions' in which the species or community occurs and includes habitat preferences, physic-chemical preferences and, hence, geographic range.

species and habitats, and to allow comparison with the predicted effects of project proposals. In this way, those species or habitats that are most sensitive to a pressure or range of pressures can be identified.

In translating from the sensitivity assessments present to assessments at a site level, it is thus important that there is a good understanding of the level of actual pressure caused by an activity at a local level. If the pressure level is significantly different from the benchmark, the sensitivity score should be re-evaluated.

Spatial and temporal scale of pressures

The sensitivity assessments provided relate to the magnitude of a pressure and its proposed duration (where stated in the benchmark). Thus in seeking to make use of the assessments at site level, it is also important to obtain further information on both the frequency and spatial extent of a pressure before discussing possible requirements for management measures. For example, deployment of a ship's anchor could cause damage through penetration of the sea-bed. However, the spatial extent of such damage may be very small and, on its own, of no particular consequence. Although, if multiple anchoring events were occurring on a daily basis, the cumulative effect of such damage could be more significant.

Scale of features relative to scale of pressures

In considering possible requirements for management advice or measures, it is also necessary to consider the scale of a pressure in relation to the scale of the features of conservation interest that it might affect. Thus, for example, the change in substratum type caused by the placement of scour protection around an offshore structure on a large subtidal sandbank feature may be of little consequence. However, should such scour protection be placed on a more spatially limited seagrass bed, this could result in the loss of a large proportion of the feature.

Assumptions about recovery

The sensitivity assessment methodology takes account of both resistance and resilience (recovery). Recovery is assumed to have occurred if a species population and/or habitat returns to a state that existed prior to the impact of a given pressure, not to some hypothetical pristine condition. Furthermore, we have assumed recovery to a 'recognisable' habitat or similar population of species, rather than presume recovery of all species in the community and/or total recovery to prior biodiversity.

Recovery pre-supposes that the pressure has been alleviated but this will often only be the case where management measures are implemented. For certain resistance-resilience combinations, it may be possible to obtain a 'low' sensitivity score even where resistance is 'medium' or 'low', simply because of assumed 'high' recovery. The headline sensitivity assessment score might suggest that there was less need for management measures.

However, in the absence of such measures the impacts could be significant and preclude achievement of conservation objectives. Therefore in considering the possible requirement for management measures users of the matrix should consider both the sensitivity assessment score and the separate resistance and recoverability scores. As a general rule, where resistance is 'low', the need for management measures should be considered, irrespective of the overall sensitivity assessment.

Limitations of scientific evidence

The sensitivity assessment process chosen provides a systematic approach for the collation of existing evidence to assess resistance, recovery and hence sensitivity to a range of pressures. Expert judgement is often required because the evidence base itself is incomplete both in relation to the biology of the features and understanding of the effects of human pressures.

Biology of species and habitat features

In the marine environment, there is a relatively good understanding of the physical processes that structure sedimentary and rocky habitats but understand biological processes less well. For example, sediment type in strongly correlated with water flow and wave energy and changes in hydrology will influence the sediment and hence the communities it is capable of supporting. In contrast, biological processes can be highly variable between sites and within assemblages, so that responses to impacts can be unpredictable.

In particular, there is a lack of basic biological knowledge about many of the species of conservation concern, or important species that make up habitats of conservation concern. For example, the life history (e.g. larval ecology) of species such as *Eunicella verrucosa*, *Atrina pectinata* and *Leptopsammia pruvoti*, and hence their recruitment and potential recovery rates, are poorly known. Even where life histories are well known and recovery rates might be expected to be good (due to highly dispersive and numerous larvae), other factors influence their recovery. For example, native oyster and horse mussel have not recovered from past losses due to a multitude of factors including poor effective recruitment, high juvenile mortality, continued impact, or loss of (or competition for) habitat.

Deep sea species and habitats have generally been less well studied than those in coastal areas and information both on their biology and their response to human pressures is limited. The assessments for these features therefore relied heavily on the expert judgment of deep-sea biologists.

Understanding the Effects of Pressures

There are significant limitations in understanding of the effects associated with some of the pressures. For example, there is a paucity of research concerning the effects of underwater noise or particle on marine invertebrates. While it is generally believed that invertebrates are relatively insensitive to these pressures, compared to other marine receptors such as marine mammals and fish, the evidence base for this is poor (Tasker *et al* 2010).

Galgani *et al* (2010) recently reviewed information on the prevalence of litter in the marine environment. This identified a lack of good quantitative data and an absence of studies concerning the effects of litter on marine invertebrates.

Potential effects from electromagnetic fields have been identified for a range of invertebrate species (ICES 2003; Gill 2005; OSPAR 2008). OSPAR (2008) states that ‘In regard to effects on fauna it can be concluded that there is no doubt that electromagnetic fields are detected by a number of species and that many of these species respond to them. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds. The significance of the response reactions on both individual and population level is uncertain if not unknown.’

There is very limited information on the effects of the introduction of light on marine invertebrates. Tasker *et al* (2010) did not consider this pressure when developing indicators relating to the introduction of energy for the purposes of the Marine Strategy Framework

Directive 'due partly to their relatively localised effects, partly to a lack of knowledge and partly to lack of time to cover these issues'.

Use of confidence scores

Notwithstanding the limitations of the evidence base, there is a large volume of general evidence to call on against which to make judgements on the most likely effects of pressures on species and habitats based on past experience; especially with respect to fishing, industrial effluents and accidents (e.g. oil spills). Most lacking are specific studies that look at the specific impacts of a given activity (or pressure) on a large number of species and habitats. While, such studies are available for the effects of fishing and pollutants, the effects of many pressures have to be inferred from the available evidence base, in the knowledge that the evidence base will continue to grow.

The sensitivity assessments are accompanied by confidence assessments which take account of the relative scientific certainty of the assessments on a scale of high, medium and low. In the revised methodology adopted here, confidence examines distinguishes between the quality of the evidence (peer review vs. grey literature), and its applicability to the assessment in question, and the degree of concordance (agreement) between studies in the magnitude and direction of the effect. The level of confidence should be taken into account in considering the possible requirements for management measures.

In line with the precautionary principle, a lack of scientific certainty should not, on its own, be a sufficient reason for not implementing management measures or other action.

Limitations – general

It follows from the above, that the sensitivity assessments presented are general assessments that indicate the likely effects of a given pressure (likely to arise from one or more activities) on species or habitats of conservation concern. They need to be interpreted within each region against the range of activities that occur within that region and the habitats and species present within its waters.

In particular, interpretation of any specific pressure should pay careful attention to:

- the benchmarks used;
- the resistance, resilience and sensitivity assessments listed;
- the evidence provided to support each assessment; and
- the confidence attributed to that assessment based on the evidence.

It is important to note that benchmarks are used as part of the assessment process. While they are indicative of levels of pressure associated with certain activities they are not deterministic, i.e. if an activity results in a pressure lower than that used in the benchmark this does not mean that it will have no impact. A separate assessment will be required.

Similarly, all assessments are made based 'on the level of the benchmark'. Therefore, a score of '**not sensitive' does not mean that no impact is possible** from a particular 'pressure vs. feature' combination, only that a limited impact was judged to be likely at the specified level of the benchmark. It is particularly true of the pollution (contaminant) benchmark, which are set to Water Framework Directive compliant levels so that all features are 'not sensitive' by definition. However, this does not mean that feature are 'not sensitive' to accidental spills, localised discharges or other pollution incidents.

A further limitation of the methodology is that it is only able to assess single pressures and does not consider the cumulative risks associated with multiple pressures of the same type (e.g. anchoring and beam trawling in the same area which both caused abrasion) or different types of pressure at a single location (e.g. the combined effects of siltation, abrasion, synthetic and non-synthetic substance contamination and underwater noise). When considering multiple pressures of the same or different types at a given location, a judgment will need to be made on the extent to which those pressures might act synergistically, independently or antagonistically.

It should also be noted that the evidence provided, and the nature of the species and habitat features may need interpretation by experienced marine biologists. Agencies, managers and projects should, therefore, turn to the marine biologists (preferably from different disciplines) within their teams for advice on interpretation or seek to engage scientists within stakeholder groups.