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Assessing the sensitivity of seagrass bed biotopes to pressures associated with marine activities

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Summary

This project was commissioned to generate an improved understanding of the sensitivities of seagrass habitats to pressures associated with human activities in the marine environment - to provide an evidence base to facilitate and support management advice for Marine Protected Areas; development of UK marine monitoring and assessment, and conservation advice to offshore marine industries.

Seagrass bed habitats are identified as a Priority Marine Feature (PMF) under the Marine (Scotland) Act 2010, they are also included on the OSPAR list of threatened and declining species and habitats, and are a Habitat of Principle Importance (HPI) under the Natural Environment and Rural Communities (NERC) Act 2006, in England and Wales.

The purpose of this project was to produce sensitivity assessments with supporting evidence for the HPI, OSPAR and PMF seagrass/*Zostera* bed habitat definitions, clearly documenting the evidence behind the assessments and any differences between assessments.

Nineteen pressures, falling in five categories - biological, hydrological, physical damage, physical loss, and pollution and other chemical changes - were assessed in this report. Assessments were based on the three British seagrasses *Zostera marina, Z. noltei* and *Ruppia maritima*. *Z. marina* var. *angustifolia* was considered to be a subspecies of *Z. marina* but it was specified where studies had considered it as a species in its own rights. Where possible other components of the community were investigated but the basis of the assessment focused on seagrass species.

To develop each sensitivity assessment, the resistance and resilience of the key elements were assessed against the pressure benchmark using the available evidence. The benchmarks were designed to provide a 'standard' level of pressure against which to assess sensitivity. Overall, seagrass beds were highly sensitive to a number of human activities:

- penetration or disturbance of the substratum below the surface;
- habitat structure changes – removal of substratum;
- physical change to another sediment type;
- physical loss of habitat;
- siltation rate changes including and smothering; and
- changes in suspended solids.

High sensitivity was recorded for pressures which directly impacted the factors that limit seagrass growth and health such as light availability. Physical pressures that caused mechanical modification of the sediment, and hence damage to roots and leaves, also resulted in high sensitivity.

Seagrass beds were assessed as 'not sensitive' to microbial pathogens or 'removal of target species'. These assessments were based on the benchmarks used. *Z. marina* is known to be sensitive to *Labyrinthula zosterae* but this was not included in the benchmark used. Similarly, 'removal of target species' addresses only the biological effects of removal and not the physical effects of the process used. For example, seagrass beds are probably not sensitive to the removal of scallops found within the bed but are highly sensitive to the effects of dredging for scallops, as assessed under the pressure penetration or disturbance of the substratum below the surface'. This is also an example of a synergistic effect

between pressures. Where possible, synergistic effects were highlighted but synergistic and cumulative effects are outside the scope off this study.

The report found that no distinct differences in sensitivity exist between the HPI, PMF and OSPAR definitions. Individual biotopes do however have different sensitivities to pressures. These differences were determined by the species affected, the position of the habitat on the shore and the sediment type. For instance evidence showed that beds growing in soft and muddy sand were more vulnerable to physical damage than beds on harder, more compact substratum. Temporal effects can also influence the sensitivity of seagrass beds. On a seasonal time frame, physical damage to roots and leaves occurring in the reproductive season (summer months) will have a greater impact than damage in winter. On a daily basis, the tidal regime could accentuate or attenuate the effects of pressures depending on high and low tide. A variety of factors must therefore be taken into account in order to assess the sensitivity of a particular seagrass habitat at any location.

No clear difference in resilience was established across the three seagrass definitions assessed in this report. The resilience of seagrass beds and the ability to recover from human induced pressures is a combination of the environmental conditions of the site, growth rates of the seagrass, the frequency and the intensity of the disturbance. This highlights the importance of considering the species affected as well as the ecology of the seagrass bed, the environmental conditions and the types and nature of activities giving rise to the pressure and the effects of that pressure. For example, pressures that result in sediment modification (e.g. pitting or erosion), sediment change or removal, prolong recovery. Therefore, the resilience of each biotope and habitat definitions is discussed for each pressure.

Using a clearly documented, evidence based approach to create sensitivity assessments allows the assessment 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. 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 seagrass habitats may 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

The Joint Nature Conservation Committee (JNCC) commissioned this project to generate an improved understanding of the sensitivities of seagrass habitats (defined in three different pieces of European and national nature conservation legislation) 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.

Seagrass bed habitats are identified as a Priority Marine Feature (PMF) under the Marine (Scotland) Act 2010, they are also included on the OSPAR list of threatened and declining species and habitats, and are a Habitat of Principle Importance (HPI) under the Natural Environment and Rural Communities (NERC) Act 2006, in England and Wales.

The purpose of this project was to produce sensitivity assessments with supporting evidence for the HPI, OSPAR and PMF seagrass/*Zostera* bed habitat definitions, clearly documenting the evidence behind the assessments and any differences between assessments.

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 1.1). 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 1.1. 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 and 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, 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 detailed definitions used in this study are given on 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

[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.

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) 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 characterizing 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 attached ‘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. sub-surface abrasion or damage), 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 seagrass 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.

All literature collated was managed through the referencing software EndNote. 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 habitats and associated species assemblages;
- Likely rates of recovery based on the habitat and the characteristic species present within the habitats.

3 Description of seagrass bed habitats

This section briefly describes the habitat and relevant definitions, characteristic species and ecology of seagrass beds. Pressures arising from human activities that impact these habitats and the relevant impact pathways are outlined. This section also summarises key recovery information for these habitats and other relevant features e.g. habitat substratum and any important characterising species.

3.1 Definition and characteristics of feature – including characteristic species

Seagrasses are aquatic angiosperms (flowering plants), adapted to submerged, saline environments. Seagrasses are found in the intertidal as well as in the subtidal where they form extensive beds or meadows. Out of 55 seagrass species worldwide (Green and Short 2003), three are found in the UK: the eelgrass *Zostera marina*, the narrow leaved eelgrass *Zostera angustifolia* and the dwarf eelgrass *Zostera noltei*.

The HPI and PMF definitions also include *Ruppia maritima*, which is not a true seagrass. Although often found with seagrasses, *R. maritima*, also known as wigeon grass or tassel pondweed, is not a true marine plant but considered a freshwater species with a pronounced salinity tolerance (Zieman 1982). The characteristics and basic habitat preferences of each species are described below. The seagrass biotopes and their respective definitions assessed in this report are given in Table 3.1.

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

EUNIS Code	Biotope	HPI	OSPAR	PMF
A2.61	Seagrass beds on littoral sediments	X		
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	X	X	
A2.6111	*Z. noltei* beds in littoral muddy sand	X	X	X
A2.612	Macaronesian *Z. noltei* meadows		X	
A2.614	*R. maritima* on lower shore sediment	X		
A5.53	Sublittoral seagrass beds	X		
A5.533	*Zostera* beds in full salinity infralittoral sediments	X	X	
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	X	X	X
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	X		X
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	X	X	

Z. marina is a subtidal species, growing in depths of up to 10m depending on water clarity. The plant has dark green, narrow blade-like leaves. The leaf width varies between 2cm for young individuals and up to 10cm for mature plants. The leaves grow between 30 and 60cm in length but can in some cases reach 1.5m. Morphological differences may vary with environmental conditions (Phillips & Menez 1988). *Z. marina* can be a perennial or annual species showing seasonal changes in particular in leaf growth. Indeed the long summer leaves are replaced by shorter, slower growing ones during the winter months. The seagrass is found on soft sediments such as sand, mud or a mixture of sand, gravel and mud in sheltered environments such as bays, estuaries, shallow inlets and saline lagoons.

There is a current debate whether *Z. angustifolia* is a distinct species or a species closely related to *Z. marina*. Although *Z. angustifolia* is an accepted species on the World Register of Marine Species, the current consensus is that *Z. angustifolia* is not a separate species but a variant of *Z. marina* (Jim Provan pers. comm.). The differences in terms of morphology and life history are likely to be adaptations to different habitats. Van Lent and Verschuure (1994) suggest that there is a continuum of life history strategies exhibited by *Z. marina* for survival in a wider range of environments. Compared to *Z. marina*, var. *Z. angustifolia* is found predominantly in the intertidal zone and displays a wider salinity tolerance. The plant has narrower leaves than that of *Z. marina* and its annual life history strategy focuses on reproducing less by vegetative means in favour of seed production. The variety is also distinct in that it survived the wasting disease which destroyed *Z. marina* populations in the 1930s (Rasmussen 1977).

Z. noltei is the smallest of British seagrasses. *Z. noltei* has between 2 and 5 non-flowering leaves which grow 10 to 25cm long and 0.5 to 2mm wide. The species occurs in the intertidal region on mud and sand mixtures of varying consistency but can also be found subtidally. However, where water cover is permanent, *Z. noltei* is often outcompeted by *Z. marina* (Borum *et al* 2004).

R. maritima is found in marine as well as brackish and fresh water environments with a typical depth range between 0 to 4.5m*.* *R. maritima* is found in sheltered areas with low flow such as estuaries, tidal rivers, aquaculture ponds, and lagoons. Even though *R. maritima* tolerates hyposaline as well as hypersaline conditions (Kantrud 1991), repeated salinity fluctuations may be limit its growth and distribution (La Peyre & Rowe 2003). *R. maritima* is both an annual and a perennial species, experiencing discontinued growth in unfavourable habitats beyond its physiological limits (i.e. prolonged desiccation, major changes in salinity) and year-long growth in deeper, more stable environments (Richardson 1980; Bigley & Harrison 1986). Due to the variety of environments in which it is found, *R. maritima* can be highly polymorphic. However in general, the plant has thin, thread-like leaves, less than 1mm wide and up to 20cm long.

All three British *Zostera* species are found on sedimentary substrata, in sheltered or extremely sheltered locations with slow current velocity. Excessive sedimentation can be harmful as it smothers plants and turbid water also inhibits growth by reducing the amount of light available for photosynthesis.

For the seagrass biotopes, *Z. marina, Z. noltei* and *R. maritima* are the keystone species creating this habitat. No obligate relationships between the key feature and other species have been identified. Where relevant, effects on other components of the community were also reported, however sensitivity assessments were be based on the characteristic species of the assessed feature.

3.2 Ecological function and conservation

Seagrass beds are productive and diverse ecosystems. They provide a range of environmental services and contribute to the primary productivity of oceans via photosynthesis. Seagrass beds can improve water clarity by trapping re-suspended sediments and are their extensive root systems act as bottom stabilisers reducing the risk of coastal erosion. Roots and leaves provide important food for wildfowl, such as brent geese, and nutrients to support animal communities on the seabed. Seagrass beds also provide fish nurseries for economically important species such as plaice, pollock, herring, cod and whiting (Bertelli & Unsworth 2013 (in press)) and constitute permanent habitats for species of principle importance for conservation such as stalked jellyfish and seahorses (Hiscock *et al* 2005). Seagrass beds thus constitute an important reservoir of coastal biodiversity and are considered of considerable economic and conservation importance.

3.3 Resilience (recovery rates) of seagrass bed biotopes

Although seagrass species are fast-growing and relatively short-lived, they can take a considerable time to recover from damaging events, if recovery does occur at all. Every seagrass population will have a different response to pressures depending on the magnitude or duration of exposure pressure as well as the nature of the receiving environment. In general terms, the resilience of seagrass biotopes to external pressures is low, as shown by the very slow or lack of recovery after the epidemic of the wasting disease in the 1930s (see pressure 4.2.2, 'microbial pathogens' for more information).

Seagrass recolonisation of a disturbed area can occur through sexual (seed supply) and asexual (vegetative growth from adjacent rhizomes), although the latter is more common, particularly for *Z. marina*. Boese *et al* (2009) found that natural seedling production was not of significance in the recovery of seagrass beds but that recovery was due exclusively to rhizome growth from adjacent perennial beds.

Genetic diversity also influences the resilience of seagrasses in particular when pressure persists over a long period of time. The genetic diversity of *Zostera* population is very high, particularly in the North East Atlantic (Olsen *et al* 2004). Rice and Emery (2003) showed that evolutionary change in seagrasses can occur within a few generations, suggesting that genetically diverse population would be more resilient to changes in environmental conditions compared to genetically conserved populations. Pressures causing a rapid change in seagrass environments will have a greater impact as the natural ability of the plants to adapt is compromised.

Maxwell *et al* (2014) investigated the response of seagrass ecosystems to severe weather events (i.e. flooding) in order to understand the process that promotes acclimation. The study found that phenotypic plasticity plays an important role in withstanding external pressures. The phenotypic plasticity comprises of changes in physiological and morphological characteristics which enables species to cope with varying degrees of stress to avoid mortality. Phenotypic plasticity can thus increase the length of time seagrass can persist in unfavourable environments such as reduced light availability. Plasticity is therefore a key element in the resilience of seagrass biotopes.

Different populations will thus have different resilience to external pressures. Boese *et al* (2009) examined the recolonisation of gaps created experimentally within *Z. marina* beds. The study looked at two zones, the lower intertidal covered with almost continuous seagrass and an upper intertidal transition zone where there were patches of perennial and annual *Z. marina*. Recovery started within a month after disturbance in the lower intertidal continuous perennial beds and was complete after two years. Plots in the transition zone, however, took almost twice as long to recover.

Both *Zostera* and *Ruppia* are monomorphic, restricted to horizontal growth of roots and, hence, unable to grow rhizomes vertically. This restriction to horizontal elongation of the roots makes the recolonisation of adjacent bare patches difficult and explains why large beds are only found in gently sloping locations. A depression of the seabed caused by disturbance of the sediment can thus restrict the expansion of the bed. The size and shape of impacted areas will also have a considerable effect on resilience rates (Creed *et al* 1999). Larger denuded areas are likely to take longer to recover than smaller scars. For example, seagrass beds are likely to be more resilient to physical damage resulting from narrow furrows left after anchoring because of large edge to area ration and related availability of plants for recolonisation.

Changes in biological communities after seagrass disappear might also impact seagrass resilience. A rise in the abundance of sea urchin for instance could prevent the recovery of seagrass beds due to increased herbivory (Valentine & Heck Jr 1991). Similarly, colonisation by *Arenicola marina* at high abundance before *Zostera noltei* are able to recolonise may inhibit recolonisation by the seagrass (Philippart 1994).

The removal of seagrass plants can induce a negative feedback loop inhibiting recovery. Indeed the removal of plants can cause chronic turbidity due to continual resuspension of unconsolidated sediments. When water quality conditions do not return to their original state, recovery of seagrass beds may not occur at all (Giesen *et al* 1990).

Seagrass species comprise an important winter food for wildfowl. Tubbs and Tubbs (1983) reported that wildfowl were responsible for a reduction of 60 to 100% of *Z. marina* and *Z. noltei* biomass from mid-October to mid-January. The removal of plants by wildfowl is part of the natural seasonal fluctuation in seagrass cover. Similarly Nacken and Reise (2000) found that intertidal *Z. noltii* bed biomass was reduced by 63% due to wildfowl feeding. Beds, however, recovered by the following year and the authors suggested that this disturbance was necessary for the persistence of intertidal populations. The recovery of intertidal seagrass beds after natural disturbance events provides a good indication on recovery rates following anthropogenic damage.

3.3.1 Resilience (recovery) assessment

To assess resilience of seagrass bed biotopes, this report looked at the time to achieve full recovery. Full recovery is defined as the return to the state of the habitat that existed prior to impact. This does not necessarily mean that every component species has 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.

The resilience of seagrass beds and the ability to recover from human induced pressures is a combination of the environmental conditions of the site, growth rates of the seagrass, the frequency (repeated disturbances versus a one off event) and the intensity of the disturbance. This highlights the importance of considering the species affected as well as the ecology of the seagrass bed, the environmental conditions and the types and nature of activities giving rise to the pressure.

No clear difference in resilience was established across the three seagrass definitions assessed in this report. The resilience of each biotope and habitat definitions is discussed for each pressure in section 4 below.

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 2013).

4.1 Summary of pressures reported to affect seagrass bed habitats

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 & translocation of indigenous species
	Introduction of microbial pathogen
	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
	Salinity changes - local
	Temperature changes - local
	Water flow (tidal current) changes - local, including sediment transport considerations
	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 land and freshwater habitat)
Pollution and other chemical changes.	Nutrient enrichment
	Organic enrichment

Table 4.2. Non-assessed pressures.

Pressure Theme	ICG-C Pressure	Reason for exclusion
Biological pressures	Visual disturbance	Seagrass species do not have visual perception
Other physical pressures	Barrier to species movement[2]	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	Seagrass species are unable to sense electromagnetic field
	Introduction of light	Seagrass species do not have visual perception
	Litter	No benchmark proposed
	Underwater noise changes	Seagrass species do not have 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 Excel ‘proforma’ spreadsheet provided with the report.

4.2 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

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

web, or removal of species on which the feature depends. Physical and chemical impacts are addressed in later sections.

4.2.1 Genetic modification & 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). 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, 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 stock derives'.

Evidence description
Translocation of seagrass seeds, rhizomes and seedlings is a common practice globally to counter the decline in seagrass beds. However, Williams and Davis (1996) found that levels of genetic diversity of restored eelgrass *Z. marina* beds in Baja California, USA, were significantly lower than in natural populations. A subsequent study by Williams (2001) determined that the observed genetic bottleneck was a consequence of the collection protocol of source material (i.e. founder effect). Founder effects are likely to occur if seeds used to revegetate restoration sites are collected from a limited number of sources. Similar to episodes of colonisation, the 'founding' propagules can represent only a portion of the genetic diversity present in the source populations, and they might hybridise with local genotypes (Hufford & Mazer 2003). The loss of genetic variation can lead to lower rates of seed germination and fewer reproductive shoots, suggesting that there might be long-term detrimental effects for population fitness. Williams (2001) affirms that genetic variation is essential in determining the potential of seagrass to rapidly adapt to a changing environment. Transplanted populations are therefore more sensitive to external stressors such as eutrophication and habitat fragmentation, with a markedly reduced community resilience, than natural populations (Hughes & Stachowicz 2004).

Even though restoration efforts tend to focus on *Z. marina*, transplantation of Z*. marina var. angustifolia* (Ranwell *et al* 1974), *Z. noltei* (Martins *et al* 2005) and *R. maritima* (Bird *et al* 1994; Hammerstrom *et al* 1998) have also been undertaken. Similar reductions in genetic diversity are expected, making the transplanted populations particularly sensitive to external stressors.

Translocation also has the potential to transport pathogens to uninfected areas (see 4.2.2 introduction of microbial pathogens). The sensitivity of the 'donor' population to harvesting to supply stock for translocation is assessed below for the pressure 'removal of target species'.

Sensitivity assessment

No evidence was found for the impacts of translocated beds on adjacent natural seagrass beds. However, it has been suggested that translocation of plants and propagules may lead to hybridisation with local wild populations. If this leads to loss of genetic variation there may be long-term effects on the potential to adapt to changing environments and other stressors. This impact is considered to apply to all seagrass biotopes equally, as the main habitat forming species (*Z. marina, Z. noltei* and *R. maritima*) can be translocated.

Presently, there is no evidence of a loss of habitat due to genetic modification and translocation of seagrass species, **resistance** to this pressure is thus considered to be **'High'.** However, if hybridisation occurred, recovery would not be considered possible unless the population is eradicated and replaced**. Resilience** is thus deemed **'Very Low'.** The **sensitivity** of all seagrass biotopes to this pressure is therefore considered to be **'Low'**.

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 'Low' - based on expert judgement.
Applicability is 'Not assessed' - based on expert judgement.
Concordance is 'Not assessed' - based on expert judgement.

4.2.2 Introduction of microbial pathogen

ICG-C pressure description
Untreated or insufficiently treated effluent discharges & run-off from terrestrial sources & vessels. It may also be a consequence of ballast water releases. In mussel or shellfisheries where seed stocks are 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* and *Martelia refringens* to an area where they are currently not present.

Evidence description
The microbial pathogens identified in the benchmark are parasites affecting shellfish and are thus not a direct threat to seagrass species. Potential indirect effects could however occur as bivalves are often associated with seagrass bed. Indeed bivalves have been shown to significantly contribute to the clearance of the water column which subsequently increases light penetration, facilitating the growth and reproduction of *Zostera* species (Wall *et al* 2008). Newell and Koch (2004) using modelling, predicted that when sediments were resuspended, the presence of even low numbers of oysters (25g dry tissue weight m^2) distributed uniformly throughout the domain, reduced suspended sediment concentrations by nearly an order of magnitude. A healthy population of suspension-feeding bivalves thus improves habitat quality and promotes seagrass productivity by mitigating the effects of increased water turbidity in degraded, light-limited habitats (see section 4.4.3, changes in suspended solids). Bivalves also contribute pseudofaeces to fertilise seagrass sediments (Bradley & Heck Jr 1999). A reduction of bivalves caused by the microbial pathogens *Bonamia* or *Martelia* could thus indirectly affect the health of seagrass beds.

Historic records show that seagrass species, in particular *Z. marina*, are highly susceptible to microbial pathogens. During the 1930s, a so-called 'wasting disease' decimated the eelgrass *Z. marina* in Europe and along the Atlantic Coast of North America with over 90% loss (Muehlstein 1989). Wasting disease resulted in black lesions on the leaf blades which potentially lead to loss of productivity, degradation of shoots and roots, eventually leading to the loss of large areas of seagrass (Den Hartog 1987). Wasting disease is caused by infection with a marine slime mould-like protist, called *Labyrinthula zosterae* (Short *et al*

1987; Muehlstein *et al* 1991). Recovery of seagrass beds after the epidemic has been extremely slow or more or less absent in some areas such as the Wadden Sea (van der Heide *et al* 2007). The disease continues to affect *Z. marina* in temperate regions with variable degrees of losses but not to the extent of an epidemic (Short *et al* 1988). The exact conditions responsible for an outbreak are still unknown but it has been shown that already weakened plants are more susceptible to infection (Tutin 1938; Rasmussen 1977) and that salinity plays a role the pathogen activity (Muehlstein *et al* 1988).

Z. noltei populations did not suffer to the same extent even though the disease also occurs in this species (Vergeer & Den Hartog 1991). *Z. marina var. angustifolia* on the other hand survived the wasting disease epidemic which decimated *Z. marina* populations (Rasmussen 1977). No evidence was found about the wasting disease affecting *R. maritima.* Wasting disease is not evaluated as it is not included in the pressure benchmark for assessment.

Sensitivity assessment

The microbial pathogens assessed at the pressure benchmark do not infect seagrass and therefore there is no direct impact from this pressure. **All seagrass biotopes** are therefore considered to be **'Not Sensitive'** to the pressure benchmark. However, indirect effects may occur through changes to water quality where large numbers of shellfish die through infection.

4.2.3. Introduction and 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
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.

Evidence description

Non-native invasive plants

Among the NIS currently present in the UK, the large brown seaweed *Sargassum muticum* has the most direct impact on *Zostera* species. Druehl (1973) was the first to raise concern about the potential negative effects of *S. muticum* on *Zostera* beds in British waters. *Zostera* and *S. muticum* were thought to be spatially separated due to their preferred habitat. *Zostera* species grow on sand and muddy bottoms, whereas *S. muticum* attaches to solid substratum. However, when the seabed consists of a mixed substratum of sand, gravel and stones both species may occur together. Even though there are no indications of direct competition between the two species (Den Hartog 1997), *S. muticum* establishes itself within seagrass habitats where beds are retreating due to natural or anthropogenic causes. The invasive seaweed almost immediately occupies the empty spaces thereby interfering with the natural regeneration cycle of the bed. In addition, a study in Salcombe, SW England by Tweedley *et al* (2008) demonstrated that the presence of *Z. marina* may help the attachment of *S. muticum* on soft substrata by trapping drifting fragments thereby allowing viable algae spores to settle on the seagrass matrix in an otherwise unfavourable environment. Once the invasive seaweed establishes itself, *Z. marina* is unable to regain the lost territory indicating that eventually *S. muticum* is able to replace seagrass beds particularly on mixed substratum (Den Hartog 1997). The literature does not specify any examples of *S. muticum* co-occurring with *R. maritima*.

The cord grass *Spartina anglica* is non-native grass, which was recorded to have negative effects on seagrass beds. This hybrid species of native (*Spartina alterniflora*) and an introduced cord grass species (*Spartina maritima*) colonises the upper part of mud flats, where due to its extensive root system, it effectively traps and retains sediments. *S. anglica* has rapidly colonised mudflats in England and Wales due to its fast growth rate and high fecundity. Deliberate planting to stabilise sediments accelerated its spread throughout Britain (Hubbard & Stebbings 1967). By consolidating the sediments the plant is responsible for raising mud flats as well as reducing sediment availability elsewhere. Butcher (1934) raised concerns that its pioneering consolidation may result in the removal of sediments from *Zostera* beds. Declines in *Z. noltei* due to encroachment of *S. anglica* were observed in Lindisfarne National Reserve in north-east England (Percival *et al* 1998). The reduction in *Z. noltei* beds had a direct impact on wildfowl populations as the food availability for the wildfowl was reduced on the top of the shore. This pressure will affect the upper limits of the intertidal rather than subtidal biotopes. *Z. noltei* and *R. maritima* are therefore more at risk than *Z. marina* plants.

The invasive green algae *Codium fragile* ssp*. tomentosoides*, now found throughout Britain has been reported to occur in habitats dominated by *Z. marina* (Garbary *et al* 1997). It was initially thought that *Zostera* out-competes *Codium* at high *Zostera* densities (Malinowski and Ramus 1973). But a study by Garbary *et al* (2004) in Canada found that the invasive algae has morphological adaptations that allow it to compete with *Zostera* even in healthy eelgrass beds. *C. fragile* ssp. *tomentosoides* have a wide salinity tolerance 12 to 40ppt and are thus a concern to biotopes in full as well as in reduced salinity. However, direct ecological impacts remain unknown and no quantitative evidence is available to assess resistance at the benchmarks used in this study.

Non-native invasive invertebrates

Benthic macroinvertebrates can have a significant impact on seagrass beds, by either influencing abundance through seed herbivory (Fishman & Orth 1996) or by influencing seed germination and seedling development by affecting vertical distribution of seeds. Some species have a positive effect by burying seeds to shallow depths and thereby reducing seed predation and facilitating seed germination whilst other species bury seeds too deep to allow germination. The invasive polychaete *Marenzelleria viridis*, a species naturally occurring on the east coast of North America but introduced to Europe via transport in ballast waters, was recorded to directly impact seed banks of *Z. marina* beds in its new territory (Delefosse & Kristensen 2012). The study carried out on the island of Fyn, Denmark, determined that the impact of *M. viridis* on seagrass beds depended on the abundance of worms within a bed. Negative effects were only observed at high abundances (1600 individual per m^2) causing seeds to be buried too deep to germinate. However, the study by Delefosse and Kristensen (2012) is the only publication on the impact of this particular invasive species on seagrass beds, and more evidence is needed in order to determine the ecological implications of this introduced polychaete in UK waters.

The invasive tunicate *Didemnum vexillum* has been reported growing on stalks and blades of *Z. marina* plants in New England, USA (Carman & Grunden 2010). The ecological effects of invasive tunicates introduced to seagrass beds remain unassessed, but in general terms, introduced epibionts have been shown to have negative effects on marine flora (Williams 2007). Their considerable weight combined with their rapid asexual and sexual reproduction and an absence of predators (Carman *et al* 2009) make them a considerable threat to marine plant communities as they increase the risk of smothering. The absence of predators could be related to anti-fouling microbial compounds present in *D. vexillum* (Tait *et al* 2007). Although the direct effect of invasive tunicates on seagrass remains unknown and no records of *D. vexillum* growing on *Zostera* plants in the UK exist yet, there are concerns about possible negative interactions. No quantitative evidence regarding the level of impact has been found to assess this pressure.

Other invasive species could affect seagrass beds via indirect pathways. For instance, the Atlantic oyster drill *Urosalpinx cinerea*, a small predatory sea snail is unlikely to have a direct effect on seagrass beds but by preying on mussels and other bivalves, the sea snail could be responsible for a drop in water clarity which in turn will affect *Zostera* species (see sections 4.4.3 changes in suspended solids). The invasive Pacific oyster *Crassostrea gigas* can also have negative effects. Oysters physically alter their environment by increasing habitat complexity and altering water flow, and causing sulphide to accumulate in the sediment. Sulphide is toxic to eelgrass and a decline in *Z. marina* as a consequences of invasive oyster growth was observed in British Columbia, Canada (Kelly & Volpe 2007). The authors did not state the level of effect quantitatively and therefore the level of impact in terms of the resistance benchmarks used in this study is not clear.

Invasive species are affecting seagrass habitats around the UK with invasive flora having the greatest impact on seagrass beds so far recorded. However, there are extensive knowledge gaps on how invasive species influence the health of *Zostera* and *Ruppia* beds in UK waters. More research is needed in order to fully comprehend this pressure.

Sensitivity assessment

The **sensitivity** score for each of the HPI, OSPAR and PMF seagrass / *Zostera* bed definitions was recorded as **'High'**, because at least one biotope within each definition was assessed as '**Low' resistance and 'Low' resilience** against one of the NIS mentioned above (Table 4.3). A more detailed breakdown of each biotope's sensitivity to each NIS can be found below in Table 4.4.Table 4.5 shows that all biotopes are exposed to one or several invasive species which can have detrimental effects on seagrass beds**.**

Table 4.3. Sensitivity score of individual biotopes within each habitat definition to the introduction or spread of non-indigenous species.

EUNIS Code	Biotope	HPI	OSPAR	PMF
A2.61	Seagrass beds on littoral sediments	High		
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	High	High	
A2.6111	*Z. noltei* beds in littoral muddy sand	High	High	High
A2.612	Macaronesian *Z. noltei* meadows		No evidence	
A2.614	*R. maritima* on lower shore sediment	High		
A5.53	Sublittoral seagrass beds	High		
A5.533	*Zostera* beds in full salinity infralittoral sediments	High	High	
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	High	High	High
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	Medium		Medium
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	High	High	

Resistance confidence

Quality of evidence is 'Medium' – 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 peer reviewed literature.
Applicability is 'Low' - based on proxies (natural events) and effects of other pressures.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

Effects include *S. muticum* which is able to replace *Zostera* beds. Seagrass beds have a **'Low' resistance** and **'Low' resilience** to *S. muticum* resulting in a **'High' sensitivity** score (no evidence was found for *R. maritima*). *S. anglica* is most damaging to upper littoral biotopes **('Low' resistance and 'Low' resilience leading to 'High' sensitivity)** but will not affect sublittoral habitats. *Codium fragile ssp. tomentosoides* have been found to directly compete with seagrass species, however ecological impacts remain unknown and no quantitative evidence is available to assess resistance at the benchmarks used in this study (Table 4.4)

Table 4.4. Sensitivity score of individual plant NIS for each biotope code (Not Sens = Not Sensitive)

EUNIS Code	Biotope	*S. muticum*	*S. anglica*
A2.61	Seagrass beds on littoral sediments	High	High
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	High	High
A2.6111	*Z. noltei* beds in littoral muddy sand	High	High
A2.614	*R. maritima* on lower shore sediment	No evidence	High
A5.53	Sublittoral seagrass beds	High	Not Sens
A5.533	*Zostera* beds in full salinity infralittoral sediments	High	Not Sens
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	High	Not Sens
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	No evidence	Not Sens
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	High	Not Sens

* The biotope A2.612 (Macaronesian *Z. noltei* meadows) was not assessed as no evidence was found on the presence of NIS in this particular area.

For invasive invertebrates, *M. viridis* has been shown to impact the seed bank of *Z. marina* beds. *Z. marina* recolonisation occurs most commonly via asexual reproduction (vegetative growth from adjacent rhizomes). Established beds are thus not likely to be impacted by this pressure. However, annual population of *Z. noltei* regrow from seed banks every year, resulting in a **'Medium' sensitivity**. The invasive polychaete might affect the reseeding of new beds, however this assessment focuses on already existing seagrass beds and therefore scores 'Not sensitive'. *D. vexillum* has not yet been recorded in association with seagrass beds in the UK but this NIS may pose a potential threat in terms of shading and leaf damage and so this assessment may require updating in the future as trends become clearer. *Urosalpinx cinerea* is unlikely to have a direct effect on seagrass beds. And finally, seagrass bed **resistance** to *C. gigas* is considered to be **'Low'** with a **'Medium' recovery** resulting in a **'Medium' sensitivity**.

Table 4.5. Sensitivity score of individual invertebrate NIS for each biotope code (Not Sens = Not Sensitive)

EUNIS Code	Biotope	*M. viridis*	*D. vexillum*	*U. cinerea*	*C. gigas*
A2.61	Seagrass beds on littoral sediments	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A2.6111	*Z. noltei* beds in littoral muddy sand	**Medium**	**No evidence**	**Not Sens**	**Medium**
A2.614	*R. maritima* on lower shore sediment	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A5.53	Sublittoral seagrass beds	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A5.533	*Zostera* beds in full salinity infralittoral sediments	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	**Not Sens**	**No evidence**	**Not Sens**	**Medium**
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	**Not Sens**	**No evidence**	**Not Sens**	**Medium**

* The biotope A2.612 (Macaronesian *Z. noltei* meadows) was not assessed as no evidence was found on the presence of NIS in this particular area.

4.2.4 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 this pressure 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
Filter-feeders such as mussels, clams and scallops are often associated with seagrass beds. Fisheries targeting these bivalves employ methods such as trawling, dredging, digging and raking which all result in the non-targeted removal of seagrass species. The direct physical effects of such fishing methods on seagrass are described in detail below for the pressures 'abrasion' (section 4.4.1) and 'penetration and/or disturbance of the substratum' (section 4.4.2). The effects relating to the removal of seagrass on other organisms including wildfowl are described below for the pressure 'removal of target species'. The sensitivity assessment

for this pressure considers any biological effects resulting from the removal of non-target species on this seagrass beds.

Sensitivity assessment

Seagrass habitats are not dependent on other organisms likely to the removed by fishing activities. Removal of non-target species will therefore not have a significant biological impact. **Resistance** to this pressure is deemed **'High'. Resilience** is also **'High'** as there are no ecological impacts to recover from, resulting in a **'Not Sensitive'** score for **all three seagrass / *Zostera* bed definitions**.

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 impact to recover from.
Applicability is 'High' - based on no impact to recover from.
Concordance is 'High' - based on no impact to recover from.

4.2.5 Removal of target species

ICG-C pressure description
The commercial exploitation of fish & 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; while 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
Seagrass is not a species targeted by commercial fishery. Seeds and shoots are however harvested for extensive transplantation project aimed at promoting seagrass populations in areas denuded by natural or anthropogenic causes. Divers are most commonly employed to remove material from the source population, an activity with a low overall impact on seagrass habitats. In the USA however, a mechanical seed harvesting technique was invented and put into practice (Orth & Marion 2007). The mechanised harvester is able to drastically increase the number of *Z. marina* seed collected from a source population (1.68 million seeds in one day compared to 2.5 million seeds collected by divers in one year). However the removal at large scale of seeds, the productive output of seagrasses, can affect the integrity of the natural seagrass beds. To date, no mechanical harvesting has been employed in the UK. The ecological impact of seed collection by divers is low; the harvesting of *Zostera* in British waters has therefore a minimal effect on natural seagrass habitats. The effect of the translocation of species is covered above in the pressure 'genetic modification and translocation of indigenous species' (section 4.2.1). The direct physical effects on seabed habitats from activities are described below in 'abrasion/disturbance' of the substratum on the surface of the bed' (section 4.4.1) and 'penetration and/or disturbance of the substratum below the surface' (section 4.4.2).

Harvesting of seagrasses as craft material is a small, but growing, industry. However, the present legislation for conservation of seagrasses will discourage expansion of this industry (see Jackson *et al* (2013) for the full political framework for seagrass protection in the UK).

Seagrass beds are not considered dependent on any of the organisms that may be targeted for direct removal e.g. oysters, clams and mussels. However, an indirect effect of fisheries targeting bivalves is a change in the water clarity, crucial for the growth and development of *Zostera* and *Ruppia* species (see pressure below on 'changes in suspended solids', section 4.4.3).

Sensitivity assessment

Seagrass beds have no avoidance mechanisms to escape targeted harvesting of leaves, shoots and rhizomes but are reported to recover quickly from grazing by wildfowl (see resilience section 3.3 above). **Resistance** to this pressure is therefore assessed as **'None'** but **Resilience** as **'High'. Sensitivity** is thus deemed **'Medium' for all three seagrass / *Zostera* bed definitions.**

Resistance confidence

Quality of evidence is 'Medium' – based on peer reviewed and grey literature.
Applicability is 'High' – based on directly applicable evidence.
Concordance is 'High – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Medium' - based on the effects of similar pressures.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.3 Hydrological pressures

4.3.1 Emergence regime changes - local, including tidal level change considerations

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
Seagrasses are generally not tolerant to exposure to aerial conditions, suggesting that the shallowest distribution should be at a depth below mean low water (MLW) (Koch 2001). *Z. noltei* and *R. maritima* grow predominantly in the intertidal zone and demonstrate higher resistance to desiccation than *Z. marina* which occurs more frequently in the subtidal. To understand the differences in desiccation tolerance between *Z. marina* and *Z. noltei*, Leuschner *et al* (1998) investigated the photosynthetic activity of emerged *Zostera* plants and found that after 5 hours of exposure to air during low tide, leaves of *Z. noltei* had lost up to 50% of their water content. Decreasing leaf water content resulted in a reversible reduction in light-saturated net photosynthesis rate of the plant. The experiment further showed that photosynthesis was more sensitive to desiccation in *Z. marina* plants than in *Z. noltei* under a given leaf water content. The experiment confirms that *Z. marina* is most susceptible to local changes in emergence regimes by being less tolerant to desiccation pressure.

R. maritima occurs in tidal areas, from mean high water (MHW) to MLW. Kantrud (1991) reported that *R. maritima* is restricted to areas exposed for a maximum of four hours daily or approximately seven hours per low tide but quickly disappeared from areas emersed for extended periods. Although *R. maritima* is relatively tolerant to changes in emergence regime, increased aerial exposure is likely to result in reduced growth, productivity and the loss of the upper portion of the population.

Tolerances vary not only between species but also within species. For instance, annual and perennial forms of *Z. marina* were observed to tolerate desiccation to different extents. Van Katwijk and Hermus (2000) noted that in intertidal areas of the Wadden Sea, annual *Z. marina* plants tended to lie flat on the moist sediment when exposed in low tide. Perennial plants on the other hand had stiffer stems inhibiting contact with the sediment. These upright sheaths desiccate more rapidly when exposed. Morphology is therefore a factor partly determining tolerance to desiccation. The same phenomena was observed by Boese *et al* (2003) on *Z. marina* in Aquinas Bay, USA.

The overall low tolerance of seagrass species to aerial exposure means that an increase in tidal amplitudes could force seagrass to grow deeper where there was less chance of exposure to the air. As the depth limit of seagrasses is set by light penetration, this change is likely to reduce the extent of suitable habitat. Changes in seagrass distribution along a depth gradient will have an impact further down the food chain.

Sensitivity assessment

Sensitivity to changes in emergence regimes varies between species and habitats. *Z. marina* will be more susceptible than *Z. noltei* or *R. maritima*. Species growing in intertidal habitats have greater tolerance to exposure to air than species inhabiting subtidal beds. Recovery will be enabled by recolonisation from surrounding communities located further down the shore and via the remaining seed bank. Recovery is therefore considered to be rapid**. *Z. marina*** has **'Low' resistance** and **'Medium' resilience** to this pressure resulting in a **'Medium' sensitivity** score. ***Z. noltei* and *R. maritima*** have a **'Medium' resistance** and a **'Medium' resilience** also resulting in a **'Medium' sensitivity** score.

All three seagrass/*Zostera* bed definitions are therefore assessed as having a **'Medium' sensitivity** score to this pressure.

Resistance confidence

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

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.3.2 Salinity changes - local

ICG-C pressure description
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.

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

Evidence description
In general, seagrass species have a wide salinity tolerance. *Zostera* species are found in salinities ranging from 10 to 39ppt (Davison 1997) whilst *R. maritima* is even more tolerant growing in full saline, brackish as well as fresh water environments (Kantrud 1991). Salinity tolerances vary among species found in different habitats. For instance, Den Hartog (1997) stated that *Z. noltei* was a euryhaline species, being more tolerant to extremes salinities than *Z. marina* due to its intertidal habitat.

Significant salinity fluctuations can alter important plant biochemical and physiological processes, which in turn, can influence plant metabolism, growth, development and reproduction. Such effects were observed in a study conducted on *Halophila johnsonei* in the USA (Torquemada *et al* 2005). Leaf production and growth of the seagrass were completely inhibited at both ends of extreme salinities (0ppt and 60ppt).

Phenotypic plasticity can play an important role in withstanding external pressures such as changes in salinity. Changes in physiological and morphological characteristics of seagrass plants will enable species to cope with varying degrees of stress for an extend period of time (Maxwell *et al* 2014). Therefore at the level of the benchmark, *Zostera* and *Ruppia* species will be not sensitive to changes in salinity.

Other components of the community might however be more affected. In general terms estuarine and low salinity fauna are likely to be replaced by comparable marine species as salinity increases and *vice versa*. Important seagrass grazers such as *Hydrobia ulvae* and *Lacuna vincta* are adapted to a wide range of salinities and are unlikely to be affected at the level of the benchmark. Therefore a habitat as a whole will probably be little impacted by changes in salinity but different biotopes will however have different sensitivities. Intertidal habitats will have a greater tolerance than subtidal beds. *R. maritima* biotopes will have the highest tolerance to this pressure.

Sensitivity assessment

R. maritima has a very wide salinity tolerance and is assessed as **'Not sensitive'** to this pressure (resistance is assessed as 'High' and resilience as 'High', no impact to recover from). *Zostera* plants are slightly more sensitive with *Z. marina* having the lowest resistance to this pressure. However, *Zostera* spp. may be more sensitive to acute changes (i.e. a decrease of 10 salinity units or hypersaline effluents). Therefore, ***Z. noltei*** **biotopes** score a **'Low' sensitivity ('Medium' resistance** and **'High' resilience)** whilst ***Z. marina*** **biotopes** score a **'Medium' sensitivity ('Medium' resilience and 'Medium' resistance)**

The **sensitivity** score for each of the HPI, OSPAR and PMF **seagrass /** ***Zostera*** **bed definitions** was recorded as **'Medium'**, based on the highest sensitivity score of each definition. It should be noted that the precautionary principle was applied and that the overall sensitivity of seagrass/*Zostera* species is probably lower than the stated score.

Resistance confidence

Quality of evidence is 'Medium' – based on inference from peer reviewed and grey literature.
Applicability is 'Medium' – based on the effects of similar pressures.
Concordance is 'Medium' – evidence agreed on direction but not magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

Table 4.6. Sensitivity score of individual biotopes within each habitat definition to changes in salinity regime pressure (Not Sens = Not Sensitive)

EUNIS Code	Biotope	HPI	OSPAR	PMF
A2.61	Seagrass beds on littoral sediments	**Low**		
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	**Low**	**Low**	
A2.6111	*Z. noltei* beds in littoral muddy sand	**Low**	**Low**	**Low**
A2.612	Macaronesian *Z. noltei* meadows		**Low**	
A2.614	*R. maritima* on lower shore sediment	**Not Sens**		
A5.53	Sublittoral seagrass beds	**Low**		
A5.533	*Zostera* beds in full salinity infralittoral sediments	**Low**	**Low**	
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	**Medium**	**Medium**	**Medium**
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	**Not Sens**		**Not Sens**
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	**Low**	**Low**	

4.3.3 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 subsea 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
Temperature is considered the overall parameter controlling the geographical distribution of seagrasses. All enzymatic processes, related to plant metabolism are temperature dependent and specific life cycle events, such as flowering and germination, are also often related to temperature (Phillips *et al* 1983). For seagrasses, temperature affects biological processes by increasing reaction rates of biological pathways. Photosynthesis and respiration increase with higher temperature until a point where enzymes associated with these processes are inhibited. Beyond a certain threshold, high temperatures will result in respiration being greater than photosynthesis resulting in a negative energy balance. Increased temperatures do also encourage the growth of epiphytes increasing the burden upon seagrass beds and making them more susceptible to disease (Rasmussen 1977).

Temperature tolerances of seagrass depend on individual species. *Z. marina* can tolerate temperatures between -1 to 25°C with optimum conditions for growth being around 10 to 15°C, and 10°C for seedling development (Hootsmans *et al* 1987). A study by Nejrup and Pedersen (2007) found that low water temperatures(5°C) slowed down photosynthetic rate by 75%; growth was also affected with the production of new leaves reduced by 30% and leaf elongation rate reduced by 80% compared to the control, however, mortality was not affected. High temperatures (25 to 30°C) lowered photosynthetic rates by 50% as well as growth (production of new leaves by 50% and leaf elongation rate by 75%) (Nejrup & Pedersen 2007). High temperatures also resulted in a 12-fold increase in mortality of *Z. marina* plants.

Z. noltei is more temperature resistant and can withstand slightly higher temperatures than *Z. marina*. A study in southern Portugal recorded that *Z. noltei* survival at 35 and 37°C was 95 and 90% respectively (Massa *et al* 2009). However at 39°C and above the rate of shoot mortality was close to 100%.

Verhoeven (1979) noted that *R. maritima* plants survived between 0 and 38°C, grew exponentially between 10 and 30°C and withstood fluctuations of 15°C in laboratory experiments. However, temperatures above 30°C were harmful if sustained for prolonged periods of times, and *R. maritima* was replaced by *Potamogeton pectinatus* in high temperature environments such as in the vicinity of thermal effluent (Kantrud 1991).

The exposure of seagrass beds to temperature changes depend on their location on the shore. Seagrass beds in the intertidal zone are more susceptible to temperature extremes whilst subtidal beds are more protected. The formation of ice amongst the sediments of eelgrass beds can lead to the erosion of surface sediments as well as uprooting of rhizomes and frost damage to foliage (Den Hartog 1987). At the level of the benchmark however, seagrass biotopes, both subtidal and intertidal, are unlikely to be severely affected. However, other species associated with seagrass habitats are less resilient to changes in temperature than the plant itself. For instance, the gastropod *Lacuna vincta*, an important grazer found in seagrass beds, is near its southern range limit in the British Isles. Long term increases in temperature due to human activity may limit the survival of the snail and restrict subsequent distribution whilst a short term acute temperature increase may cause death (Tyler-Walters & Wilding 2008). The loss of grazers could have detrimental effects on seagrass beds as the leaves provide a substratum for the growth of many species of epiphytic algae. These epiphytes may smother the *Zostera* plants unless kept in check by the grazing activities of gastropods and other invertebrates. Healthy populations of epiphyte grazers are therefore essential to the maintenance of seagrass beds.

Sensitivity assessment

A 5°C change in temperature for one month period or a 2°C change in temperature for one year are unlikely to severely affect seagrass habitats. ***R. maritima*** has a very wide temperature tolerance and is deemed **'Not sensitive'** to this pressure (**resistance** is assessed as **'High'** and **resilience** as **'High'** (no impact to recover from)). ***Zostera* species** have a slightly less pronounced tolerance to temperature extremes (in particular *Z. marina*) and therefore **sensitivity** is assessed as **'Low'** (based on **'Medium' resistance** and **'High' resilience**).

Table 4.7. Sensitivity score of individual biotopes within each habitat definition to changes in temperature pressure (Not Sens = Not Sensitive).

EUNIS Code	Biotope	HPI	OSPAR	PMF
A2.61	Seagrass beds on littoral sediments	**Low**		
A2.611	Mainland Atlantic *Z. noltei* or *Z. angustifolia* meadows	**Low**	**Low**	
A2.6111	*Z. noltei* beds in littoral muddy sand	**Low**	**Low**	**Low**
A2.612	Macaronesian *Z. noltei* meadows		**Low**	
A2.614	*R. maritima* on lower shore sediment	**Not Sens**		
A5.53	Sublittoral seagrass beds	**Low**		
A5.533	*Zostera* beds in full salinity infralittoral sediments	**Low**	**Low**	
A5.5331	*Z. marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	**Low**	**Low**	**Low**
A5.5343	*R. maritima* in reduced salinity infralittoral muddy sand	**Not Sens**		**Not Sens**
A5.545	*Zostera* beds in reduced salinity infralittoral sediments	**Low**	**Low**	

All three seagrass/*Zostera* bed definitions are therefore assessed as having a **'Low' sensitivity** score to this pressure.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed and UK observations.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.3.4 Changes in water flow

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 areas >1km^2 or 50% if width of water body for more than 1 year.

Evidence description
A complex interaction exists between seagrass beds and water flow. Water flow determines the upper distribution of plants on the shore whilst plants mediate the velocity of the flow by extracting momentum from the moving water. Reducing the flow increases water transparency (see below ‘changes in suspended sediments’, section 4.4.3) and causes the deposition and retention of fine sediments. Increased flow rates are likely to erode sediments, expose rhizomes and lead to loss of the plants.

There are several advantages for seagrass beds growing in low current velocity. Water transparency is greater due to limited sediment re-suspension. Light availability is also promoted by a reduction in self-shading as leaves tend to adopt a more vertical position in the water column when drag is reduced (Fonseca & Bell 1998). A further advantage is greater nutrient availability in the sediments and a greater settlement of algal spores and faunal larvae which may result in higher overall diversity. However, at low current velocity sulphide concentrates in the sediments increase due to reduced water transport across the water sediment boundary and within the sediment itself (Koch 1999). The diffusion of nutrients into the leaves is inhibited by thicker diffusion boundary layers on the surface of the leaf. As the current velocity decreases there is a critical diffusion boundary level thickness, where the flux of carbon to the plant does not meet the requirement to support maximum photosynthesis (Jones *et al* 1999). The lowest current velocity a seagrass can survive is thus determined by the physiology of the plant as it relates to oxygen availability.

The highest current velocity a seagrass can withstand is determined by a threshold beyond which sediment re-suspension and erosion rates are greater than the seagrasses ability to bind sediment and attenuate currents. In very strong currents, leaves might lie flat on the sea bed reducing erosion under the leaves but not on the unvegetated edges which begin to erode. High velocity currents can thus change the configuration of patches within a meadow, creating striations and mounding in the seagrass beds. Such turreted profiles destabilise the bed and increase the risk of 'blow outs'. Populations found in stronger currents are usually smaller, patchy and more vulnerable to storm damage (Tyler-Walters & Wilding 2008).

A review by Koch (2001) determined that the range of current velocities tolerated by seagrass lies approximately between a minimum of 5cm/s and a maximum of 180cm/s. Fonseca *et al* (1983) found a lower maximum for *Z. marina* and estimated the highest current velocity at approximately 120–150cm/s. No numerical estimates were found for *Z. noltei* or *R. maritima*. However a review by Kantrud (1991) on *R. maritima* found that the species is highly susceptible to changes in water flow. He suggested that its weak root system is responsible for confining *Ruppia* plants to areas with low flow velocities.

Human activities in coastal waters which alter hydrology have been implicated in the disappearance of seagrass beds. For instance, van der Heide *et al* (2007) noted that the construction of a dam in the Wadden Sea influencing the hydrological regime, inhibited the recovery of *Zostera* plants after their initial decline following the wasting disease in the 1930s. Aquaculture installations can also change water flow and have shown to directly impact seagrass habitats. An experimental study by Everett *et al* (1995) investigated the effects of commercial culture of the oyster *Crassostrea gigas* on *Z. marina* in South Slough estuary, USA, using both stake and rack methods. The study found that both culture methods caused a sharp decline in *Z. marina* plants with cover being less than 25% compared to control plots after one year of culture due to changes in local hydrological regime. The rack treatment of oysters caused the total disappearance of *Z. marina* after 17 months of culture. Both culture methods produced strong, although dissimilar, changes in local hydrological conditions, which had clear effects on sediment characteristics. In general, stakes resulted in local sediment deposition while racks produced local erosion, both leading to the reduction of nearby seagrass species.

Sensitivity assessment

Any changes in hydrology will have a considerable impact on the integrity of seagrass habitat. A change in water flow at the level of the benchmark of 10 to 20cm/s for more than 1 year would not cause direct mortalities in seagrasses but is likely to have sub-lethal effects. Recovery will depend on the species capacities to adapt to changes in water flow regime. A laboratory study by Peralta *et al* (2006) on *Z. noltei* demonstrated that plants are able to acclimate to hydrodynamic stresses by changing their architecture. When exposed to a water flow of 35cm/s for four weeks, *Z. noltei* plants had an improved anchoring system and changed leave morphology. The above ground/below ground biomass ratio was thereby reduced and the cross sections of leaves and rhizomes increased leading to a reduced risk in shoot breakage. Both **resistance** and **resilience** to this pressure is assessed as **'Medium'** for **all biotopes**, resulting in a '**Medium' sensitivity** score.

All three seagrass/Zostera bed definitions are therefore assessed as having a **'Medium' sensitivity** score to this pressure.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed and UK observations.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.3.5 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 near shore significant wave height >3% but <5%.

Evidence description
An absolute wave exposure limit and maximum wave height for *Zostera* has not been established (Short *et al* 2002) but an increase in wave action can harm the plants in several ways. Seagrasses are not robust. Strong waves can cause mechanical damage to leaves and to the rest of plant. McCann (1945) noted that waves caused injury to *Ruppia* branches leaving broken tips incapable of survival, and Verhoeven (1979) observed that the base of leaves detached easily in turbulent water to avoid damage to the root system. By losing above ground biomass due to increased wave action, productivity of seagrass plants is limited. Small and patchy populations as well as seedlings will be particularly vulnerable to wave exposure as they lack extensive rhizome systems to effectively anchor the plant to the seabed.

Wave action also continuously mobilises sediments in coastal areas causing sediment re-suspension which in turn leads to a reduction in water transparency (Koch 2001) (see below pressure on ‘changes in suspended sediments, section 4.4.3). Photosynthesis can be further limited by breaking waves inhibiting light penetration to the seafloor.

Wave exposure can also influence the sediment grain size, with areas of high wave exposure having coarser sediments with lower nutrient concentrations. Coarser sediments reduce the vegetative spreading of seagrasses and inhibit seedling colonisation (Gray & Elliott 2009). Changes in sediment type can therefore have wider implications for the sensitivity of the beds on a long term scale.

Sensitivity assessment

No evidence was available to determine the impact of this pressure at the benchmark level. However, exposure models from Studland Bay and Salcombe, where seagrass beds are limited to low wave exposure, show that even a change of 3% is likely to influence the upper shore limits as well as beds living at the limits of their wave exposure tolerance (Rhodes *et al* 2006; Jackson *et al* 2013). At the benchmark level, increases in wave exposure are likely to remove surface vegetation or the majority of the root system. Intertidal populations and seagrass beds located on the upper shore are the most exposed to this pressure. Furthermore a change in wave exposure will impact the upper limit of seagrass and thus influence its wider distribution. A decrease in wave exposure is unlikely in the sheltered habitats that seagrass inhabit. Recovery will depend on recolonisation by seagrass propagules (rhizomes or seeds) which could take several years to become established. **The sensitivity score to this pressure for all three seagrass/*Zostera* bed definitions is therefore set at ‘Medium’ (‘Medium’ resistance and ‘Medium’ resilience).**

Resistance confidence

Quality of evidence is 'Medium' – based on inference from peer reviewed and grey literature.
Applicability is 'Medium' – based on the effects of similar pressures.
Concordance is 'Medium' – evidence agreed on direction but not magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.4 Physical damage pressures

4.4.1 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 & 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 & 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
Seagrasses are not physically robust. The leaves and stems of seagrass plants rise above the surface and the roots are shallowly buried so that they are vulnerable to surface abrasion. The removal of above-ground biomass would result in a loss of productivity whilst the removal of roots would cause the death of the plant. For *Z. noltei*, the naturally recorded rhizome depth was recorded to be 0.6 ± 0.3cm (from 0 to 1.4cm) in the field, and the observed preferential depth was 0.3 to 0.8cm (Han *et al* 2012). Kantrud (1991) noted that nearly 100% of the below ground biomass (roots and rhizomes) of *R. maritima* usually lie within the upper 10cm of the substratum and sometimes nearly 90% in the upper 5cm. This shallow and rather weak root system makes seagrasses particularly vulnerable to abrasion pressure.

Seagrasses are limited to shallow, protected waters and soft sediments. These areas are often open to public access and are widely used in commercial and recreational activities. The level of impact of this pressure on seagrass will depend on the activity that causes abrasion. Heavy abrasion accompanied by crushing or compaction of sediments would lead to more severe effects. Evidence for abrasion impacts is summarised below for activities that give rise to this pressure.

Trampling

Human wading in shallow coastal waters is a common activity that inherently involves trampling of the substratum. Activities such as trampling are likely to damage rhizomes and cause seeds to be buried too deeply to germinate (Fonseca 1992). A field experiment in Puerto Rico on *Thalassia testudinum* beds showed that seagrass biomass was inversely related to trampling intensity and duration (Eckrich & Holmquist 2000). The study design involved three experimental trampling lanes (5m x 2.5m) at 10 sites. The trampling intensity was defined by a 57kg individual wearing rubber-soled shoes and consisted of 20 and 50 passes (to the end of the lane and back), applied once a month for 4 months. The study found that sand cover increased in the heavily trampled treatments. With exceptions at one site, heavy trampling (50 passes per month for four months) resulted in reduced rhizome biomass of up to 72% and loss of standing crop up to 81%. The study also noted that trampling or wading depth may influence trampling disturbance. Less force is exerted by an individual at greater depths due to the effects of buoyancy, meaning that wading intensities are greatest in shallow areas. The study monitored the recovery of the seagrass and found that recovery occurred within a period of seven months after trampling ceased. Reduced cover was still visually distinguishable at several study sites 14 months after the experiment.

Major *et al* (2004) investigated the impact of a single footprint, placed at the centre of sampling points positioned at set locations along a 10m transect on seagrass beds (*Zostera japonica*) at two sites in the Willapa Bay, USA. One site had a deep soft muddy substratum and the second a hard packed sand substratum. A significant decrease in shoot density was only observed at the site with soft muddy substratum. Trampling impact is thus greatest on seagrass beds growing on soft substrata.

Damage induced by accessing seagrass beds by vehicle have been reported to cause damage. Hodges and Howe (1997) found that *Z. angustifolia* beds in Angle Bay, Wales were severely damaged after the *Sea Empress* oil spill by the vehicles required for the initial clean up. After the clean-up operations, *Z. angustifolia* beds were left patchy, criss-crossed with wheel ruts up to 1m deep.

Boating activities

Seagrasses are restricted to low energy environments. Boats passing in close proximity to seagrass beds can create waves. Turbulence from propeller wash and boat wakes can resuspend sediments, break off leaves, dislodge sediments and uproot plants. The re-suspension of sediments is further assessed below in section 4.4.3 ‘changes in suspended sediment’. Koch (2002) established that physical damage from boat wakes was greatest at low tide but concluded that negative impacts of boat-generated waves were marginal on seagrass habitats.

The physical impact of the engine’s propellers, shearing of leaves and cutting into the bottom, can also have damaging effects on seagrass communities. In severe cases, propellers cutting into the bottom may completely denude an area resulting in narrow dredged channels through the vegetation called propeller scars. Scars might expand and merge to form larger denuded areas. A study in Florida looking at *Thalassia testudinum*, *Syringodium filiforme* and *Halodule wrightei* determined that recovery of seagrass to propeller impact depend on species (Kenworthy *et al* 2002). For *S. filiforme* recovery was estimated at 1.4 years and for *H. wrightei* at 1.7 years, whilst recovery for *T. testudinum* was estimated to require 9.5 years. Variations in recovery time were explained by different growth rates. However, it is not appropriate to assume that recovery rates are similar from one geographical or climatic region to another and more in-depth research is needed for *Zostera* and *Ruppia* species around the British Isles.

Potting

Static gear is commonly deployed in areas where seagrass beds are found, either in the form of pots, or as bottom set gill or trammel nets. Whilst the potential for damage is lower per unit deployment compared to towed gear (see below pressure on penetration and/or disturbance of the substratum below the surface of the seabed), there is a risk of cumulative damage if use is intensive. Damage could be caused during the setting of pots or nets and their associated ground lines and anchors, by their movement over the bottom during rough weather and during recovery. Hall *et al* (2008) using the modified Beaumaris approach to sensitivity assessment, categorised seagrass beds as being highly sensitive to high intensities of potting (pots lifted daily, with a density of over 5 pots per ha) and medium sensitivity to lower levels (pots lifted daily, less than 4 pots per ha). However, no direct evidence was found.

Sensitivity assessment

The resilience and recovery of seagrass beds to abrasion of the seabed surface depends on the frequency, persistence and extent of the disturbance. Boese *et al* (2009) examined the recolonisation of experimentally created gaps within intertidal perennial and annual *Z. marina* beds in the Yaquina River Estuary, USA. The experiment looked at two zones, the lower intertidal almost continuous seagrass and an upper intertidal transition zone where there were patches of perennial and annual *Z. marina*. The study found that recovery began within a month after disturbance in the lower intertidal continuous perennial beds and was complete after two years, whereas, plots in the transition zone took almost twice as long to recover. Physical disturbance and removal of plants can lead to increased patchiness and destabilisation of the seagrass bed, which in turn can lead to reduced sedimentation within the seagrass bed, increased erosion, and loss of larger areas of plants (Davison & Hughes 1998).

In summary, a wide range of activities gives rise to this pressure. Seagrass plants are not physically robust and their root system is located in the upper layer of the sediment making them prone to damage by abrasion. There is considerable evidence that the type of substratum plays a role in determining the magnitude of impact. Soft and muddy substratum was found to be more easily damaged than harder more compact ground. All seagrass species found in the UK are equally affected due to shallow roots systems and a lack of vertical rhizome growth. Intertidal habitats are more exposed to this pressure as they are more readily accessible than subtidal beds. Temporal effects relating to the state of the tide will have an influence of the magnitude of damage. Seasonal effects are also important to consider as damage induced in winter is likely to have a lesser impact than damage occurring during the growing season. Studies suggest little or no resistance to abrasion with slow recovery. The overall **sensitivity** score to this pressure is '**Medium** (**'Low' resistance** and **'Medium' resilience**) for all three seagrass/*Zostera* bed definitions.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed and UK observations.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.4.2 Penetration and/or disturbance of the substratum below the surface of the seabed

ICG-C pressure description
See description provided for abrasion/disturbance of the substratum on the surface of the seabed (section 4.4.1).

Pressure benchmark
Damage to sub seabed-surface features.

Evidence description
Abrasion to the sub-surface will directly impact seagrass habitats as the plant is confined to the upper layer of the sediment. The shallow root systems are thus likely to be removed leading to the death of the plant.

Seagrass beds are often associated with commercially important bivalves (see section 4.2.2 on 'introduction of microbial pathogens'). Fisheries targeting these species are therefore likely to impact seagrass habitats and are the most widespread (and best studied) activities giving rise to this pressure on this habitat. The extent of the damage on seagrass beds depends on fishing method.

Mechanical harvest

Bottom trawling and dredging are industrial fishing methods which scour the seabed to collect target species. Neckles *et al* (2005) investigated the effects of trawling for the blue mussels *Mytilus edulis* on *Z. marina* beds in Maquoit Bay, USA. Impacted sites ranged from 3.4 to 31.8ha in size and the majority were characterised by the removal of above and below ground plant material. The study found that one year after the last trawl, *Z. marina* shoot density, shoot height and total biomass averaged respectively 2-3%, 46-61% and <1% that of the reference sites. Substantial differences in *Z. marina* biomass persisted between disturbed and reference sites up to seven years after trawling. Rates of recovery depended on initial fishing intensity but the authors estimated that an average of 10.6 years was required for *Z. marina* shoot density to match pre-trawling standards.

The effects of dredging for scallops on *Z. marina* beds was investigated by Fonseca *et al* (1984) in Nova Scotia, USA. Dredging was carried out when *Z. marina* was in its vegetative stage on hard sand and on soft mud substrata. Damage was assessed by analysing the effects of scallop harvesting on eelgrass foliar dry weight and on the number of shoots. Lower levels of dredging (15 dredges) had a different impact depending on substrata, with the hard bottom retaining a significantly greater overall biomass than soft bottom. An increase in dredging effort (30 dredges) led to significantly reduced levels of *Z. marina* biomass and shoot number on both hard and soft bottoms. Solway Firth is a British example for the detrimental effects of dredging on seagrass habitats. In the area, where harvesting for cockles by hand is a traditional practice, suction dredging was introduced in the 1980s to increase the yield. A study by Perkins (1988) found that where suction dredging occurred, the sediment was smoothened and characterised by a total absence of *Zostera* plants. The study concluded that the fishery was causing widespread damage and could even completely eradicate *Zostera* from affected areas. Due to concerns over the sustainability of this fishing activity, the impacts on cockle and *Zostera* stocks, and the effects on overwintering wildfowl, the fishery was closed to all forms of mechanical harvesting in 1994.

Manual harvest

Racking and digging for shellfish is a common practice in the intertidal zone. Several studies looked into the effects of manual clam harvesting on the seagrass *Z. noltei* in southern

Portugal. In this region, at every low tide, clam harvesters dig up intertidal sediments dominated by the seagrass *Z. noltei*, using a hand-blade, which breaks and removes the shoots and rhizomes of plants. Cabaço and Santos (2007) found that clam harvesting activities change the species population structure by significantly reducing shoot density and total biomass, particularly during August, when the harvest effort is highest. Experimental harvest revealed a short-term impact on shoot density, which however rapidly recovered to control levels during the following month. By experimentally manipulating rhizome fragmentation, the authors determined that plant survival was only reduced when fragmented rhizomes were left with less than two intact internode; fragmented rhizomes having 2 to 5 internodes were not significantly affected, even though growth and production were lower with fewer internodes. The results of this study suggest that *Z. noltei* can be adversely affected by clam harvesting, however the species is able to rapidly recover from this physical disturbance. Using the same study area, Alexandre *et al* (2005) looked into the effects of clam harvesting on sexual reproduction. Disturbed meadows showed significantly lower vegetative shoot density but significantly higher reproductive effort. These results were confirmed by manipulative experiments and suggest that *Z. noltei* responds to clam harvesting disturbance by both increasing its reproductive effort and extending its fertile season.

The effect of manual clam harvesting on *Z. marina* was experimentally tested by raking or digging for clams in experimental 1m^2 plots in Yaquina Bay, USA (Boese 2002). After three monthly treatments, measures of biomass, primary production (leaf elongation), and percent cover were compared between disturbed and undisturbed plots. The study found that clam raking did not significantly impact any measured parameter. In contrast, clam digging reduced cover, above-ground biomass and below-ground biomass. Differences between manipulated and control plots persisted 10 months after the last digging event, but were not statistically significant. The effect of clam harvesting seem thus to relate to the extent and depth to which sediment is dislodged.

Anchoring and mooring

An anchor landing on a patch of seagrass can bend, damage and break seagrass shoots (Montefalcone *et al* 2006) and an anchor being dragged as the boat moves driven by wind or tide causes abrasion to the seabed surface. Evidence in the literature of anchor damage on *Zostera* and *Ruppia* species is limited. There is however extensive evidence of widespread damage for other seagrass species.

Milazzo *et al* (2004) tested whether different anchor types (Hall, Danforth and folding grapnel) had different effects on *Posidonia oceanica* beds in the Mediterranean. The study found that damage by the folding grapnel was greatest compared to the other two with an average number of 5.5 uprooted shoots for the grapnel and 1.8 for both the Hall and Danforth. A previous study on *P. oceanica* found that on average, anchoring uprooted 34 shoots, about 50 per m^2 (Francour *et al* 1999). Differences between impacts could have been caused by different weight of anchors and sizes of boats taken into consideration. A heavier anchor is expected to sink deeper into the bottom whilst a larger boat causes more pressure on the anchor (Milazzo *et al* 2004). Both studies used *P. oceanica* as study specimen, a species of seagrass capable of vertical and horizontal rhizomatous growth, growing on robust root rhizome mats. Seagrass species found in the UK can only produce horizontally growth and the root rhizomes are confined to the upper layer of the sediment making them therefore easier to uproot. A further issue is that anchoring and mooring usually creates an indent on the seafloor. Due to the lack of vertical growth output, British seagrass species are unable to recolonise the denuded areas leading to more permanent scaring of the seagrass bed. Areas of low accretion will be less able to recover from this pressure. Anchor damage on *Zostera* and *Ruppia* species is thus expected to be even greater than on the Mediterranean species.

Traditional mooring further contributes to the degradation of seagrass habitats. A traditional swing mooring is a buoy on a chain attached to a static anchoring block fixed on the seabed, to buffer any direct force on the permanent block, the chain lies on the seabed where it moves around with wind and tides, as the chain pivots on the block it scours the seabed. In proximity to seagrass beds, the chain usually removes not only the seagrass above ground parts such as leaves and shoots but also the roots anchored in the sediment. Further sediment abrasion may occur in vicinity to the anchoring blocks due to eddying of currents. The blocks themselves may increase the competition of seagrass with other algae as they provide ideal settlement surfaces.

Boats might also moor on intertidal sediments. When the tide goes out, the boat sits directly on top of the soft sediment. Walker *et al* (1989) found that boat moorings caused circular or semi-circular depressions of bare sand within seagrass beds between 3 to 300m^2 causing important habitat fragmentation. The scours created by moorings in the seagrass canopy interfere with the physical integrity of the meadow. Though relatively small areas of seagrass are damaged by moorings, the effect is much greater than if an equivalent area was lost from the edge of a meadow. Such mooring scars have been observed for *Zostera marina* around the UK such as in Porth Dinllaen in the Pen Llyna'r Sarnau Special Area of Conservation, Wales (Egerton 2011) and at Studland Bay (Jackson *et al* 2013).

Sensitivity assessment

In summary, fishing activities targeting shellfish and the anchoring and mooring of boats can pose a severe threat to seagrass beds. The deployment of fishing gears on seagrass beds results in physical damage to the above surface part of the plants as well as to the root systems. Manual harvesting methods have a lesser impact on the integrity of the habitat. The recovery of seagrass beds after disturbance to the sub-surface of the sediment will be slow with the speed depending on the extent of removal. Rates may be accelerated where adjacent seed sources and viable grass beds are present, but can be considerably longer where rhizomes and seed banks were removed. Using a model simulation, it has been suggested that with favourable environmental conditions, seagrass beds might recover from dragging disturbance in 6 years; conversely, recovery under conditions less favourable to seagrass growth could require 20 years or longer (Neckles *et al* 2005).

Even though little evidence was found on the effects of this pressure on *R. maritima*, the plant has a shallow and weak root system (Verhoeven 1979; Kantrud 1991) making it sensitive to sub-surface abrasion.

The mechanical harvest of shellfish damaging the sub-surface of the sediments poses a very severe threat to seagrass habitats.

Resistance to this pressure is thus **'None'** and **resilience** will be **'Low'** resulting in a **'High'** sensitivity score for **all three seagrass/*Zostera* bed definitions**.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed and UK observations.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'High' - based on the same pressures acting on these features.

Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.4.3 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.

Evidence description
Irradiance decreases exponentially with increasing depth, and the suspended sediment concentration has a direct linear effect on light attenuation (van Duin *et al* 2001). Changes in suspended solids will thus reduce light available for seagrass plants necessary for photosynthesis. Impaired productivity due to a decrease in photosynthesis will affect the growth and reproductive abilities of plants. Turbidity also results in a reduction of the amount of oxygen available for respiration by the roots and rhizomes thus lowering nutrient uptake. The resulting hypoxic conditions will lead to a build-up of sulphides and ammonium, which can be toxic to seagrass at high concentrations (Mateo *et al* 2006). Considerable declines in seagrass populations related to increase in turbidity from dredging in the Wadden Sea have been recorded (Davison & Hughes 1998).

Water clarity is a vital component for seagrass beds as it determines the depth-penetration of photosynthetically active radiation of sunlight. Seagrasses have light requirements an order of magnitude higher than other marine macrophytes making water clarity a primary factor in determining the maximum depth at which seagrasses can occur. The critical threshold of light requirements varies among species ranging from 2% in-water irradiance for *Z. noltei,* to 11 to 37% for *Z. marina* (Erftemeijer & Robin 2006). These differences in light requirement for *Zostera* are reflected by the position of species along a depth gradient with *Z. noltei* occurring predominantly in the intertidal and *Z. marina* found at greater depth in the subtidal. However differences in light requirements also vary within species. For example, the minimum light requirement for *Z. marina* in a Danish embayment was 11% in-water irradiance, whereas the estimated light requirement for the same species in the Netherlands was 29.4% in-water irradiance (Olesen 1993). This variability within species is likely attributed to photo-acclimation to local light regimes. Similar to *Zostera* species, *R. maritima* requires a high level of sunlight. Verhoeven (1979) suggested that *R. maritima* can only develop in clear water and Joanen and Glasgow (1965) found that plants preferred turbidity levels less than 25-55ppm.

Wetzel and Penhale (1983) compared the photosynthetic parameters of *R. maritima* and *Z. marina*. *R. maritima* was found to be photosynthetically less efficient in low levels of underwater light compared to *Z. marina*. *R. maritima* also has a relatively high ratio of chlorophyll α to chlorophyll β, suggesting that it is less adapted to low-light environments than seagrasses (Evans *et al* 1986). A shading experiment by Congdon and McComb (1979) on *R. maritima* determined that a 40% reduction in light availability resulted in a 50% reduction in standing crop.

A study by Peralta *et al* (2002) investigated the effects of reduced light availability on *Z. noltei* in Spain. The authors determined that plants were able to tolerate acute light reductions for a short period of time (below 2% of surface irradiance for two weeks) by storing and mobilizing carbohydrates at a low level of irradiance. However, *Z. noltei* are likely to be more intolerant to chronic increases in turbidity. In a six month long experiment in the Dutch Wadden Sea, Philippart (1995) found that shading induced a 30% decrease in the leaf growth rate, a 3-fold increase in the leaf loss rate, and a 80% reduction in the total biomass of *Z. noltei*. The decreasing growth rate is most probably the result of reduction of photosynthesis due to shading. The increased leaf loss may have been the result of enhanced deterioration of leaf material under low light conditions. The study also established that during the summer period, the maximum biomass of *Z. noltei* under the control light conditions was almost 10 times higher than those under the low light conditions (incident light reduced to 45% of natural light conditions). The summer is a critical period for maintenance and growth of vegetative shoots. The effects of shading may therefore be most severe during summer months. Similar response to reduced light availability for *Z. marina* was observed by Moore and Wetzel (2000).

Increases in turbidity over a prolonged period of time are therefore highly likely to impact seagrass species. Sensitivity will depend on individual seagrass beds. Older, more established perennial meadows have greater carbohydrate reserves and are thus more able to resist to changes in light penetration than annual plants (Alcoverro *et al* 2001). Seagrass plants found in clear waters may be able to tolerate sporadic high turbidity (Newell & Koch 2004). However, where seagrass beds are already exposed to low light conditions, then losses may result from even short-term events (Williams 1988). Growth of both *Z. marina* and its associated epiphytes are reduced by increased shading due to turbidity (reduction of light penetration by 42, 28 and 9%). Backman and Barilotti (1976) further established that intensive shading (reduction of light penetration by 63%) inhibited flowering in *Z. marina* plants.

Sensitivity assessment

Turbidity is an important factor controlling production and ultimately survival and recruitment of seagrasses. Seagrass populations are likely to survive short term increases in turbidity however a prolonged increase in light attenuation, especially at the lower depths of its distribution, will probably result in loss or damage of the population. A loss of seagrass beds will promote the re-suspension of sediments, making recovery unlikely as seagrass beds are required to initially stabilise the sediment and reduce turbidity levels (van der Heide *et al* 2007). A high turbidity state appears to be a highly resilient alternative stable state; hence return to the seagrass biotope is unlikely. **All the seagrass/*Zostera* bed definitions** should be considered intolerant of any activity that changes the sediment regime where the change is greater than expected due to natural events, yielding a **'High' sensitivity** score (**'Low' resistance** and **'Low' resilience**).

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is ‘High’ - based on peer reviewed literature.
Applicability is ‘Low’ - based on the effects of other pressures or natural events.
Concordance is ‘Medium’ – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.4.4 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 recolonise; 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 extraction of sediments to 30cm (the benchmark) will result in the removal of every component of seagrass beds. Roots and rhizomes are buried no deeper than 20cm below the surface (see sections 4.4.1 on ‘abrasion’ and 4.4.2 on ‘penetration and/or disturbance of the substratum below the surface of the seabed’). **Resistance** is therefore assessed as **‘None’** for all seagrass biotopes and **resilience** is considered **‘Very Low’** resulting in a **‘High’ sensitivity** score. The **sensitivity assessment applies to all biotopes** and therefore all the seagrass habitat definitions (OSPAR, HPI and PMF) are equally sensitive.

Resistance confidence

Quality of evidence is ‘High’ – based on the characteristics of the pressure i.e. complete removal of the feature within the pressure footprint.
Applicability is ‘High’ – based on the characteristics of the pressure.
Concordance is ‘High’ – based on the characteristics of the pressure.

Resilience confidence

Quality of evidence is ‘High’ - based on peer reviewed literature.
Applicability is ‘Low’ - based on the effects of other pressures or natural events.
Concordance is ‘Medium’ – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.4.5 Siltation rates 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 (for full description see Appendix 2).

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

Evidence description
Several studies have documented deterioration of seagrass meadows by smothering due to excessive sedimentation. Consequences of enhanced sedimentation for seagrass beds depend on several factors such as the depth of burial and life history and characteristics of the species involved (Duarte *et al* 1997).

Vermaat *et al* (1997) found that *Z. marina* in the Dutch Wadden Sea is able to cope with sedimentation rates between 2 and 13cm per year as the plant has the capacity to elongate verticals stems enabling it to raise the leaf canopy above the sediment load. A study in the USA, however, observed a mortality of over 50% of plants of *Z. marina* in field burial treatments of 4cm (corresponding with 25% of plant height) for 24 days (Mills & Fonseca 2003). Plants buried 75% or more of their height (16cm) experienced 100% mortality indicating a low resistance of *Z. marina* to burial. The differences observed between studies were probably caused by different phenotypes adapted to local conditions.

For *Z. noltei,* a study conducted in southern Portugal found that plants were not able to survive more than 2 weeks under complete burial (Cabaço & Santos 2007). According to the authors, *Z. noltei* is highly sensitive to burial and erosion disturbances due to the small size of this species and the lack of vertical rhizomes. Buried plants however produced longer rhizome internodes as a response to burial, suggesting an attempt to relocate the leaf-producing meristems closer to the sediment surface. The carbon content of leaves and rhizomes, as well as the non-structural carbohydrates (mainly the starch in rhizomes), dropped significantly along the experimental period, indicating an internal mobilisation of carbon to meet the plant demands as a consequence of light deprivation. Tu Do *et al* (2012) investigated the recovery of *Z. noltei* beds in Arcachon Bay in France after dredging activities and found that six months after works, seagrass beds had been completely destroyed in affected sites and remained absent over 5 years after the incident.

Whereas the mortality caused by burial increased with decreasing seagrass size, the potential to recover from disturbances by growth is enhanced with decreasing seagrass size. Indeed, Duarte *et al* (1997) found that small seagrass species, such a *Halophila ovalis* and *Halodule uninervis* were able to recover within four months after burial disturbance, whilst Cabaco and Santos (2007) did not observe any recovery of *Z. noltei* within two months after experimental burial. It seems that *Z. noltei* is well adapted to cope with sediment disturbances of limited amplitude (i.e. ±6cm) and with continuous events by rapidly relocating their rhizomes to the preferential depth. A trade-off related to seagrass size thus exists, in terms of recovery time versus resistance to stresses, such as sediment disturbance (Han *et al* 2012).

The timing of the siltation event also plays a role in particular for intertidal beds. At low tide, the seagrass bed is exposed with plants lying flat on the substratum. The addition of material would immediately smother the entire plant and have a greater impact on leaves and stem than if added on plants standing upright. The resistance of intertidal beds to this pressure may thus vary with time of day.

Sensitivity assessment

All studies indicate that seagrass species are sensitive to an increase in sedimentation rates and at the benchmark level of 30cm. In addition, seagrass beds are restricted to low energy environments, suggesting that once the silt is deposited, it will remain in place for a long period of time so habitat conditions will not reduce exposure. **Resistance** is assessed as **'None'** as all individuals exposed to siltation at the benchmark level are predicted to die and consequent **resilience** as **'Low' to 'Very Low'**. **Sensitivity** based on combined resistance and resilience is therefore assessed as **'High'** for **all three seagrass/*Zostera* bed definitions**.

Resistance confidence

Quality of evidence is 'High' – based on peer reviewed evidence and observations in the UK.
Applicability is 'High' – based on the effects of the same pressure.
Concordance is 'High' – evidence agreed on direction and magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on the effects of other pressures or natural events.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.5 Physical loss pressures

4.5.1 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 & 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
Seagrass beds occur almost exclusively in shallow and sheltered coastal waters anchored in sandy and muddy bottoms. A physical change to another seabed type such as a change in Folk class (Folk 1954) will therefore have a detrimental effect on seagrass beds as they will be excluded from the newly created habitat. A change towards a coarser sediment type would inhibit seagrasses from becoming established due to a lack of adequate anchoring substratum. A more mud dominated habitat on the other hand could increase sediment re-suspension and exclude seagrasses due to unfavourable light conditions.

Sensitivity assessment

The **resistance** was assessed as **'Low** and **resilience** as **'Very Low'** resulting in a **'High' sensitivity** of seagrass beds. The sensitivity assessment applies to all biotopes and therefore **all the seagrass habitat definitions (OSPAR, HPI and PMF) are equally**

sensitive. As there is no direct evidence to support resistance assessments these are based on expert judgement.

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 'Low' - based on expert judgement.
Applicability is 'Not assessed' - based on expert judgement.
Concordance is 'Not assessed' - based on expert judgement.

4.5.2 Physical loss (to land and freshwater habitat)

ICG-C pressure description
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.

Pressure benchmark
Permanent loss of existing saline habitat.

Sensitivity assessment

All marine habitats and benthic species are considered to have **'No' resistance** to this pressure and to be unable to recover from a permanent loss of habitat**. 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. The sensitivity assessment applies to all biotopes and therefore all the seagrass habitat definitions (OSPAR, HPI and PMF) are equally sensitive.

4.6 Pollution and other chemical pressures

4.6.1 Nutrient enrichment

ICG-C pressure description
ıncreased 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.

Pressure benchmark
Compliance with WFD criteria for good status.

Evidence description
During the past several decades, important losses in seagrass meadows have been documented worldwide related to an increase in nutrient load. Seagrasses are typically found in low energy habitats such as estuaries, coastal embayments and lagoons with reduced tidal flushing where nutrient loads are both concentrated and frequent. A typical response of nutrient enrichment is a decline in seagrass populations in favour of macroalgae or phytoplankton (Baden *et al* 2003). Nutrient enrichment, especially of nitrogen and phosphorus, can lead to eutrophication.

The mechanisms responsible for seagrass decline under eutrophication are complex and probably involve direct and indirect effects relating to changes in water quality, smothering by macroalgal blooms (Den Hartog & Phillips 2000), and competition for light and nutrients with epiphytic microalgae and with phytoplankton (Nienhuis 1996). In the Mondego estuary (Portugal), eutrophication triggered serious biological changes, which led to an overall increase in primary production and to a progressive replacement of seagrass *Z. noltei* beds by coarser sediments and opportunistic macroalgae (Cardoso *et al* 2004).

Nutrients stimulate phytoplankton blooms that compete for nutrients but more importantly increase the turbidity and absorb light, reducing seagrass productivity (discussed above in section 4.4.3 - changes in suspended solids). In general terms, algae are able to out-compete seagrasses for water column nutrients since they have a higher affinity for nitrogen (Touchette & Burkholder 2000). In an experimental study, Twilley *et al* (1985) added fertilisers to ponds occupied by *R. maritima*. The enrichment resulted in extensive epiphytic community development on plants which was responsible for >80% reduction of incident radiation 60 days after the fertiliser was added. Short and Burdick (1996) found similar results for *Z. marina* in relation to nutrient enrichment with excessive nitrogen loading stimulating the proliferation of algal competitors that cause shading and thereby stress the plant.

Many seagrasses have a positive response to nitrogen and/or phosphorous enrichment (Peralta *et al* 2003) but excessive loads can inhibit seagrass growth and survival, not only indirectly through light reduction resulting from increased algal growth but also directly in terms of the physiology of the seagrass. Direct physiological responses include ammonium toxicity and water column nitrate inhibition through internal carbon limitation (Touchette & Burkholder 2000).

Indirect effects of nutrient enrichment can accelerate decreases in seagrass beds such as sediment re-suspension from seagrass loss (see above section 4.4.3 - ‘changes in suspended solids’).

Sensitivity assessment

The loss of seagrass beds worldwide has been attributed to nutrient enrichment, due in part to the likeliness of smothering by epiphytes, and the effects of reduced light penetration caused by eutrophication. For instance, a study by Greening and Janicki (2006) found that in Florida, USA, recovery of seagrass beds was incomplete 20 years after nutrient enrichment causing an eutrophication event. Seagrass beds are regarded as highly intolerant (or of low resistance) to this pressure.

However, the benchmark of this pressure (compliance with WFD ‘good’ status) allows for a 30% loss of intertidal seagrass beds under the WFD criteria for good status. Therefore, at the level of the benchmark **resistance** of seagrass beds to this pressure is assessed as **‘Medium’**. **Resilience** of seagrass beds this degree of impact is assessed as **‘Medium’**. The **sensitivity** score is therefore assessed as **‘Medium’ for all seagrass/*Zostera* bed definitions** (OSPAR, HPI and PMF).

Resistance confidence

Quality of evidence is ‘Medium’ – based on inference from peer reviewed papers.
Applicability is ‘Medium’ – based on evidence of the effects of similar pressures.
Concordance is ‘Medium’ – evidence agreed on direction but varied on magnitude.

Resilience confidence

Quality of evidence is ‘High’ - based on peer reviewed literature.
Applicability is ‘Low’ - based on proxies (natural events) and effects of other pressures.
Concordance is ‘Medium’ – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

4.6.2 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 may lead to eutrophication with adverse environmental effects including deoxygenation, algal blooms and changes in community structure (see section above 4.6.1 on ‘nutrient enrichment’). Evidence on the effects of organic enrichment on *Zostera* and *Ruppia* is limited, but abundant for other seagrass species.

Neverauskas (1987) reported the effects of a discharge of digested sludge from a sewage treatment plant on the distribution of *Posidonia* spp. and *Amphibolis* spp. in South Australia. Within 5 years the outfall had affected an area of approximately 1900ha, 365ha of which were completely denuded of seagrasses. The author suggests that the excessive growth of epiphytes on the leaves of seagrasses was a likely cause for reduced abundance. A subsequent study by Bryars and Neverauskas (2004) determined that 8 years after the cessation of sewage output, total seagrass cover was approximately 28% of its former extent. While these results suggest that seagrasses can return to a severely polluted site if the pollution source is removed, they also suggest that it will take many decades for the seagrass community to recover to its former state.

The effects of organic enrichment from fish farms were investigated on *Posidonia oceanica* seagrass beds on Minorca, Balearic Islands (Delgado *et al* 1999). Changes in plant and bed features (e.g. shoot morphology, shoot density, biomass, rhizome growth, nutrient and soluble sugars concentrations) were recorded at three sites subject to organic pollution. The fish culture had ceased in 1991; however, seagrass populations were still in decline at the time of sampling in July 1994. The site closest to the former fish cages showed a marked reduction in shoot density, shoot size, underground biomass, sucrose concentration and photosynthetic capacities. The shoot also had high phosphorus concentration in tissues and higher epiphyte biomass compared to the other sites. Since water conditions had recovered completely by the time of sampling, the authors suggest that the continuous seagrass decline was due to the excess organic matter remaining in the sediment (Delgado *et al* 1999).

It should be noted that coastal marine sediments where seagrasses grow are often anoxic and highly reduced due to the high levels of organic matter and slow diffusion of oxygen from the water column to the sediment. Seagrasses are adapted to these conditions but if the water column is organically enriched, plants are unable to maintain oxygen supply to the meristem and die fairly quickly. The enrichment of the water column could therefore significantly increase the sensitivity of seagrasses to this pressure.

Sensitivity assessment

The organic enrichment of marine environment increases turbidity and causes the enrichment of the sediment in organic matter and nutrients (Pergent *et al* 1999). Evidence shows that seagrass beds found in proximity to a source of organic discharge were severely impacted with important losses of biomass. Although no study was found on the British species, the evidence suggests that *Zostera* and *Ruppia* would be negatively affected by organic enrichment.

No evidence was found addressing the benchmark of this study. A deposition of 100gC/m^2/year is considerably lower than the amount of organic matter discharged by sewage outlets and fish farms. **Resistance** to this pressure is thus deemed **'Medium'**. Recovery is likely to be slow resulting in a **'Medium' resilience**. Overall **sensitivity** of seagrasses to this pressure is **'Medium'** for **all seagrass/*Zostera* bed definitions** (OSPAR, HPI and PMF).

Resistance confidence

Quality of evidence is 'Medium' – based on inference from peer reviewed papers.
Applicability is 'Medium' – based on evidence of the effects of similar pressures.
Concordance is 'Medium' – evidence agreed on direction but varied on magnitude.

Resilience confidence

Quality of evidence is 'High' - based on peer reviewed literature.
Applicability is 'Low' - based on proxies (natural events) and effects of other pressures.
Concordance is 'Medium' – evidence agrees on direction but speed of recovery varies with type of impact, nature of site and sediment, and seagrass species.

5 Overview of information gaps and confidence in assessments

The sensitivity of seagrass beds to anthropogenic pressures is well documented. There is a large amount of field and laboratory based studies investigating the response of seagrass to human pressures, providing us with extensive knowledge on seagrass sensitivity. Some activities have been better documented than others, and some research gaps still persist.

The best documented activities are the impacts of physical damage on seagrass beds, in particular on the effects of surface and sub-surface abrasion. A wide range of activities give rise to this pressure and seagrass populations are especially at risk due to their preferred habitat. Indeed, shallow and protected waters are open to public access and thus exposed to trampling as well as boating activities (including anchoring and mooring). Each of these activities has been explored by a range of experimental or observatory studies and found that although seagrass plants are sensitive to physical damage, resilience was fairly high due to fast recovery rates. Studies focusing on the impacts of fishing gear (causing the abrasion of the sub-surface of the seabed) found much slower recovery rates. The extent of impact of this pressure occurs at a much larger scale explaining differences in resilience. The effects of fishing, in particular mechanical harvesting, were deemed so detrimental to seagrass populations, that legislation was put into place to regulate this pressure. A large amount of research has been conducted on the impact of individual fishing techniques; but the majority of studies focus on *Zostera* species. The sensitivity of *Ruppia* to fishing pressures is thus mostly based on expert judgment but with a high level of confidence due to the morphology of the plant. Similar to *Zostera* species, *R. maritima* has a shallow and weak root system and is incapable of vertical rhizome growth. More in depth research focusing on *Ruppia* is required to determine any differences in responses to assessed pressures.

Hydrological pressures were also widely studied, with large amounts of information available for *Zostera* and *Ruppia* species. In general, seagrass species have a wide tolerance for changes in environmental factors such as salinity and temperature. Any variation within tolerance limits to these factors observed between studies can be explained by differences in methodologies used to derive these values. Methodologies range from physiological studies, field observations and experimental manipulation to statistical models. Wide tolerance indicates that seagrass species growing in the mid-range of their tolerance will not be affected by environmental changes. Populations growing on the lower or upper limit can however be adversely impacted.

For several pressures, for example ‘changes in wave exposure’ and ‘organic enrichment’, a large quantity of information was available in relation to seagrass sensitivity to these pressures. But, much of the information was not directly comparable to the benchmarks used in this study. For instance, evidence exists that an increase in wave exposure causes mechanical damage to seagrass plants but no literature was found on how the height of a wave (the benchmark for this pressure) would affect plants. Expert knowledge was thus required to define the sensitivity of habitats in the light of available information.

Large knowledge gaps exist in particular in relation to invasive species. Several invasive plants and invertebrates were found to have negative impacts on seagrass beds but only very few studies were based in the UK. The lack of evidence made an adequate assessment of sensitivity impossible. More research is therefore needed to fill these gaps and understand ecological impacts of NIS on seagrass beds. New arrivals of NIS are posing a further threat; for instance, scientists believe that the invasive seagrass *Zostera japonica* will arrive on the British Isle in the new future. Occurring, in the same niche that the three British seagrasses currently occupy, *Z. japonica* could out-compete indigenous *Zostera* and *Ruppia* species.

There was a lack of information on the biotope A2.612 Macaronesian *Zostera noltei* meadows included in the OSPAR definition. No studies were found addressing this particular geographic region.

Overall, the literature provided strong evidence that the effects of pressures depended on the nature of the receiving habitat and the intensity of damage, with high intensity resulting in reduced biodiversity, reduced abundance or biomass of seagrass species and increased bare spaces. The size of the cleared area had an important effect on the recovery of the seagrass habitat with the recovery period exponentially increasing with size of impact scar.

There is also the potential for multiple stressors causing synergistic and additive effects. For instance, a rise in water temperature is non-lethal to seagrass plants but it may weaken the ability of the bed to resist other pressures therefore potentially shifting low sensitivity scores to medium or high sensitivity. However synergistic effects are not the focus of this report and were therefore not assessed.

6 Comparison with MB0102 sensitivity assessments

Nineteen 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. For seven of the pressures the evidence review assessment has supported the existing MB0102 assessment, although it should be noted that for wave exposure the underlying resilience score from MB0102 suggests a much slower recovery rate (although the overall score is the same).

Table 6.1. Comparison of sensitivities between this report and in 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), Not sensitive (NS), and Not assessed (NA).

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
Biological pressures	Genetic modification & translocation of indigenous species	NA	L (H/VL)	L (H/VL)	L (H/VL)	MB0102 considered only commercially farmed species and did not assess this pressure.
	Introduction of microbial pathogen	NS	NS (NS/NS)	NS (NS/NS)	NS (NS/NS)	Seagrass is not sensitive at the pressure benchmark.
	Introduction or spread of non-indigenous species (NIS)	M-H (L-M/VL-M)	H (L/L)	H (L/L)	H (L/L)	Assessment basis not recorded for MB0102, sensitivity was considered to be either Medium or High by workshops and reviewers for MB0102.
	Removal of non-target species	H (L/L)	M (N/H)	M (N/H)	M (N/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	NS (H/H)	NS (H/H)	NS (H/H)	NS (H/H)	MB0102 assessment supported by this evidence review.
Hydrological changes (inshore/local)	Emergence regime changes - local	L-M (M/L-H)	M (M/M)	M (M/M)	M (M/M)	The resistance assessment for MB0102 from workshops is in accordance with the conclusion reached through the evidence review. The range for MB0102 was generated by differences in the resilience score provided by the two expert workshops.
	Salinity changes - local	NS (H/H)	M (M/M)	M (M/M)	M (M/M)	Both MB0102 workshops suggested that seagrass would not be impacted by changes in salinity at the pressure benchmark. The evidence review score is based on the greater sensitivity of *Z. marina*.
	Temperature changes - local	NS (H/H)	L (M/H)	L (M/H)	L (M/H)	An MB0102 workshop suggested that seagrass would not be

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
						impacted by changes in salinity at the pressure benchmark. The evidence review score is based on the greater sensitivity to acute change and is more precautionary.
	Water flow (tidal current) changes - local, including sediment transport considerations	NS-M (M-H/M-H)	M (M/M)	M (M/M)	M (M/M)	The two MB0102 workshops disagreed regarding resistance of seagrass beds which led to differences in sensitivity categorisation. The conclusion of the first workshop is supported by the evidence review.
	Wave exposure changes - local	M (M/VL)	M (M/M)	M (M/M)	M (M/M)	The resistance scores developed by an MB0102 workshop were supported by the evidence review. MB0102 assessment and the evidence review differ in resilience but this has not led to a difference in the final score.
Physical damage (reversible change)	Abrasion/disturbance of the substrate on the surface of the seabed	L-M (L-M/H-M)	M (L/M)	M (L/M)	M (L/M)	The two MB0102 workshops disagreed on the level of resistance and hence subsequent recovery so that sensitivity was categorised as Low or Medium. The evidence review supports an assessment of Medium.
	Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	H (N/L-VL)	H (N/L)	H (N/L)	H (N/L)	The resistance scores developed by the MB0102 workshop were supported by the evidence review. The MB0102 assessment and the evidence review differ in resilience but this has not led to a difference in the final score.
	Changes in suspended solids (water clarity)	L-H (VL-M/VL-H)	H (L/L)	H (L/L)	H (L/L)	There was considerable uncertainty regarding sensitivity to this pressure. The evidence review assessment supports the earlier MarLIN assessment included in the MB0102 proforma and not the conclusions of the workshops.
	Habitat structure changes - removal of substratum (extraction)	H (N/VL-L)	H (N/VL)	H (N/VL)	H (N/VL)	The resistance scores developed by the MB0102 workshops were supported by the evidence review.
	Siltation rate changes, including smothering (depth of vertical sediment overburden)	M-H (N/L-M)	H (N/L)	H (N/L)	H (N/L)	The sensitivity range from the two MB0102 workshops results from underlying differences in resilience categorisation between the workshops which and hence sensitivity. The evidence review supports the more conservative resilience score and hence the

Pressure Theme	ICG-C Pressure	MB102	HPI	PMF	OSPAR	Comments
						high sensitivity score.
Physical loss (permanent change)	Physical change (to another seabed type)	M (L/M)	H (L/VL)	H (L/VL)	H (L/VL)	The evidence review suggested that seagrass beds were more sensitive to this pressure than indicated by MB0102 due to lower resilience so that recovery times are protracted.
	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.	Nutrient enrichment	M (M/M)	M (H/M)	M (H/M)	M (H/M)	The evidence review suggests that seagrass beds have higher resistance to this pressure than indicated for the assessments developed by MB0102 but suggests recovery is protracted resulting in a 'Medium' sensitivity.
	Organic enrichment	NS-M (M-H/M-H)	M (M/M)	M (M/M)	M (M/M)	The sensitivity range from the two MB0102 workshops results from underlying differences in resistance categorisation and hence resilience so that the workshops categorised sensitivity differently. The evidence review supports the more conservative resilience score and hence the higher sensitivity score of 'Medium'. The evidence review supports the assessments from one workshop.

Many 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. For two pressures, organic enrichment and siltation, it is the resilience scores, rather than the resistance assessments, that are the source of the range. In all the other instances where the sensitivity from MB0102 was expressed as a range both the resistance and resilience scores differ. The evidence review has reduced the uncertainty around these assessments by assigning a single sensitivity score to the pressures. For every pressure where sensitivity was previously assessed as a range of scores, the assessments made by the evidence review have supported one of the MB0102 assessments.

In three instances (salinity change, temperature change and physical change) the existing sensitivity assessments developed by MB0102 were dissimilar to the evidence review assessment. In each case the evidence review has developed an assessment of greater sensitivity. For physical change the greater sensitivity was due to a slower rate of recovery used for resilience. In the case of temperature and salinity changes the assessment was based on lower resistance (and hence there was an impact to recover from). The assessment for removal of non-target species is not discussed as the benchmark used is not clear; it is suspected that the assessment developed by MB0102 could have been based on physical disturbance rather than ecological effects.

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'[3].
- 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**.

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[3] 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.

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 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 Conclusions

The aim of this project was the development of sensitivity assessments for seagrass beds to 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 seagrass definitions given by HPI, PMF and OSPAR.

Nineteen pressures, falling in five categories - biological, hydrological, physical damage, physical loss, and pollution and other chemical changes - were assessed in this report. Assessments were based on the three British seagrasses *Zostera marina, Z. noltei* and *Ruppia maritima*. *Z. marina* var. *angustifolia* was considered to be a subspecies of *Z. marina* but it was specified where studies had considered it as a species in its own rights. Where possible other components of the community were investigated but the basis of the assessment focused on seagrass species.

To develop each sensitivity assessment, the resistance and resilience of the key elements were assessed against the pressure benchmark using the available evidence. The benchmarks were designed to provide a 'standard' level of pressure against which to assess sensitivity. Overall, seagrass beds were highly sensitive to a number of human activities:

- penetration or disturbance of the substratum below the surface;
- habitat structure changes – removal of substratum;
- physical change to another sediment type;
- physical loss of habitat;
- siltation rate changes including and smothering; and
- changes in suspended solids.

High sensitivity was recorded for pressures which directly impacted the factors that limit seagrass growth and health such as light availability. Physical pressures that caused mechanical modification of the sediment, and hence damage to roots and leaves, also resulted in high sensitivity.

Seagrass beds were assessed as 'not sensitive' to microbial pathogens or 'removal of target species'. These assessments were based on the benchmarks used. *Z. marina* is known to be sensitive to *Labyrinthula zosterae* but this was not included in the benchmark used. Similarly, 'removal of target species' addresses only the biological effects of removal and not the physical effects of the process used. For example, seagrass beds are probably not sensitive to the removal of scallops found within the bed but are highly sensitive to the effects of dredging for scallops, as assessed under the pressure penetration or disturbance of the substratum below the surface'. This is also an example of a synergistic effect between pressures. Where possible, synergistic effects were highlighted but synergistic and cumulative effects are outside the scope off this study.

The report found that no distinct differences in sensitivity exist between the HPI, PMF and OSPAR definitions. Individual biotopes do however have different sensitivities to pressures. These differences were determined by the species affected, the position of the habitat on the shore and the sediment type. For instance evidence showed that beds growing in soft and muddy sand were more vulnerable to physical damage than beds on harder, more compact substratum. Temporal effects can also influence the sensitivity of seagrass beds. On a seasonal time frame, physical damage to roots and leaves occurring in the reproductive season (summer months) will have a greater impact than damage in winter. On a daily basis, the tidal regime could accentuate or attenuate the effects of pressures depending on high and low tide. A variety of factors must therefore be taken into account in order to assess the sensitivity of a particular seagrass habitat at any location.

No clear difference in resilience was established across the three seagrass definitions assessed in this report. The resilience of seagrass beds and the ability to recover from human induced pressures is a combination of the environmental conditions of the site, growth rates of the seagrass, the frequency and the intensity of the disturbance. This highlights the importance of considering the species affected as well as the ecology of the seagrass bed, the environmental conditions and the types and nature of activities giving rise to the pressure and the effects of that pressure. For example, pressures that result in sediment modification (e.g. pitting or erosion), sediment change or removal, prolonged recovery. Therefore, the resilience of each biotope and habitat definitions is discussed for each pressure.

Using a clearly documented, evidence based approach to create sensitivity assessments allows the assessment 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. The evidence review has reduced the uncertainty around the MB0102 assessments by assigning a single sensitivity score to the pressures. 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.

Finally, as seagrass habitats may 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

ASFA - Aquatic Sciences and Fisheries Abstracts

EUNIS - European Union Nature Information System

HPI - Habitat of Principle Importance

ICG-C - Intercessional Correspondence Group on Cumulative Effects

JNCC - Joint Nature Conservation Committee

MCZ - Marine Conservation Zone

MHW - Mean High water

MLW - Mean Low water

MNCR - Marine Nature Conservation Review

NIS - Non-indigenous Species

NMBL - National Marine Biological Library

OSPAR - Oslo and Paris Commission

PMF - Priority Marine Feature (in Scotland)

WoRMS - World Register of Marine Species

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; Hollings (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[4] 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 and Hull (2012-2013), who introduced a detailed evaluation and audit trail of evidence on which to base the sensitivity assessments.

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

To facilitate the assessment of features, pressure definitions and benchmarks were established. Pressure definitions and associated benchmarks were supplied by JNCC for 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 & 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 10.1** and **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 physicochemical 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 physicochemical 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 physicochemical 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 definitions and benchmarks

Pressures and definitions from the Intercessional Correspondence Group on Cumulative Effects (OSPAR 2011) and 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, 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 *Martelia 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 in Central and Eastern Baltic).	Removal of features through pursuit of a target fishery at a commercial scale

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
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
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	Increase from 35 to 38 units for one year. Decrease in Salinity by 4-10 units a year

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
		event/activity and local environment.	
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%
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

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
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 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	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
		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
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-colonize; 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

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
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). 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)	up to 30cm of fine material added to the seabed in a single event

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
		- 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
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

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
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
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

Pressure theme	ICG-C Pressure	ICG-C description	MB0102 benchmark
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 10 μSv 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 ~2700 μSv/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)

A2.61 – Seagrass beds on littoral sediments

Dominants are *Zostera* spp.

A2.611 – Mainland Atlantic *Zostera noltii* or *Z. angustifolia* meadows

Formations of *Zostera noltii* or *Z. angustifolia* of the Atlantic, North Sea and Baltic shores of continental Europe and of its continental shelf islands.

A2.6111 – *Zostera noltii* beds in littoral muddy sand

Mid and upper shore wave-sheltered muddy fine sand or sandy mud with narrow-leafed eel grass *Zostera noltii* at an abundance of frequent or above. It should be noted that the presence of *Z. noltii* as scattered fronds does not change what is otherwise a muddy sand biotope. Exactly what determines the distribution of *Z. noltii* is not entirely clear. It is often found in small lagoons and pools, remaining permanently submerged, and on sediment shores where the muddiness of the sediment retains water and stops the roots from drying out. An anoxic layer is usually present below 5 cm sediment depth. The infaunal community is characterised by the polychaetes *Scoloplos armiger, Pygospio elegans* and *Arenicola marina*, oligochaetes, the spire shell *Hydrobia ulvae*, and the bivalves *Cerastoderma edule* and *Macoma balthica*. The green algae *Enteromorpha* spp. may be present on the sediment surface. The characterising species lists below give an indication both of the epibiota and of the sediment infauna that may be present in intertidal seagrass beds. The biotope is described in more detail in the British National Vegetation Classification (see the chapter on saltmarsh communities in Rodwell (Rodwell 2000)). Situation: *Z. noltii* is most frequently found on lower estuary and sheltered coastal muddy sands, together with biotopes such as unit A2.242. Temporal variation: There may be seasonal variation in the area covered by intertidal seagrass beds, as plants die back during cold temperatures in winter. Intertidal seagrass beds may also be subject to heavy grazing by geese, which can reduce the extent of the plant cover significantly. The rhizomes of the plants will remain in place within the sediment in both situations.

A2.612 –Macaronesian *Zostera noltii* meadows

Very local *Zostera noltii* formations of Fuerteventura and Lanzarote.

A2.614 – *Ruppia maritima* on lower shore sediment

Proposed new unit. No description available.

A5.53 - Sublittoral seagrass beds

Beds of submerged marine angiosperms in the genera *Cymodocea, Halophila, Posidonia, Ruppia, Thalassia, Zostera*.

A5.533 – *Zostera* beds in full salinity infralittoral sediments

Beds of seagrass (*Zostera marina* or *Ruppia* spp.) in shallow sublittoral sediments. These communities are generally found in extremely sheltered embayments, marine inlets, estuaries and lagoons, with very weak tidal currents. They may inhabit low, variable and full salinity marine habitats. Whilst generally found on muds and muddy sands they may also occur in coarser sediments, particularly marine examples of *Zostera* communities.

A5.5331 – *Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand

Expanses of clean or muddy fine sand and sandy mud in shallow water and on the lower shore (typically to about 5 m depth) can have dense stands of *Zostera marina/angustifolia.* Note: the taxonomic status of *Z. angustifolia* is currently under consideration. In A5.5331 the community composition may be dominated by these *Zostera* species and therefore characterised by the associated biota. Other biota present can be closely related to that of areas of sediment not containing *Zostera marina*, for example, *Laminaria saccharina*, *Chorda filum* and infaunal species such as *Ensis* spp. and *Echinocardium cordatum*. From the available data it would appear that a number of sub-biotopes may be found within this biotope dependant on the nature of the substratum and it should be noted that sparse beds of *Z. marina* may be more readily characterised by their infaunal community. For example, coarse marine sands with seagrass have associated communities similar to A5.133, A5.137 or A5.135 whilst muddy sands may have infaunal populations related to A5.241, A5.243 and A5.242. Muddy examples of this biotope may show similarities to A5.332, A5.343, A5.342 or A5.351. At present the data does not permit a detailed description of these sub-biotopes but it is likely that with further study the relationships between these assemblages will be clarified. Furthermore, whilst the *Zostera* biotope may be considered an epibiotic overlay of established sedimentary communities it is likely that the presence of *Zostera* will modify the underlying community to some extent. For example, beds of this biotope in the south-west of Britain may contain conspicuous and distinctive assemblages of Lusitanian fauna such as *Laomedea angulata*, *Hippocampus* spp. and *Stauromedusae*. In addition, it is known that seagrass beds play an important role in the trophic status of marine and estuarine waters, acting as an important conduit or sink for nutrients and consequently some examples of *Zostera marina* beds have markedly anoxic sediments associated with them.

A.5.5343 – *Ruppia maritima* in reduced salinity infralittoral muddy sand

In sheltered brackish muddy sand and mud, beds of *Ruppia maritima* and more rarely *Ruppia spiralis* may occur. These beds may be populated by fish such as *Gasterosteus aculeatus* which is less common on filamentous algal-dominated sediments. Seaweeds such as *Chaetomorpha* spp., *Enteromorpha* spp., *Cladophora* spp., and *Chorda filum* are also often present in addition to occasional fucoids. In some cases the stoneworts *Lamprothamnium papulosum* and *Chara aspera* occur. Infaunal and epifaunal species may include mysid crustacea, the polychaete *Arenicola marina*, the gastropod *Hydrobia ulvae*, the amphipod *Corophium volutator* and oligochaetes such as Heterochaeta costata. In some areas *Zostera marina* may also be interspersed with the *Ruppia* beds.

A5.545 – *Zostera* beds in reduced salinity infralittoral sediments

No description available.

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'[5];

- 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

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[5]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.

guidance values for sensitivity assessment, to allow comparison of sensitivities between 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.