Strategic review of sectoral impacts on coastal marine ecosystems in Ireland

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Key Messages

Ireland's coastal waters are very important to its society and its economy. A wide range of activities impinge on them, with potential to affect biodiversity and the provision of ecosystem services. As such, EU and national legislation provides for these activities to be regulated to ensure the long-term sustainability of this valuable resource. Effective implementation of this legislation requires a sound knowledge of the nature and relative importance of impacts caused by different activities.

Our assessment of potential impacts on coastal marine ecosystems of pressures associated with sectoral activities involved a systematic review of the literature and consultation with appropriate experts. Relevant research often focuses on pressures, such as pollution, habitat loss and hydrological changes rather than on the sectors of activity that introduce them. The first step was therefore to map pressures to sectors of human activity, such that the overall effects of particular sectors could be interpreted from available research findings. We then categorised the resistance of each habitat to potential impacts of each pressure on extent and quality and assessed the likely time to recovery (resilience). Our findings are outlined here and presented in more detail as a series of summary tables, which include clarification of the extent, nature, quality and applicability in an Irish context of the evidence that underpins each entry.

Pressures which result in habitat loss or change or direct physical disturbance clearly have the most direct and irreparable impacts on the extent of habitats, particularly sedimentary habitats. Such pressures are exerted by sectors such as fisheries and aquaculture, the construction industry with lesser influences of the shipping, leisure, tourism and energy sectors.

Sedimentary habitats also have limited resistance to changes in water flow and/or tidal emergence regimes, which are also caused by physical installations, such as those associated with aquaculture, construction, shipping and the energy industry.

Exposed rocky reefs are comparatively resistant to physical pressures, but less so to chemical contaminants or biological pressures such as harvesting and non-indigenous species. Sheltered reefs on the other hand are also vulnerable to physical pressures such as siltation. If pressures are removed and there is an appropriate source of larvae, most rocky substrata can be recolonised and tend to recover within 10 to 15 years.

The addition of inorganic nutrients and organic matter leading to eutrophication and deoxygenation causes changes to many of the habitats, particularly muddy sands, seagrass and sheltered rocky reefs. These are derived from agricultural and industrial discharges, sewage and aquaculture, which need to be considered as cumulative sources in a given estuary or embayment and associated catchment.

Shipping, leisure boating and aquaculture are the main sources of non-indigenous species, some of which become invasive and cause substantial changes to marine ecosystems with little scope for recovery.

In Ireland, perhaps the most extensive industries with potential to influence coastal marine biodiversity are agriculture, fisheries and aquaculture. These activities occur in many SACs and SPAs and finding an acceptable balance between their important economic and social benefits and the achievement of conservation objectives presents a significant challenge.

We emphasise that the summary tables should serve as a guide only and that their applicability to any site-specific assessment process should be informed by appropriate expert judgement. We argue that the knowledge-base to anticipate cumulative and combined impacts of multiple pressures is not sufficiently well developed for most pressures and receiving environments. We therefore recommend a precautionary approach of assuming additive or synergistic effects of multiple pressures where there is uncertainty.

Key areas for future research include:

- The introduction and spread of invasive non-indigenous species and the resistance of ecosystems to their effects.
- The influence of sectoral activities on maërl and seagrass.
- Assessment of the compatibility of aquaculture activities with the conservation objectives of SACs and SPAs to inform the development of management plans.
- Links between changes in biodiversity, ecosystem functioning and the provision of ecosystem services to assess how sectoral activities may influence the flow of economic and societal services from ecosystems.
- How multiple sectoral pressures combine to affect ecosystems and how their effects may be modified by global climate change and changes to the pH and carbonate chemistry of the oceans.
- Resilience – the capacity of ecosystems to recover after impact.
- Tipping points into alternative states from which recovery may be unlikely.

- Carefully designed long-term sampling to detect changes in biodiversity and ecosystem functioning and interpret them in relation to sectoral activities and the pressures they exert. Such programmes could be built around compliance monitoring required under the Habitats Directive, Water Framework Directive and Marine Strategy Framework Directive.

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Introduction

Ireland has one of the largest marine territories in Europe, covering some 220 million acres (Marine Institute, 2012). It is a rich resource of great cultural and monetary value. A large proportion of the human population of Ireland leaves near the coast and a range of sectoral activities take place in the marine environment or impinge on it indirectly via terrestrial run-off. Coastal waters are the most closely involved with human activities and as such are potentially the most impacted. This review will therefore focus on the coastal marine environment.

Legislative context

Three main European Directives directly drive the management and protection of coastal habitats in Ireland: the Habitats Directive (HD), the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). These directive share some features that contribute to the rationale and structure of the current review. For each of them, member states are required to take stock of aspects of their marine environments, assess risks to their conservation, ecological or environmental status respectively and put in place management plans for the achievement of good status. Each of them contains provision for the restriction of human activities in selected areas based upon assessments of their potential to impact coastal marine ecosystems. Additional relevant details are summarised in Appendix 1.

Sectoral activities impinging on coastal marine environments

A range of sectors impinge on marine coastal environments in Ireland, spanning fisheries and aquaculture, agriculture, waste management, industry, construction and development, shipping, leisure and tourism and energy. Each may affect ecosystems by imposing a number of specific pressures, which may be physical, such as the direct destruction of habitat, physical disturbance or changes in siltation or wave exposure, chemical such as the introduction of contaminants, nutrients or organic matter into the environment or biological, by removal of biota or introduction of pathogens or non-indigenous species (Robinson et al. 2008). Assessment of sectoral impacts requires consideration of the pressures each sector exerts and the impact of those pressures on particular habitat types.

Objectives and approach

This review aims to provide a basis for assessing the impact of sectoral activities on marine coastal ecosystems in Ireland. Such an assessment may be required at a national level, e.g. in developing policy or as part of Strategic Environmental Assessment, or at a local level, e.g. as part of Environmental Impact Assessment, Appropriate Assessment or the development of

Programmes of Measures under the Water Framework Directive or Marine Strategy Framework Directive.

The marine coastal environment is a mosaic of different habitat types, each with particular characteristics and susceptibilities to anthropogenic impact. For the purposes of this review, we have applied the classification of habitats recommended by Crowe et al. (2011) into gravels, sands, muds, muddy sands/sandy muds, exposed reef, sheltered reef and biogenic communities (e.g. Maërl, seagrass (*Zostera*)). Differences between these habitat types have been recognised in the formulation and implementation of legislation for the protection and management of the marine environment (Appendix 1).

Assessment of proposed activities requires that two key questions be addressed: 'What would be the likely impacts of the proposed activity?' and 'How quickly could the ecosystem recover from the impact?' For each of the focal habitats, we undertook to address these questions for the range of applicable sectors of human activities and the pressures they exert. We considered impacts and recover both in terms of the *extent* and *quality* of focal habitats. The extent of habitats is self-explanatory. The quality of habitats refers to the integrity of their biotic and abiotic components and/or their capacity to function efficiently and deliver ecosystem services. The quality of a seagrass bed may be diminished, for example, if shoot density is reduced, shoots are damaged or smothered, the community of associated flora and fauna is altered or productivity and nutrient cycling are affected.

A standard list of anthropogenic pressures as set out under OSPAR and refined from Robinson et al. (2008) was compiled (see Table A2.1, Appendix 2). Each sector of human activity results in one or more of the described pressures. From the comprehensive list, some pressures of limited relevance to Ireland were omitted from in-depth analysis. The first step in the review process involved the production of a matrix of pressures against sectors, summarising the pressures that arise from each sector of human activity (Table 1a). The association of pressures with sectors is based on Robinson et al (2008) (see Table A2.2, Appendix 2).

Where evidence was lacking, the precautionary principle and/or best expert judgement was generally applied. It is important to note that the generic review provided in this report will not be sufficient to provide detailed advice in relation to impacts of particular activities in particular contexts. The intention is merely to provide initial guidance based on the best available evidence. Clearly, pressures will be exerted at different scales and intensities by different activities and this must be taken into account in interpreting the conclusions of this report. It is also important to note that the knowledge base is expanding rapidly. Recommendations may need to be revised in future as new evidence comes to light.

Although the potential modification of localised impacts by future climate change and ocean acidification is an issue, it is beyond the scope of the current review. The review focuses on the unmitigated impacts of each sector of human activity. Convincing approaches to mitigation can then be taken into account in particular cases.

A systematic review of the literature relating to the impacts of pressures (linked to sectors) on each of the habitat units was undertaken. A set of search terms (Appendix 3) was used to search for relevant literature in two databases: ISI Web of Science and Aquatic Science and Fisheries Abstracts. Articles returned by the searches were filtered for relevance and used to complete a set of Tables for each habitat, summarising their susceptibility to the pressures described above (Table 1a and b). Where available, peer reviewed review articles and meta-analyses were used to inform the completion of cells in the Tables. No cells required completion through expert judgement alone, however all values have been reviewed by relevant experts from the list of consultees (see Acknowledgements). No major changes were recommended to any entries, though advice was given on additional literature to consult (which is identified separately in reference lists). Due to the large volume of literature returned from searches it has not been possible to include details from every paper in the report.

Table 1a. A matrix of pressures associated with sectoral activities (**P**-physical, **C**-chemical and **B**-biological). Pressures and sectors are derived from Robinson et al (2008). Explanatory notes for the different sectors are provided below.

	Sector/Pressure	Fisheries		Aquaculture		Sewage discharge	Agricultural discharge	Industrial discharge	Construction/ development	Shipping	Leisure & tourism	Energy
		Active	Passive	Fin	Shellfish							
P	**Habitat loss (to land)**						■		■		■	
P	**Habitat change (to another marine habitat)**	■		■	■	■		■	■			
P	**Physical disturbance**	■	■	■	■	■			■	■	■	■
P	**Siltation rate changes**	■	■	■	■	■	■	■	■			■
P	**Temperature change**					■		■				■
P	**Salinity change**					■		■				■
P	**Water flow**			■	■			■	■	■		■
P	**Emergence regime**											
P	**Wave exposure changes-local**			■	■				■	■	■	
P	**Litter**	■	■	■	■	■		■	■	■	■	
C	**Non-synthetic compounds**	■		■	■	■		■	■	■		■
C	**Synthetic compounds**	■		■		■	■	■	■	■	■	■
C	**De-oxygenation**			■	■	■	■	■				
C	**Inorganic nutrients**			■	■	■	■	■				
C	**Organic enrichment**			■	■	■	■	■				
B	**Introduction of microbial pathogens**			■	■	■	■			■	■	
B	**Introduction/spread of non-indigenous species**			■	■					■		■
B	**Removal of target and non-target species**	■	■		■				■		■	■

□ - no association between sector and pressure ■ - potential association between sector and pressure

Table 1b. Explanatory notes for the sectors and sub-sectors in Table 1a. The explanations given in this table are examples and are not intended to be exhaustive for the sectors described.

Sector	Description of sector and clarification of pressures
Fisheries- active	Biomass is removed with the use of mobile gear through trawling and/or dredging.
Fisheries- passive	Biomass is removed with the use of stationary gear such as potting, staked nets and lines.
Aquaculture- fin	The cultivation, in suspended cages, of finned fish such as salmon.
Aquaculture- shellfish	The cultivation of bivalves such as oysters and mussels on bottom and suspended substrata.
Sewage discharge	Includes the discharge of raw, primary and secondary treated effluent and of storm water runoff from roads.
Agricultural discharge	Includes diffuse inputs of nutrients from land, often via freshwater systems.
Industrial discharge	Includes effluent (not sewage) resulting from industrial activities such as brewing, pharmaceuticals, metal works and food processing.
Construction development	Construction of coastal infrastructure and activities related to this; including navigational dredging, aggregate extraction, sea defences, barrages, weirs, marinas and harbours and beach replenishment.
Shipping	Includes shipping in industrial sectors such as oil and gas and container shipping.
Leisure and tourism	Activities include angling, bait collection and the use of small motor craft for pleasure.
Energy	Includes power stations where cooling water maybe produced and the construction of marine based renewable energy structures such as wind, tidal and wave turbines.

Summary of findings in relation to each of the focal habitats

The summary descriptions below are based on the Tables presented in the 'Summary Tables' section, which include all the references on which the statements are based. The Tables are based on a finer subdivision of habitat types than the description below, which seeks to summarise the information into a more accessible form.

A number of ecological concepts underpin the approach taken here, specifically: resistance stability, resilience stability, cumulative and interactive effects, tipping points, the precautionary principle. These concepts and the terminology that is used in the text below are explained in the 'Explanation of concepts' section.

Coarse sediments (sands and gravels)

Gravels are generally home to comparatively depauperate communities. The grains are large, mobile and abrasive. In common with all of the habitats based on physical substrata (i.e. other sedimentary habitats and rocky reefs), their extent is only strongly influenced by habitat loss or change or direct physical disturbance. If lost or replaced then the action of geological/geomorphological processes would be required for them to recover. In terms of quality, they have medium or high resistance and resilience to most pressures, with the exception of changes to water flow and contamination with synthetic compounds; they have low resilience to physical disturbance (Table GR1). The available literature was not extensive, but there was generally a high degree of concordance and relevance to the Irish context (Table GR2).

Sands have a very similar matrix of resistance and resilience to gravels. They have a higher degree of resistance and resilience to water flow, but the biota is sensitive to changes to emergence regime (Table SD1). There are documented impacts of removal of target and non-target species by harvesting activities, but no evidence was available to judge the impact of non-indigenous species. Overall, sandy habitats have medium or high resilience to the pressures considered (Table SD1). The evidence base in support of the assessment is comparatively extensive and there was a high degree of concordance and relevance to the Irish context (Table SD2).

Fine sediments (muds and muddy sands)

Muds and muddy sands are the most extensively studied sedimentary habitats. They differ substantially in their resistance and resilience to pressures, however, with muddy sands generally more sensitive to a wide range of pressures and showing limited resilience to several of them. Muds have low resistance to physical disturbance, wave exposure changes, synthetic compounds and removal of target and non-target species (Table MD1). They have medium or high resilience to all pressures considered. Muddy sands on the other hand also have low resistance to salinity change, non-synthetic compounds, de-oxygenation and inorganic nutrient enrichment and are slow to recover from impacts of wave exposure changes and contamination by synthetic or non-synthetic compounds (Table MS1).

For most of the pressures on muds, different studies agreed on the direction of change caused, but not on its magnitude (Table MD2). For muddy sands, different studies generally agreed on both the direction and magnitude of change (Table MS2). For both habitats, the evidence base was highly applicable to the Irish context, studies having been completed in Ireland, UK or similar latitudes in northern Europe (Tables MD2, MS2).

Rocky reefs

Rocky reefs are comparatively well studied, including a large body of relevant research in the British Isles and temperate Europe. Sheltered reefs tend to be more susceptible to a range of pressures and slower to recover than exposed reefs. Exposed reefs have high resistance to most physical pressures, but medium to low resistance to chemical or biological pressures (Table ER1). They are particularly vulnerable to contamination by synthetic and non-synthetic compounds, to modification by non-indigenous species and to removal of target and non-target species, e.g. through scraping of mussels from rocky shores for aquaculture. Once non-indigenous species such as the oyster *Crassostrea gigas* have become established, there is little scope for eradication or a return to natural communities.

Sheltered reefs have medium to low resistance to most physical, chemical or biological pressures and are more prone than exposed reefs to siltation, temperature changes, salinity changes, changes in water flow, non-synthetic compounds and organic enrichment (Table SR1). They occur in semi-enclosed, low energy environments in which sediments are often deposited and contaminants are retained. Resilience to physical disturbance and organic and inorganic enrichment is considered low, but harvested populations have shown a high capacity for recovery (Table SR1).

Much of the evidence underpinning these inferences is derived from reviews which include experimental work and reveal a high degree of concordance among studies (Tables ER2, SR2).

Biogenic habitats of high conservation value

Biogenic habitats, unlike those based on physical substrata, can have both their extent and quality impacted by the full range of pressures considered because even chemical and biological pressures can cause death or degradation of the organisms that form their foundations. They also have capacity to recover in extent as well as quality if they are damaged or lost because their foundation species can, in principle, recolonise. Neither maërl nor seagrass (*Zostera*), however, have much resilience to physical disturbances or habitat changes or loss (Tables MR1, Z1).

Maërl

Maërl is a complex biogenic reef habitat formed subtidally by a coralline alga. It is explicitly protected by the Habitats Directive. Based on available evidence, it has low resistance to physical disturbance, siltation or removal by fishing gear, but medium to high resistance to all other pressures studied (Table MR1). There is no evidence in relation to litter and synthetic compounds. Its resilience in relation to chemical pressures is medium or high, but it has low capacity to recover from removal by fishing or impacts by non-indigenous species.

It is important to note that the evidence base for inferring resistance or resilience to impacts by many of the pressures is very limited and much more research is needed on this habitat (Table MR2).

Seagrass

Seagrass (predominantly *Zostera* in Ireland) has been more extensively studied than maërl. It is widely regarded as a key habitat in coastal systems containing high biodiversity and serving as a nursery habitat for species of commercial and conservation importance. It too is directly protected under the Habitats Directive. It is very sensitive to habitat loss, physical disturbances and siltation (Table Z1). It shows little to no capacity for recovery from removal or disturbance, but can re-establish itself after siltation events. Changes in emergence regime can also cause its irretrievable loss. Its sensitivity to nutrient and organic enrichment and deoxygenation is well documented, with little resistance to impacts on quality and low to medium resistance to impacts on extent.

Although the evidence base is fairly extensive, it is patchy and there is limited concordance in relation to some of the pressures and only moderate applicability to the Irish context for most pressures, with much of the work having been done in the USA or Australia (Table Z2).

Overall conclusions

Pressures which result in habitat loss or change or direct physical disturbance clearly have the most direct and irreparable impacts on the extent of habitats, particularly sedimentary habitats, which are widely being replaced by hard substrata as coastal development and defences proliferate. Such pressures are exerted by sectors such as fisheries and aquaculture, the construction industry with lesser influences of the shipping, leisure, tourism and energy sectors (Table 1).

Sedimentary habitats also have limited resistance to changes in water flow and/or tidal emergence regimes, which are also caused by physical installations, such as those associated with aquaculture, construction, shipping and the energy industry.

Exposed rocky reefs are comparatively resistant to physical pressures, but less so to chemical contaminants or biological pressures such as harvesting and non-indigenous species. Sheltered reefs on the other hand are also vulnerable to physical pressures such as siltation. If pressures are removed and there is an appropriate source of larvae, most rocky substrata can be recolonised and tend to recover with 10 to 15 years.

The addition of inorganic nutrients and organic matter leading to eutrophication and deoxygenation presents problems for many of the habitats, particularly muddy sands, seagrass and sheltered rocky reefs. These are derived from agricultural and industrial discharges, sewage and aquaculture, which need to be considered as cumulative sources in a given estuary or embayment and associated catchment.

Shipping, leisure boating and aquaculture are the main sources of non-indigenous species, some of which become invasive, are very difficult to control once established and cause substantial changes to marine ecosystems, with limited scope for recovery. Potentially invasive species in marine habitats in Ireland include the oyster *Crassostrea gigas* and the tunicate *Didemnum vexillum*, both of which are established in some locations.

In an Irish context, perhaps the most extensive industries on or near the coast with the greatest potential to influence coastal marine biodiversity are agriculture (through run-off of inorganic nutrients and biocides), fisheries and aquaculture (through direct physical effects as well as localised addition of nutrients and biocides). The interactions of aquaculture with biodiversity and potential approaches to mitigation are summarised in another SIMBIOSYS strategic review (Callier et al. 2012). These sectoral activities occur extensively in SACs and finding an acceptable balance between their important economic and social benefits and the achievement of conservation objectives presents a significant challenge.

Key areas for future ecological research

Specific gaps in knowledge identified in the systematic review of literature included the following (for which either zero or one article was revealed by the formal searches performed):

- Resistance of most habitats to litter.
- Resistance of sandy and muddy sand habitats to non-indigenous species.
- Resistance of muddy sand habitats to changes in temperature and salinity and microbial pathogens.
- Resistance of maërl to many physical and chemical pressures.
- Resistance of seagrass habitats to changes in wave exposure, emergence regime and microbial pathogens.

Not all of these gaps, however, should necessarily form a high priority for research in Ireland. In most cases, for example, litter could be expected to have only minor impacts. However, the potential impacts of microplastics derived from litter is a recently developed but active area of research with potentially far-reaching implications.

Invasive non-indigenous species constitute a very substantial threat to the integrity of native ecosystems and the services they provide. Counteracting that threat is very challenging and requires co-ordinated surveys and ecological research to document, understand and predict spread of invaders and research into their impacts to underpin analysis of tradeoffs between the costs and benefits of management interventions.

Changes in temperature and salinity in Ireland are less likely to be driven by sectoral activities as by climate change. As such, they do not represent a priority focus for research in the current context, except as modifiers of the impact of pressures derived from sectoral activity (see below). The influence of sectoral activities on maërl and seagrass clearly require further research if these habitats are to be conserved effectively.

Targeted research may be needed to assess the compatibility of aquaculture activities with the conservation objectives of Special Areas of Conservation and Special Protection Areas to inform the development of management plans for those areas (see Callier et al. 2012).

Although the sensitivity of the habitats to a range of sectoral pressures was documented in the literature, much of that information related primarily to biodiversity and community structure. The stability of ecosystem functioning is much less well understood in many marine habitats. Links between biodiversity, ecosystem functioning and the provision of ecosystem services is also an area of active research that is urgently needed if we are to understand how sectoral activities may influence the flow of crucial economic and societal services from ecosystems.

In general, resilience of ecosystems after the removal of particular sectoral pressures is much less well understood than resistance. Even the definition of resilience is contentious and it is much more challenging to gather the evidence required to characterise it. Relevant research requires complex, well designed experiments or sampling programmes done at large spatial scales (to simulate meaningful recolonisation processes) and over extended periods of time to allow for recovery to take place.

Other key issues for which understanding is limited include tipping points and the ways in which multiple pressures combine to affect ecosystems (see ‘Additional issues and considerations’ section). Localised pressures can combine with each other in as yet un-predictable ways and their effects in turn may be modified by larger scale processes associated with global climate change and changes to the pH and carbonate chemistry of the oceans. These pressures may drive ecosystems towards unknown tipping points into alternative states from which recovery may be very unlikely. Research in these areas is essential and challenging.

Compliance monitoring is required under the Habitats Directive, Water Framework Directive and Marine Strategy Framework Directive. It is recognised that the requirements of each differ. However, if these programmes can be effectively coordinated and integrated to some degree they will be more cost effective. Minor adjustments and supplementary research to address key ecological questions could also maximise the insight gained and contribute to filling the above knowledge gaps. Long term data from an established network of carefully selected sites would be an invaluable resource for interpreting future changes in marine ecosystems, particularly if linked to monitoring of sectoral activities and the pressures they exert (see Crowe et al. 2011).

Explanations of terminology and concepts used in the review

Susceptibility of habitats to impact – resistance stability

The degree to which a particular habitat is impacted by a particular pressure varies depending on the habitat and the pressure involved. In other words, different habitats have different degrees of *resistance* to pressures. Resistance is a form of stability and is distinct from resilience (see below), which is the capacity of the system to recover from change (Grimm and Wissel 1997). The resistance categories used in Table 2 are based on Odum's (1989) definition of resistance which is '*the ability of an ecosystem to withstand disturbance without undergoing a phase shift or losing structure or function*'. They are adapted from those used by Robinson et al. (2008) for an OSPAR study which developed a protocol to assess the sensitivity of marine habitats to a variety of pressures.

Many habitats and organisms possess an inherent resistance to natural and anthropogenic pressures. However the resistance of a habitat to loss of extent in response to a given pressure does not imply its resistance to a loss of quality in the functioning of the system. Natural variability and resistance to natural disturbance can sometimes make it difficult to detect the effects of human activities on marine ecosystems.

Table 2. The resistance categories used to complete tables for each habitat (adapted from Robinson et al. 2008).

Resistance category	**Description**	
	Extent	**Quality**
None	Total removal of habitat or complete change to another marine habitat	Removal of typical fauna and flora
Low	Removal of significant proportion of habitat area or change of significant proportion of area to another marine habitat	Effect on biological structure of the habitat and widespread mortality of associated flora and fauna
Medium	Removal of some of the habitat area or some change of area to another marine habitat	Some damage to biological structure of the habitat and mortality at significant levels to flora and fauna
High	No significant change to habitat area	No effect on viable populations but may affect feeding, respiration and reproduction rates

Recoverability – resilience stability

Resilience can be defined as '*the ability of a system to recover from disturbance or change*' (Carpenter et al. 2001). Marine ecosystems have an inherent resilience to damage and loss, which varies depending on natural conditions and the nature and level of pressures impacting them. For example, relatively exposed areas which naturally experience high levels of physical disturbance may recover from anthropogenic physical disturbance more quickly than those in sheltered areas. Understanding the inherent resilience of an ecosystem, and its recoverability following particular human impacts is a key aspect of managing human activities and setting sustainable limits for those activities.

One approach to scoring resilience specifies rates of recovery of habitats from complete removal. This standardised approach leads to a single value, inherent to the system regardless of the variation in the nature or magnitude of degradation caused by the pressure involved, and enables direct comparisons among habitats. The current review recognises that different pressures cause different changes in the structure and functioning of habitats, which can therefore lead to different recovery times from impacts associated with those pressures. This information is valuable for appropriate assessment of specific activities. Resilience after degradation by different pressures was therefore classified into different categories (Table 3) based on the literature reviewed. We emphasise that such values are only indicative and will vary depending on the severity of impact in particular cases.

Table 3. The resilience categories used to complete tables for each habitat (from Robinson et al. 2008).

Category	**Description**
None	No recovery > 100 years
Low	Recovery 10 – 100 years
Medium	Recovery 2 – 10 years
High	Recovery < 2 years

Resistance should arguably be given precedence over resilience in appropriate assessment; the fact that a particular habitat generally has capacity to recover should not necessarily be used to justify causing damage to it.

Quality of evidence and applicability in an Irish context

There are a number of sources of evidence that can be used to develop a scientific basis for assigning the resistance and resilience categories described above. Correlative evidence from observational studies, such as those which sample extent or quality of habitats under different regimes of stress can give a good indication of how those stressors may affect habitats but causal links cannot be inferred. Variation in extent or quality may be underpinned by variation in factors other than the stressor of interest. Experimental evidence is required to infer causal links between particular stressors and changes to extent or quality of habitats. Experiments may be conducted in the laboratory or in the field, usually in small scale plots. Such evidence can itself be criticised on a number of grounds, such as the lack of realism (particularly in laboratory experiments), the potential for experimental artefacts and difficulties in drawing inferences about large scale processes from small scale experiments. Evidence that is published in the primary scientific literature is lent a degree of credibility by the peer review process and is the main basis for the review presented here. For each set of Tables relating to a habitat provided below, details of the papers used to derive the entries are presented. The degree to which the findings can reasonably be applied to Ireland's marine environment are also indicated. This is based on whether the evidence is derived from Ireland itself, a near neighbour or latitudinal equivalent or if the only evidence available is from very different ecological contexts. In some cases, little or no published evidence is available.

Additional issues and considerations

Tipping points

It is recognised that systems do not necessarily decline monotonically with increasing levels of disturbance. In many cases, there is a critical 'tipping point', beyond which the system makes an abrupt transition to an alternative state, often with low or no recoverability ('hysteresis'). If such tipping points can be identified for a given system, it is clearly necessary to manage the system such that degradation is halted well before that point is reached. It may be possible to recognise a threshold value beyond which it is inadvisable to progress, particularly where uncertainty exists and taking account of error in estimating key variables. Although tipping points have been observed after the event for a number of systems, few are understood well enough to be able to predict their tipping points or thresholds with any degree of accuracy or precision, although this is an active area of research (e.g. Osman et al. 2010).

Cumulative and interactive effects

A given pressure may affect a system only once or it may occur repeatedly. For example, siltation events associated with construction of a new marina may occur only once, but those associated with regular dredging of a shipping channel are recurrent. Even if the total quantity of disturbance imposed is similar under each scenario, the nature of regimes of disturbance can significantly modify their impacts on ecosystems (e.g. Benedetti-Cecchi, 2003, Elias et al. 2005, Dolbeth et al. 2007, Carlson et al. 2010). In some cases, repeated minor disturbances can ultimately have greater impact than an individual major disturbance event, and vice versa, making cumulative pressures an important consideration in appropriate assessment.

In general, more than one kind of pressure arises from each sector, or project, operating in a given area. Furthermore, in many coastal areas multiple human activities overlap and the combined effects of more than one activity can lead to a greater or lesser impact than each acting individually (an interactive effect). When decision making occurs it is important to consider the potential additive or interactive (synergistic or antagonistic) effects of pressures and the subsequent impacts they may cause. For example, seafloor disturbance aside, an area with active fin fish aquaculture may benefit, ecologically, from the introduction of algal or shell fish aquaculture because these species effectively consume excess nutrients derived from fin fish aquaculture (an antagonistic effect) (Folke and Kautsky, 1992). On the other hand, adding sewage effluent to a bay with fin fish aquaculture may cause deleterious effects greater than those expected from each pressure individually (a synergistic effect). The present scientific knowledge of the combined effects of simultaneous pressures is limited, but some conclusions can be drawn and research in this area is rapidly expanding (e.g. Crain et al. 2008, Darling and Côté 2008, Darling et al. 2010). An interaction matrix has been developed in which we aimed to summarise evidence and opinion on which pairs of stressors are likely to act independently, synergistically and antagonistically (Table 4). In many cases, information relating to the interactions between pressures is absent. Even less evidence is available for cases in which more than two stressors act simultaneously (which are not uncommon, Halpern et al. 2008). Without evidence to the contrary, managers should follow a precautionary approach and assume additive or synergistic interactions. Where antagonistic interactions have been identified, particularly in relation to the combined effects of nutrients and other pressures, the interaction can be context dependent. The impact caused by two or more pressures may be changed from antagonistic to additive or synergistic in different habitats or under different environmental conditions such as increased temperature, UV radiation or acidity.

It should also be noted that systems with low resilience (i.e. long recovery times) may be particularly vulnerable to impacts of multiple stressor events (whether they are imposed by the same or different stressors). If the system spends a long period in a degraded (recovering) state, it remains susceptible to additional pressures pushing it further towards potential tipping points and may never fully recover.

Table 4. Interaction matrix summarising evidence of the interactions of pairs of pressures which are likely to impact marine ecosystems. References used to complete this table are listed separately in the literature cited section.

	Hl	Hc	Pd	Sr	Tc	Sa	Wf	Er	We	Li	Nc	Sc	Do	Ne	Oe	Pa	In	Rs
Habitat loss (to land) (Hl)	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Habitat change (to another marine habitat) (Hc)	X	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Physical disturbance (Pd)	X	X	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Siltation rate changes (Sr)	X	X	X	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Temperature change (Tc)	X	↑	↑	X	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Salinity change (Sa)	X	X	X	X	↑	_	_	_	_	_	_	_	_	_	_	_	_	_
Water flow (Wf)	X	X	X	X	X	X	_	_	_	_	_	_	_	_	_	_	_	_
Emergence regime (Er)	X	X	X	X	X	↕	X	_	_	_	_	_	_	_	_	_	_	_
Wave exposure changes-local (We)	X	X	X	X	X	X	X	X	_	_	_	_	_	_	_	_	_	_
Litter (Li)	X	X	X	X	X	X	X	X	X	_	_	_	_	_	_	_	_	_
Non-synthetic compounds (Nc)	↑	↑	↑	X	↕	↓	X	X	X	X	_	_	_	_	_	_	_	_
Synthetic compounds (Sc)	X	X	X	X	↕	↓	X	X	X	X	X	_	_	_	_	_	_	_
De-oxygenation (Do)	↑	↑	↑	X	X	X	X	X	X	X	X	X	_	_	_	_	_	_
Inorganic nutrient enrichment (Ne)	↕	X	X	↑	+	+	X	↑	X	X	↓	↓	X	_	_	_	_	_
Organic enrichment (Oe)	X	X	X	X	X	X	X	X	X	X	X	X	↑	↕	_	_	_	_
Introduction of microbial pathogens (Pa)	X	+	+	X	X	↑	X	X	X	X	↕	X	X	X	X	_	_	_
Introduction/spread of non-indigenous species (In)	X	X	X	↕	X	X	X	X	X	X	X	X	X	X	X	X	_	_
Removal of target and non-target species (Rs)	X	X	X	X	X	X	X	X	X	X	X	X	X	↕	X	X	X	_

(+) additive; (↑) synergistic; (↓) antagonistic; (↕) complex; (x) insufficient evidence (--) not applicable.

The precautionary approach

The precautionary principle forms part of a structured approach to the analysis of risk, as well as being relevant to risk management. The approach also covers cases where scientific evidence is insufficient, inconclusive or uncertain and where preliminary scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the high level of protection chosen by the EU.

A high level of protection in the environment, human, animal and plant health fields underpins the precautionary approach. Where there are reasonable grounds for concern that potential hazards may affect the environment or human, animal or plant health, and when there is a lack of scientific information the precautionary principle is an acceptable risk management strategy. The principle provides a basis for action when science is unable to give a clear answer but is not a justification for ignoring scientific evidence and taking protectionist decisions.

Where action is deemed necessary, measures based on the precautionary principle should be:

- proportional to the chosen level of protection,
- non-discriminatory in their application.
- consistent with similar measures already taken,
- based on an examination of the potential benefits and costs of action or lack of action (including where appropriate and feasible, an economic cost/benefit analysis),
- subject to review in light of new scientific data, and
- capable of assigning responsibility for producing the scientific evidence necessary for a more comprehensive risk assessment.

Literature Cited

Benedetti-Cecchi L (2003) The Importance of the Variance around the Mean Effect Size of Ecological Processes. Ecology 84:2335-2346

Bremner J, Frid CLJ, Rogers SI (2003) Assessing Marine Ecosystem Health: The Long-Term Effects of Fishing on Functional Biodiversity in North Sea Benthos. Aquatic Ecosystem Health & Management 6:131

Bremner J, Rogers SI, Frid CLJ (2006) Matching Biological Traits to Environmental Conditions in Marine Benthic Ecosystems. Journal of Marine Systems 60:302-316

Cabaco S, Machas R, Santos R (2007) Biomass-Density Relationships of the Seagrass Zostera Noltii: A Tool for Monitoring Anthropogenic Nutrient Disturbance. Estuar Coast Shelf Sci 74:557-564

Callier M, Crowe T, Green D, Kochmann J, O'Beirn F, O'Brien G (2012) Strategic overview of influences of aquaculture on biodiversity and ecosystems services in Ireland. Unpublished report, Environmental Protection Agency, Ireland.

Carlson PR, Yarbro LA, Kaufman KA, Mattson RA (2010) Vulnerability and Resilience of Seagrasses to Hurricane and Runoff Impacts Along Florida's West Coast. Hydrobiologia 649:39-53

Carpenter S, Walker B, Anderies JM, Abel N (2001) From Metaphor to Measurement: Resilience of What to What? Ecosystems 4:765-781

Crain CM, Kroeker K, Halpern B, S (2008) Interactive and Cumulative Effects of Multiple Human Stressors in Marine Systems. Ecology Letters 11:1304-1315

Crowe TP, Smith EL, Donkin P, Barnaby DL, Rowland SJ (2004) Measurements of Sublethal Effects on Individual Organisms Indicate Community-Level Impacts of Pollution. Journal of Applied Ecology 41:114-123

Crowe TP, Fitch JE, Frid CLJ, Somerfield PJ (2011) A framework for managing sea bed habitats in near shore Special Areas of Conservation. Unpublished report, Department of Environment Heritage and Local Goverment.

Cusack C, O'Beirn F, King J, Silke J, Keirse G, Whyte I, Leahy Y, Noklegaard T, McCormack E, McDermott G (2008) Water Framework Directive –Marine Ecological Tools for Reference, Intercalibration and Classification (Metric). EPA

Darling ES, Cote IM (2008) Quantifying the Evidence for Ecological Synergies. Ecology Letters 11:1278-1286

Darling ES, McClanahan TR, Cote IM (2010) Combined Effects of Two Stressors on Kenyan Coral Reefs Are Additive or Antagonistic, Not Synergistic. Conservation Letters 3:122-130

Dauvin J-C (1984) Dynamique d'ecosystemes macrobenthiques des fonds sedimentaires de la Baie de Morlaix et leur perturbation par les hydrocarbures de l'Amoco Cadiz. Doctoral Thesis, Univ. Pierre et Marie Curie, Paris.

Dehnad K (1989) Quality Control, Robust Design, and the Taguchi Method, Vol. Wadsworth & Brooks, California

Dernie KM, Kaiser MJ, Warwick RM (2003) Recovery Rates of Benthic Communities Following Physical Disturbance. Journal of Animal Ecology 72:1043-1056

Dolbeth M, Cardoso PG, Ferreira SM, Verdelhos T, Raffaelli D, Pardal MA (2007) Anthropogenic and Natural Disturbance Effects on a Macrobenthic Estuarine Community over a 10-Year Period. Marine Pollution Bulletin 54:576-585

Duncan AJ (1974) Quality Control and Industrial Stastics, Vol. Irwin-Dorsey Ltd., London

Elias R, Palacios JR, Rivero MS, Vallarino EA (2005) Short-Terrn Responses to Sewage Discharge and Storms of Subtidal Sand-Bottom Macrozoobenthic Assemblages Off Mar Del Plata City, Argentina (Sw Atlantic). Journal of Sea Research 53:231-242

Ferwerda JG, de Leeuw J, Atzberger C, Vekerdy Z (2007) Satellite-Based Monitoring of Tropical Seagrass Vegetation: Current Techniques and Future Developments. Hydrobiologia 591:59-71

Fitch JE, Crowe TP (2010) Effective Methods for Assessing Ecological Quality in Intertidal Soft-Sediment Habitats. Marine Pollution Bulletin 60:1726-1733

Folke C, Kautsky N (1992) Aquaculture with Its Environment - Prospects for Sustainability. Ocean & Coastal Management 17:5-24

Frid CLJ, Paramor OAL, Brockington S, Bremner J (2008) Incorporating Ecological Functioning into the Designation and Management of Marine Protected Areas. Hydrobiologia 606:69-79

Frost MT, Jefferson R, Hawkins SJ (Eds) (2006) The evaluation of time series: their scientific value and contribution to policy needs. Report prepared by the Marine Environmental Change Network for the Department for Environment, Food and Rural Affairs (DEFRA). Marine Biological Association , Plymouth. Contract CDEP 84/5/311. Marine Biological Association Occasional Pulication No. 22. 94pp.

Gray JS, Clarke KR, Warwick RM, Hobbs G (1990) Detection of Initial Effects of Pollution on Marine Benthos - an Example from the Ekofisk and Eldfisk Oilfields, North-Sea. Marine Ecology-Progress Series 66:285-299

Gray JS, Elliott M (2009) Ecology of Marine Sediments: Science to Management, Vol. Oxford University Press, Oxford

Grimm V, Wissel C (1997) Babel, or the Ecological Stability Discussions: An Inventory and Analysis of Terminology and a Guide for Avoiding Confusion. Oecologia 109:323-334

Hall K, Paramor OAL, Robinson LA, Frid CLJ (2008) Mapping the Sensitivity of Benthic Habitats to Fishing in Welsh Waters: Towards the Development of a Protocol. . CW Policy Research Report No 7/15

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A Global Map of Human Impact on Marine Ecosystems. Science 319:948-952

Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

Marine Institute (2012) www.marine.ie

Menezes S, Baird DJ, Soares AMVM (2010) Beyond Taxonomy: A Review of Macroinvertebrate Trait-Based Community Descriptors as Tools for Freshwater Biomonitoring. Journal of Applied Ecology 47:711-719

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: biodiversity synthesis. World Resources Institute, Washington, D.C.

Muxika I, Borja A, Bald J (2007) Using Historical Data, Expert Judgement and Multivariate Analysis in Assessing Reference Conditions and Benthic Ecological Status, According to the European Water Framework Directive. Marine Pollution Bulletin 55:16-29

NS Share (2005) www.nsshare.com

Odum EP (1989) Ecology and Our Endangered Life-Support Systems. Sinauer Associates Inc: Sunderland (USA).

Osman RW, Munguia P, Zajac RN (2010) Ecological Thresholds in Marine Communities: Theory, Experiments and Management. Marine Ecology-Progress Series 413:185-187

Raffaelli DG, Frid CLJ (2010) Ecosystem Ecology: A New Synthesis, Vol. Cambridge University Press, Cambridge

Robinson LA, Rogers S, Frid CLJ (2008) A Marine Assesment and Monitoring Framework for Application by Ukmmas and Ospar- Assesment of Pressure and Impacts. Phase Ii: Application for Regional Assesment. Contract No: C-08-0007-0027

Rogers SI, Somerfield PJ, Schratzberger M, Warwick R, Maxwell TAD, Ellis JR (2008) Sampling Strategies to Evaluate the Status of Offshore Soft Sediment Assemblages. Marine Pollution Bulletin 56:880-894

Saekadi K, Vincze I (1974) Mathmatical Methods of Statstical Quality Control, Vol. Academic Press, Budapest

Solan M, Kennedy R (2002) Observation and Quantification of in Situ Animal-Sediment Relations Using Time-Lapse Sediment Profile Imagery (T-Spi). Marine Ecology-Progress Series 228:179-191

Soule ME (1987) Viable Poopulations for Conservation, Vol. Cambridge University Press, Cambridge

Stachowicz JJ, Bruno JF, Duffy JE (2007) Understanding the Effects of Marine Biodiversity on Communities and Ecosystems. Annual Review of Ecology Evolution and Systematics 38:739-766

Steele JH (1985) A Comparison of Terrestrial and Marine Ecological Systems. Nature 313:355-358

Steele JH (1991) Can Ecological Theory Cross the Land Sea Boundary. Journal of Theoretical Biology 153:425-436

Warwick RM, Ashman CM, Brown AR, Clarke KR, Dowell B, Hart B, Lewis RE, Shillabeer N, Somerfield PJ, Tapp JF (2002) Inter-Annual Changes in the Biodiversity and Community Structure of the Macrobenthos in Tees Bay and the Tees Estuary, Uk, Associated with Local and Regional Environmental Events. Marine Ecology-Progress Series 234:1-13

Literature used to complete Table 4

Atalah J, Crowe TP (2010) Combined effects of nutrient enrichment, sedimentation and grazer loss on rock pool assemblages. Journal of Experimental Marine Biology and Ecology 388:51-57

Blake RE, Duffy J (2010) Grazer diversity affects resistance to multiple stressors in an experimental seagrass ecosystem. Oikos 119:1625-1635

Cardoso PG, Raffaelli D, Lillebo AI, Verdelhos T, Pardal MA (2008) The impact of extreme flooding events and anthropogenic stressors on the macrobenthic communities' dynamics. Estuarine Coastal and Shelf Science 76:553-565

Carlson PR, Yarbro LA, Kaufman KA, Mattson RA (2010) Vulnerability and resilience of seagrasses to hurricane and runoff impacts along Florida's west coast. Hydrobiologia 649:39-53

Carpenter SR, Cole JJ, Hodgson JR, Kitchell JF, Pace ML, Bade D, Cottingham KL, Essington TE, Houser JN, Schindler DE (2001) Trophic cascades, nutrients, and lake productivity: whole-lake experiments. Ecological Monographs 71:163-186

Carpenter SR, Kitchell JF, Cottingham KL, Schindler DE, Christensen DL, Post DM, Voichick N (1996) Chlorophyll variability, nutrient input, and grazing: Evidence from whole-lake experiments. Ecology 77:725-735

Carreiro-Silva M, McClanahan TR, Kiene WE (2009) Effects of inorganic nutrients and organic matter on microbial euendolithic community composition and microbioerosion rates. Marine Ecology-Progress Series 392:1-15

Cottingham KL, Glaholt S, Brown AC (2004) Zooplankton community structure affects how phytoplankton respond to nutrient pulses. Ecology 85:158-171

Crain CM, Kroeker K, Halpern B, S (2008) Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11:1304-1315

Dolbeth M, Cardoso PG, Ferreira SM, Verdelhos T, Raffaelli D, Pardal MA (2007) Anthropogenic and natural disturbance effects on a macrobenthic estuarine community over a 10-year period. Marine Pollution Bulletin 54:576-585

Elias R, Palacios JR, Rivero MS, Vallarino EA (2005) Short-terrn responses to sewage discharge and storms of subtidal sand-bottom macrozoobenthic assemblages off Mar del Plata City, Argentina (SW Atlantic). Journal of Sea Research 53:231-242

Fukunaga A, Anderson MJ, Webster-Brown JG, Ford RB (2010) Individual and combined effects of heavy metals on estuarine infaunal communities. Marine Ecology-Progress Series 402:123-136

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A Global Map of Human Impact on Marine Ecosystems. Science 319:948-952

Khan NY (2007) Multiple stressors and ecosystem-based management in the Gulf. Aquatic Ecosystem Health & Management 10:259-267

Koch MS, Schopmeyer S, Kyhn-Hansen C, Madden CJ (2007) Synergistic effects of high temperature and sulfide on tropical seagrass. Journal of Experimental Marine Biology and Ecology 344:91-101

Kraufvelin P (2007) Responses to nutrient enrichment, wave action and disturbance in rocky shore communities. Aquatic Botany 87:262-274

McClanahan TR, Steneck RS, Pietri D, Cokos B, Jones S (2005) Interaction between inorganic nutrients and organic matter in controlling coral reef communities in Glovers Reef Belize. Marine Pollution Bulletin 50:566-575

Sundback K, Alsterberg C, Larson F (2010) Effects of multiple stressors on marine shallow-water sediments: Response of microalgae and meiofauna to nutrient-toxicant exposure. Journal of Experimental Marine Biology and Ecology 388:39-50

Sundback K, Petersen DG, Dahllof I, Larson F (2007) Combined nutrient-toxicant effects on a shallow-water marine sediment system: sensitivity and resilience of ecosystem functions. Marine Ecology-Progress Series 330:13-30

Suomela J, Gran V, Helminen H, Lagus A, Lehtoranta J, Sipura J (2005) Effects of sediment and nutrient enrichment on water quality in the Archipelago Sea, northern Baltic: An enclosure experiment in shallow water. Estuar Coast Shelf Sci 65:337-350

Summary Tables

Below are the Tables summarising the findings of the review in detailed but accessible form. They are grouped by habitat type. For each habitat type, two Tables are presented, along with a list of the references from which the Table entries were derived. The Tables are: 1. a matrix summarising our assessment of the resistance and resilience of the habitat to each anthropogenic pressure and 2. a summary of the nature and applicability of evidence used to complete the matrix of resistance and resilience. The number of each Table is prefixed by a code for the habitat it relates to, e.g. for Seagrass (*Zostera*), the Tables are numbered Z1, and Z2.

It should again be emphasised that these tables are intended to serve as a guide only. Appropriate assessments should be made on a case by case basis, with a degree of expertise available at each stage of the assessment. The information provided here to assist assessment is based on scientific knowledge available at the time of publication and has also been reviewed by a panel of experts, but does not cover all eventualities.

Sectoral activities on different scales or of different types within a category will clearly exert different types and degrees of pressure. It is also important to recognise that impacts resulting from pressures of the same type and intensity may vary depending on localised features of the receiving environment, such as hydrodynamic and physical conditions. Differences within habitats of the same type may also be influential. For example, the 'gravels' habitat can be described as 'coarse sand with high levels of shell debris and stones' or 'cobble-like substratum'; biological communities can also vary considerably within and between areas classified into the same habitats and therefore respond very differently to pressures.

The supposition that sensitivity will vary consistently with grain size is not always borne out. Both sand, which is dominated by physical processes, and mud, will recover from impacts more quickly than muddy sands which are inherently less stable because they are driven by complex chemical, physical and biological factors (Dernie et al. 2003, Kaiser et al. 2006). Biological communities in gravel recover very slowly because they include many slow growing sessile taxa, which will not migrate into a de-faunated area but need time to recruit and grow.

Note that in the tables, the pressures described do not always affect both extent and quality of a habitat. For most habitats, 'habitat loss to land' and 'habitat change to another marine habitat' are only applicable to changes in extent and only resistance values are presented. If a given area of habitat defined in physical terms (gravel, sand, etc.) is lost to land, or changes to another marine habitat, recovery will occur through geological processes which are outside the scope of this review, so resilience from habitat loss to land and habitat change to another marine substratum are considered not applicable ('NA'). The exceptions to this are the biogenic habitats – maërl and seagrass. Recovery of these habitats from loss or change to another marine habitat is a biological phenomenon and so was reviewed here.

When the resistance and resilience of habitats was assessed, different papers sometimes indicated different magnitudes of response and speeds of recovery resulting from pressures. In such cases, the worst case for given impacts on habitats were selected and presented. The rationale for this was that it is better to alert assessors to potential risks of impact, even if they do not apply equally in all contexts. Again, it is necessary for a degree of expertise to be applied to particular cases to determine the applicability of the findings presented here.

In researching impacts of non-synthetic compounds, papers which reported on the impacts and recovery following acute oil spill events were used to ascertain resilience values only, as resistance to catastrophic oil spill events would necessarily be low or none. Impacts on resistance resulting from hydrocarbons were derived only from papers relating to chronic or small scale spills.

Gravels

Table GR1. Level of resistance to impacts on extent and quality of gravel habitats to each pressure and resilience following the impact created by each pressure and upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	L	NA	NA
Habitat change (to another marine habitat)	L	NA	NA
Physical disturbance	L	M	L
Siltation rate changes	NA	M	M
Temperature change	NA	H	H
Salinity change	NA	X	X
Water flow	NA	L	L
Emergence regime	NA	M	H
Wave exposure changes-local	NA	M	H
Litter	NA	X	X
Non-synthetic compounds	NA	M	M
Synthetic compounds	NA	L	H
De-oxygenation	NA	H	H
Inorganic nutrient enrichment	NA	H	H
Organic enrichment	NA	H	H
Introduction of microbial pathogens	NA	M	H
Introduction or spread of non-indigenous species	NA	M	M
Removal of target and non-target species	NA	M	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table GR2. Nature and applicability of evidence used to complete Table GR1.

Pressure	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R). O	F	L	R	Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Habitat loss (to land)	1	0	0	0	1	NA	***	[1]
Habitat change (to another marine habitat)	5	1	1	0	3	**	***	[1-5]
Physical disturbance	12	5	1	0	6	**	***	[1-12]
Siltation rate changes	5	1	0	0	4	**	***	[1-3, 6, 7]
Temperature change	2	0	0	0	2	***	***	[13, 14]
Salinity change	X	X	X	X	X	X	X	X
Water flow	2	0	0	0	2	**	***	[1, 2]
Emergence regime	3	0	0	0	3	***	***	[1, 13, 14]
Wave exposure changes-local	1	0	0	0	1	NA	***	[13]
Litter	X	X	X	X	X	X	X	X
Non-synthetic compounds	2	0	0	0	2	**	***	[1, 3]
Synthetic compounds	2	0	0	0	2	***	***	[1, 13]
De-oxygenation	1	0	0	0	1	NA	*	[15]
Inorganic nutrient enrichment	2	0	0	0	2	**	*	[1, 15]
Organic enrichment	2	1	0	0	2	**	*	[1, 15]
Introduction of microbial pathogens	2	0	0	0	2	***	***	[13, 14]
Introduction or spread of non-indigenous species	2	0	0	0	2	***	***	[13, 14]
Removal of target and non-target species	10	5	1	0	4	**	***	[2, 5-12, 16]

References for gravel (GR) Tables

1. Ducrotoy, J.P. and Dauvin, J.C. (2008) Estuarine Conservation and Restoration: The Somme and the Seine Case Studies (English Channel, France). Marine Pollution Bulletin 57:208-218

2. Degroot, S.J. (1996) The Physical Impact of Marine Aggregate Extraction in the North Sea. Ices Journal of Marine Science 53:1051-1053

3. Foden, J., Rogers, S.I., and Jones, A.P. (2009) Recovery Rates of UK Seabed Habitats after Cessation of Aggregate Extraction. Marine Ecology-Progress Series 390:15-26

4. Foden, J., Rogers, S.I., and Jones, A.P. (2010) Recovery of UK Seabed Habitats from Benthic Fishing and Aggregate Extraction-Towards a Cumulative Impact Assessment. Marine Ecology-Progress Series 411:259-270

5. Collie, J.S., Hermsen, J.M., and Valentine, P.C. (2009) Recolonization of Gravel Habitats on Georges Bank (Northwest Atlantic). Deep-Sea Research Part II-Topical Studies in Oceanography 56:1847-1855

6. Asch, R.G. and Collie, J.S. (2008) Changes in a Benthic Megafaunal Community Due to Disturbance from Bottom Fishing and the Establishment of a Fishery Closure. Fishery Bulletin 106:438-456

7. Barry, J., Boyd, S., and Fryer, R. (2010) Modelling the Effects of Marine Aggregate Extraction on Benthic Assemblages. Journal of the Marine Biological Association of the United Kingdom 90:105-114

8. Kaiser, M.J. (1998) Significance of Bottom-Fishing Disturbance. Conservation Biology 12:1230-1235

9. Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

10. Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. (2000) A Quantitative Analysis of Fishing Impacts on Shelf-Sea Benthos. Journal of Animal Ecology 69:785-798

11. Collie, J.S., Escanero, G.A., and Valentine, P.C. (2000) Photographic Evaluation of the Impacts of Bottom Fishing on Benthic Epifauna. Ices Journal of Marine Science 57:987-1001

12. Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A., and Rosenberg, A.A. (2009) Effects of a Large Fishing Closure on Benthic Communities in the Western Gulf of Maine: Recovery from the Effects of Gillnets and Otter Trawls. Fishery Bulletin 107:308-317

13.* Rayment, W.J. (2008) Venerid Bivalves in Circalittoral Coarse Sand or Gravel. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

14.* Rayment, W.J. (2008) Venerupis Senegalensis and Mya Truncata in Lower Shore or Infralittoral Muddy Gravel. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

15. Simenstad, C.A. and Fresh, K.L. (1995) Influence of Intertidal Aquaculture on Benthic Communities in Pacific-Northwest Estuaries - Scales of Disturbance. Estuaries 18:43-70

16. Hiddink, J.G., Rijnsdorp, A.D., and Piet, G. (2008) Can Bottom Trawling Disturbance Increase Food Production for a Commercial Fish Species? Canadian Journal of Fisheries and Aquatic Sciences 65:1393-1401

*literature recommended by expert panel

Sand

Table SD1. Level of resistance to impacts on extent and quality of sand habitats to each pressure and resilience following the impact created by each pressure and upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	L	NA	NA
Habitat change (to another marine habitat)	L	NA	NA
Physical disturbance	M	L	M
Siltation rate changes	NA	M	H
Temperature change	NA	H	H
Salinity change	NA	H	H
Water flow	NA	M	H
Emergence regime	NA	L	H
Wave exposure changes-local	NA	H	H
Litter	NA	M	H
Non-synthetic compounds	NA	M	M
Synthetic compounds	NA	M	M
De-oxygenation	NA	H	H
Inorganic nutrient enrichment	NA	H	H
Organic enrichment	NA	H	H
Introduction of microbial pathogens	NA	H	H
Introduction or spread of non-indigenous species	NA	X	X
Removal of target and non-target species	NA	L	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table SD2. Nature and applicability of evidence used to complete Table SD1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	1	0	0	0	1	NA	***	[1]
Habitat change (to another marine habitat)	6	2	0	0	4	***	***	[1-6]
Physical disturbance	10	5	0	0	5	**	***	[1, 2, 4-11]
Siltation rate changes	5	2	1	0	2	**	***	[2, 3, 6, 12, 13]
Temperature change	2	0	0	0	2	***	***	[14, 15]
Salinity change	2	0	0	0	2	***	***	[14, 15]
Water flow	4	2	0	1	1	**	***	[1, 6, 12, 16]
Emergence regime	3	0	0	0	3	***	***	[1, 14, 15]
Wave exposure changes-local	2	1	0	1	0	**	***	[6, 16]
Litter	4	3	1	0	0	***	**	[17-20]
Non-synthetic compounds	2	0	0	0	2	***	***	[1, 2]
Synthetic compounds	2	0	0	0	2	***	***	[1, 2]
De-oxygenation	2	1	0	0	1	**	***	[2, 12]
Inorganic nutrient enrichment	3	1	0	0	2	**	***	[1, 2, 12]
Organic enrichment	4	1	0	1	2	**	***	[1, 2, 12, 21]
Introduction of microbial pathogens	2	0	0	0	2	***	***	[14, 15]
Introduction or spread of non-indigenous species	X	X	X	X	X	X	X	X
Removal of target and non-target species	7	4	0	0	3	**	***	[3, 5, 7-9, 11, 22]

References for sand (SD) Tables

1. Ducrotoy, J.P. and Dauvin, J.C. (2008) Estuarine Conservation and Restoration: The Somme and the Seine Case Studies (English Channel, France). Marine Pollution Bulletin 57:208-218

2. Defeo, O., Mclachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., and Scapini, F. (2009) Threats to Sandy Beach Ecosystems: A Review. Estuarine Coastal and Shelf Science 81:1-12

3. Degroot, S.J. (1996) The Physical Impact of Marine Aggregate Extraction in the North Sea. Ices Journal of Marine Science 53:1051-1053

4. Foden, J., Rogers, S.I., and Jones, A.P. (2009) Recovery Rates of UK Seabed Habitats after Cessation of Aggregate Extraction. Marine Ecology-Progress Series 390:15-26

5. Foden, J., Rogers, S.I., and Jones, A.P. (2010) Recovery of UK Seabed Habitats from Benthic Fishing and Aggregate Extraction-Towards a Cumulative Impact Assessment. Marine Ecology-Progress Series 411:259-270

6. Dauvin, J.C., Desroy, N., Janson, A.L., Vallet, C., and Duhamel, S. (2006) Recent Changes in Estuarine Benthic and Suprabenthic Communities Resulting from the Development of Harbour Infrastructure. Marine Pollution Bulletin 53:80-90

7. Kaiser, M.J. (1998) Significance of Bottom-Fishing Disturbance. Conservation Biology 12:1230-1235

8. Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

9. Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. (2000) A Quantitative Analysis of Fishing Impacts on Shelf-Sea Benthos. Journal of Animal Ecology 69:785-798

10. Bailey-Brock, J., Brock, R., Kam, A., Fukunaga, A., and Akiyama, H. (2007) Anthropogenic Disturbance on Shallow Cryptofaunal Communities in a Marine Life Conservation District on Oahu, Hawaii. International Review of Hydrobiology 92:291-300

11. Kaiser, M.J., Spence, F.E., and Hart, P.J.B. (2000) Fishing-Gear Restrictions and Conservation of Benthic Habitat Complexity. Conservation Biology 14:1512-1525

12. Apostolaki, E.T., Tsagaraki, T., Tsapakis, M., and Karakassis, I. (2007) Fish Farming Impact on Sediments and Macrofauna Associated with Seagrass Meadows in the Mediterranean. Estuar. Coast. Shelf Sci. 75:408-416

13.* Thrush, S.F., Hewitt, J.E., Norkko, A., Cummings, V.J., and Funnell, G.A. (2003) Macrobenthic Recovery Processes Following Catastrophic Sedimentation on Estuarine Sandflats. Ecological Applications 13:1433-1455

14.* Budd, G.C. (2008) Burrowing Amphipods and *Eurydice Pulchra* in Well Drained Clean Sand Shores. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

15.* Budd, G.C. (2008) Barren Course Sand Shores. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

16. Kendrick, G.A., Langtry, S., Fitzpatrick, J., Griffiths, R., and Jacoby, C.A. (1998) Benthic Microalgae and Nutrient Dynamics in Wave-Disturbed Environments in Marmion Lagoon, Western Australia, Compared with Less Disturbed Mesocosms. Journal of Experimental Marine Biology and Ecology 228:83-105

17. Ariza, E., Jimenez, J.A., and Sarda, R. (2008) Seasonal Evolution of Beach Waste and Litter During the Bathing Season on the Catalan Coast. Waste Management 28:2604-2613

18. Claereboudt, M.R. (2004) Shore Litter Along Sandy Beaches of the Gulf of Oman. Marine Pollution Bulletin 49:770-777

19. Harms, J. (1990) Marine Plastic Litter as an Artificial Hard Bottom Fouling Ground. Helgolander Meeresuntersuchungen 44:503-506

20. Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., and Thessalou-Legaki, M. (2007) Effect of Marine Litter on the Benthic Megafauna of Coastal Soft Bottoms: A Manipulative Field Experiment. Marine Pollution Bulletin 54:771-778

21. Lee, S.Y. (1999) The Effect of Mangrove Leaf Litter Enrichment on Macrobenthic Colonization of Defaunated Sandy Substrates. Estuarine Coastal and Shelf Science 49:703-712

22. Hiddink, J.G., Rijnsdorp, A.D., and Piet, G. (2008) Can Bottom Trawling Disturbance Increase Food Production for a Commercial Fish Species? Canadian Journal of Fisheries and Aquatic Sciences 65:1393-1401

*literature recommended by expert panel

Mud

Table MD1. Level of resistance to impacts on extent and quality of mud habitats to each pressure and resilience following the impact created by each pressure and upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	L	NA	NA
Habitat change (to another marine habitat)	L	NA	NA
Physical disturbance	L	L	M
Siltation rate changes	NA	H	H
Temperature change	NA	H	H
Salinity change	NA	M	H
Water flow	NA	M	H
Emergence regime	NA	H	H
Wave exposure changes-local	NA	L	H
Litter	NA	M	H
Non-synthetic compounds	NA	M	H
Synthetic compounds	NA	L	H
De-oxygenation	NA	M	H
Inorganic nutrient enrichment	NA	H	H
Organic enrichment	NA	M	H
Introduction of microbial pathogens	NA	M	X
Introduction or spread of non-indigenous species	NA	H	H
Removal of target and non-target species	NA	L	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table MD2. Nature and applicability of evidence used to complete Table MD1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	1	0	0	0	1	NA	***	[1]
Habitat change (to another marine habitat)	5	3	0	0	2	**	***	[1-5]
Physical disturbance	13	9	1	0	3	**	***	[1-13]
Siltation rate changes	6	4	1	0	1	**	**	[1, 2, 5, 14-16]
Temperature change	4	0	0	0	4	**	***	[17-20]
Salinity change	4	0	0	0	4	**	***	[17-20]
Water flow	6	1	0	0	5	**	***	[1, 5, 17-20]
Emergence regime	5	0	0	0	5	**	***	[1, 17-20]
Wave exposure changes-local	5	1	0	0	4	**	***	[5, 17-20]
Litter	2	1	1	0	0	**	**	[21, 22]
Non-synthetic compounds	8	2	0	1	5	**	***	[1, 17-20, 23-25]
Synthetic compounds	5	0	0	0	5	**	***	[1, 17-20]
De-oxygenation	4	3	0	0	1	***	***	[1, 2, 15, 16]
Inorganic nutrient enrichment	4	2	1	0	1	***	***	[1, 2, 14, 16]
Organic enrichment	5	3	1	0	1	***	***	[1, 2, 14-16]
Introduction of microbial pathogens	4	0	0	0	4	**	***	[17-20]
Introduction or spread of non-indigenous species	2	2	0	0	0	**	**	[11, 26]
Removal of target and non-target species	8	7	0	0	1	**	***	[3, 7-11, 13, 27]

References for mud (MD) Tables

1. Ducrotoy, J.P. and Dauvin, J.C. (2008) Estuarine Conservation and Restoration: The Somme and the Seine Case Studies (English Channel, France). Marine Pollution Bulletin 57:208-218

2. Guerra-Garcia, J.M., Corzo, J., and Garcia-Gomez, J.C. (2003) Short-Term Benthic Recolonization after Dredging in the Harbour of Ceuta, North Africa. Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I 24:217-229

3. Hiddink, J.G., Rijnsdorp, A.D., and Piet, G. (2008) Can Bottom Trawling Disturbance Increase Food Production for a Commercial Fish Species? Canadian Journal of Fisheries and Aquatic Sciences 65:1393-1401

4. Foden, J., Rogers, S.I., and Jones, A.P. (2009) Recovery Rates of UK Seabed Habitats after Cessation of Aggregate Extraction. Marine Ecology-Progress Series 390:15-26

5. Dauvin, J.C., Desroy, N., Janson, A.L., Vallet, C., and Duhamel, S. (2006) Recent Changes in Estuarine Benthic and Suprabenthic Communities Resulting from the Development of Harbour Infrastructure. Marine Pollution Bulletin 53:80-90

6. Hinz, H., Prieto, V., and Kaiser, M.J. (2009) Trawl Disturbance on Benthic Communities: Chronic Effects and Experimental Predictions. Ecological Applications 19:761-773

7. Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

8. Kaiser, M.J., Spence, F.E., and Hart, P.J.B. (2000) Fishing-Gear Restrictions and Conservation of Benthic Habitat Complexity. Conservation Biology 14:1512-1525

9. Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. (2000) A Quantitative Analysis of Fishing Impacts on Shelf-Sea Benthos. Journal of Animal Ecology 69:785-798

10. Frid, C.L.J., Garwood, P.R., and Robinson, L.A. (2009) The North Sea Benthic System: A 36 Year Time-Series. Journal of the Marine Biological Association of the United Kingdom 89:1-10

11. Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A., and Rosenberg, A.A. (2009) Effects of a Large Fishing Closure on Benthic Communities in the Western Gulf of Maine: Recovery from the Effects of Gillnets and Otter Trawls. Fishery Bulletin 107:308-317

12. Sheehan, E.V., Coleman, R.A., Thompson, R.C., and Attrill, M.J. (2010) Crab-Tiling Reduces the Diversity of Estuarine Infauna. Marine Ecology-Progress Series 411:137-148

13. Frid, C.L.J., Clark, R.A., and Hall, J.A. (1999) Long-Term Changes in the Benthos on a Heavily Fished Ground Off the NE Coast of England. Marine Ecology-Progress Series 188:13-20

14. Bishop, M.J. and Kelaher, B.P. (2007) Impacts of Detrital Enrichment on Estuarine Assemblages: Disentangling Effects of Frequency and Intensity of Disturbance. Marine Ecology-Progress Series 341:25-36

15. Birchenough, S.N.R. and Frid, C.L.J. (2009) Macrobenthic Succession Following the Cessation of Sewage Sludge Disposal. Journal of Sea Research 62:258-267

16. Hall, J.A., Frid, C.L.J., and Gill, M.E. (1997) The Response of Estuarine Fish and Benthos to an Increasing Discharge of Sewage Effluent. Marine Pollution Bulletin 34:527-535

17.* Budd, G.C. (2008) *Macoma Balthica* and *Abra Alba* in Infralittoral Muddy Sand or Mud. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

18.* Budd, G.C. (2008) *Limnodrilus Hoffmeisteri*, *Tubifex Tubifex* and *Gammarus* Spp. In Low Salinity Infralittoral Muddy Sedimnets. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

19.* Hill, J.M. (2008) *Capitella Capitata* in Enriched Sublittoral Muddy Sediments. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

20.* Hill, J.M. (2008) *Polydora Ciliata* in Variable Salinity Infralittoral Firm Mud or Clay. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

21. Harms, J. (1990) Marine Plastic Litter as an Artificial Hard Bottom Fouling Ground. Helgolander Meeresuntersuchungen 44:503-506

*literature recommended by expert panel

22. Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., and Thessalou-Legaki, M. (2007) Effect of Marine Litter on the Benthic Megafauna of Coastal Soft Bottoms: A Manipulative Field Experiment. Marine Pollution Bulletin 54:771-778

23. Dauvin, J.C. (2008) Effects of Heavy Metal Contamination on the Macrobenthic Fauna in Estuaries: The Case of the Seine Estuary. Marine Pollution Bulletin 57:160-169

24. Hall, J.A., Frid, C.L.J., and Proudfoot, R.K. (1996) Effects of Metal Contamination on Macrobenthos of Two North Sea Estuaries. Ices Journal of Marine Science 53:1014-1023

25. Hall, J.A. and Frid, C.L.J. (1995) Responses of Estuarine Benthic Macrofauna in Copper-Contaminated Sediments to Remediation of Sediment Quality. Marine Pollution Bulletin 30:694-700

26. Bouchet, V.M.P. and Sauriau, P.G. (2008) Influence of Oyster Culture Practices and Environmental Conditions on the Ecological Status of Intertidal Mudflats in the Pertuis Charentais (SW France): A Multi-Index Approach. Marine Pollution Bulletin 56:1898-1912

27. Foden, J., Rogers, S.I., and Jones, A.P. (2010) Recovery of UK Seabed Habitats from Benthic Fishing and Aggregate Extraction-Towards a Cumulative Impact Assessment. Marine Ecology-Progress Series 411:259-270

Muddy-sand/
sandy-mud

Table MS1. Level of resistance to impacts on extent and quality of muddy-sand/ sandy-mud habitats to each pressure and resilience following the impact created by each pressure and upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	L	NA	NA
Habitat change (to another marine habitat)	H	NA	NA
Physical disturbance	H	L	M
Siltation rate changes	NA	H	H
Temperature change	NA	H	H
Salinity change	NA	L	H
Water flow	NA	M	H
Emergence regime	NA	M	H
Wave exposure changes-local	NA	L	L
Litter	NA	M	H
Non-synthetic compounds	NA	L	L
Synthetic compounds	NA	L	L
De-oxygenation	NA	L	M-H
Inorganic nutrient enrichment	NA	L	M-H
Organic enrichment	NA	M	H
Introduction of microbial pathogens	NA	X	X
Introduction or spread of non-indigenous species	NA	H	H
Removal of target and non-target species	NA	L	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table MS2. Nature and applicability of evidence used to complete Table MS1.

Pressure	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R). O	F	L	R	Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Habitat loss (to land)	1	0	0	0	1	NA	***	[1]
Habitat change (to another marine habitat)	4	2	0	0	2	***	***	[1-4]
Physical disturbance	11	6	1	0	4	**	***	[1-11]
Siltation rate changes	4	2	0	0	2	***	***	[1, 3, 4, 12]
Temperature change	1	0	0	0	1	NA	***	[13]
Salinity change	1	0	0	0	1	NA	***	[13]
Water flow	3	1	0	0	2	***	***	[1, 4, 13]
Emergence regime	2	0	0	0	2	***	***	[1, 13]
Wave exposure changes-local	2	1	0	0	1	***	***	[4, 13]
Litter	2	0	1	1	0	**	*	[14, 15]
Non-synthetic compounds	3	1	0	0	2	***	***	[1, 13, 16]
Synthetic compounds	2	0	0	0	2	***	***	[1, 13]
De-oxygenation	2	1	0	0	1	***	***	[12, 13]
Inorganic nutrient enrichment	2	0	0	0	2	***	***	[1, 13]
Organic enrichment	3	2	0	0	1	***	**	[1, 12, 17]
Introduction of microbial pathogens	X	X	X	X	X	X	X	X
Introduction or spread of non-indigenous species	1	1	0	0	0	NA	**	[18]
Removal of target and non-target species	10	6	1	0	3	**	***	[2, 3, 5-11, 19]

References for muddy-sand/sandy-mud (MS) Tables

1. Ducrotoy, J.P. and Dauvin, J.C. (2008) Estuarine Conservation and Restoration: The Somme and the Seine Case Studies (English Channel, France). Marine Pollution Bulletin 57:208-218

2. Hiddink, J.G., Rijnsdorp, A.D., and Piet, G. (2008) Can Bottom Trawling Disturbance Increase Food Production for a Commercial Fish Species? Canadian Journal of Fisheries and Aquatic Sciences 65:1393-1401

3. Foden, J., Rogers, S.I., and Jones, A.P. (2009) Recovery Rates of UK Seabed Habitats after Cessation of Aggregate Extraction. Marine Ecology-Progress Series 390:15-26

4. Dauvin, J.C., Desroy, N., Janson, A.L., Vallet, C., and Duhamel, S. (2006) Recent Changes in Estuarine Benthic and Suprabenthic Communities Resulting from the Development of Harbour Infrastructure. Marine Pollution Bulletin 53:80-90

5. Hinz, H., Prieto, V., and Kaiser, M.J. (2009) Trawl Disturbance on Benthic Communities: Chronic Effects and Experimental Predictions. Ecological Applications 19:761-773

6. Kaiser, M.J. (1998) Significance of Bottom-Fishing Disturbance. Conservation Biology 12:1230-1235

7. Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

8. Kaiser, M.J., Spence, F.E., and Hart, P.J.B. (2000) Fishing-Gear Restrictions and Conservation of Benthic Habitat Complexity. Conservation Biology 14:1512-1525

9. Kaiser, M.J., Broad, G., and Hall, S.J. (2001) Disturbance of Intertidal Soft-Sediment Benthic Communities by Cockle Hand Raking. Journal of Sea Research 45:119-130

10. Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. (2000) A Quantitative Analysis of Fishing Impacts on Shelf-Sea Benthos. Journal of Animal Ecology 69:785-798

11. Frid, C.L.J., Clark, R.A., and Hall, J.A. (1999) Long-Term Changes in the Benthos on a Heavily Fished Ground Off the NE Coast of England. Marine Ecology-Progress Series 188:13-20

12. Birchenough, S.N.R. and Frid, C.L.J. (2009) Macrobenthic Succession Following the Cessation of Sewage Sludge Disposal. Journal of Sea Research 62:258-267

13.* Tyler-Walters, H. and Marshall, C. (2008) Muddy Sand Shores. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

14. Harms, J. (1990) Marine Plastic Litter as an Artificial Hard Bottom Fouling Ground. Helgolander Meeresuntersuchungen 44:503-506

15. Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., and Thessalou-Legaki, M. (2007) Effect of Marine Litter on the Benthic Megafauna of Coastal Soft Bottoms: A Manipulative Field Experiment. Marine Pollution Bulletin 54:771-778

16. Gesteira, J.L.G. and Dauvin, J.C. (2005) Impact of the Aegean Sea Oil Spill on the Subtidal Fine Sand Macrobenthic Community of the Ares-Betanzos Ria (Northwest Spain). Marine Environmental Research 60:289-316

17. Lee, S.Y. (1999) The Effect of Mangrove Leaf Litter Enrichment on Macrobenthic Colonization of Defaunated Sandy Substrates. Estuarine Coastal and Shelf Science 49:703-712

18. Bouchet, V.M.P. and Sauriau, P.G. (2008) Influence of Oyster Culture Practices and Environmental Conditions on the Ecological Status of Intertidal Mudflats in the Pertuis Charentais (Sw France): A Multi-Index Approach. Marine Pollution Bulletin 56:1898-1912

19. Foden, J., Rogers, S.I., and Jones, A.P. (2010) Recovery of UK Seabed Habitats from Benthic Fishing and Aggregate Extraction-Towards a Cumulative Impact Assessment. Marine Ecology-Progress Series 411:259-270

*literature recommended by expert panel

Exposed reef

Table ER1. Level of resistance to impacts on extent and quality of exposed reef habitats to each pressure and resilience following the impact created by each pressure upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	X	NA	NA
Habitat change (to another marine habitat)	L	NA	NA
Physical disturbance	L	L	M
Siltation rate changes	NA	H	H
Temperature change	NA	H	M
Salinity change	NA	H	H
Water flow	NA	H	H
Emergence regime	NA	M	H
Wave exposure changes-local	NA	H	H
Litter	NA	X	X
Non-synthetic compounds	NA	L	M
Synthetic compounds	NA	L	M
De-oxygenation	NA	M	H
Inorganic nutrient enrichment	NA	M	H
Organic enrichment	NA	M	H
Introduction of microbial pathogens	NA	M	H
Introduction or spread of non-indigenous species	NA	L	N
Removal of target and non-target species	NA	L	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table ER2. Nature and applicability of evidence used to complete Table ER1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	X	X	X	X	X	X	X	X
Habitat change (to another marine habitat)	2	0	0	0	2	***	***	[1, 2]
Physical disturbance	5	1	1	0	3	***	***	[1-5]
Siltation rate changes	2	0	0	0	2	***	***	[1, 2]
Temperature change	4	0	0	2	2	***	***	[3, 6-8]
Salinity change	2	0	0	0	2	***	***	[1, 2]
Water flow	2	0	0	0	2	***	***	[1, 2]
Emergence regime	2	0	0	0	2	***	***	[1, 2]
Wave exposure changes-local	2	0	0	0	2	***	***	[1, 2]
Litter	X	X	X	X	X	X	X	
Non-synthetic compounds	7	2	0	0	5	**	***	[3, 6, 9-13]
Synthetic compounds	5	0	0	0	5	**	***	[3, 6, 12-14]
De-oxygenation	2	0	0	0	2	***	***	[3, 6]
Inorganic nutrient enrichment	5	0	2	1	2	***	***	[6, 15-18]
Organic enrichment	3	0	0	0	3	***	***	[3, 6, 15]
Introduction of microbial pathogens	2	0	0	0	3	***	***	[1, 2]
Introduction or spread of non-indigenous species	2	1	0	0	1	**	***	[6, 19]
Removal of target and non-target species	5	0	1	0	4	**	***	[3, 5, 6, 15, 20]

References for exposed reef (ER) Tables

1.* Hill, J.M. (2008) Barnacles and Fucoids (Moderately Exposed Shores). Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

2.* Tyler-Walters, H. (2008) *Mytilis Edulis* and Barnacles on Very Exposed Eulittoral Rock. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

3. Crowe, T.P., Thompson, R.C., Bray, S., and Hawkins, S.J. (2000) Impacts of Anthropogenic Stress on Rocky Intertidal Communities. Journal of Aquatic Ecosystem Stress and Recovery (Formerly Journal of Aquatic Ecosystem Health) 7:273-297

4. Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A., and Rosenberg, A.A. (2009) Effects of a Large Fishing Closure on Benthic Communities in the Western Gulf of Maine: Recovery from the Effects of Gillnets and Otter Trawls. Fishery Bulletin 107:308-317

5. Povey, A. and Keough, M.J. (1991) Effects of Trampling on Plant and Animal Populations on Rocky Shores. Oikos 61:355-368

6. Thompson, R.C., Crowe, T.P., and Hawkins, S.J. (2002) Rocky Intertidal Communities: Past Environmental Changes, Present Status and Predictions for the Next 25 Years. Environmental Conservation 29:168-191

7. Findlay, H.S., Kendall, M.A., Spicer, J.I., Turley, C., and Widdicombe, S. (2008) Novel Microcosm System for Investigating the Effects of Elevated Carbon Dioxide and Temperature on Intertidal Organisms. Aquatic Biology 3:51-62

8. Findlay, H.S., Kendall, M.A., Spicer, J.I., and Widdicombe, S. (2010) Post-Larval Development of Two Intertidal Barnacles at Elevated Co2 and Temperature. Marine Biology 157:725-735

9. Boer, B. (1996) Impact of a Major Oil Spill Off Fujairah. Fresenius Environmental Bulletin 5:7-12

10. Nansingh, P. and Jurawan, S. (1999) Environmental Sensitivity of a Tropical Coastline (Trinidad, West Indies) to Oil Spills. Spill Science & Technology Bulletin 5:161-172

11. Dean, T.A. and Jewett, S.C. (2001) Habitat-Specific Recovery of Shallow Subtidal Communities Following the Exxon Valdez Oil Spill. Ecological Applications 11:1456-1471

*literature recommended by expert panel

12*. Hawkins, S.J., Gibbs, P.E., Pope, N.D., Burt, G.R., Chesman, B.S., Bray, S., Proud, S.V., Spence, S.K., Southward, A.J., Southward, G.A., and Langston, W.J. (2002) Recovery of Polluted Ecosystems: The Case for Long-Term Studies. Marine Environmental Research 54:215-222

13.* Southward, A.J., Langmead, O., Hardman-Mountford, N.J., Aiken, J., Boalch, G.T., Dando, P.R., Genner, M.J., Joint, I., Kendall, M.A., Halliday, N.C., Harris, R.P., Leaper, R., Mieszkowska, N., Pingree, R.D., Richardson, A.J., Sims, D.W., Smith, T., Walne, A.W., and Hawkins, S.J., *Long-Term Oceanographic and Ecological Research in the Western English Channel*, in *Advances in Marine Biology, Vol 47*. 2005. p. 1-105.

14. Kotrikla, A. (2009) Environmental Management Aspects for Tbt Antifouling Wastes from the Shipyards. Journal of Environmental Management 90:S77-S85

15. Crowe, T.P., Thompson, R.C., Bray, S., and Hawkins, S.J. (2000) Impacts of Anthropogenic Stress on Rocky Intertidal Communities. Journal of Aquatic Ecosystem Stress and Recovery 7:273-797

16. Bokn, T.L., Duarte, C.M., Pedersen, M.F., Marba, N., Moy, F.E., Barron, C., Bjerkeng, B., Borum, J., Christie, H., Engelbert, S., Fotel, F.L., Hoell, E.E., Karez, R., Kersting, K., Kraufvelin, P., Lindblad, C., Olsen, M., Sanderud, K.A., Sommer, U., and Sorensen, K. (2003) The Response of Experimental Rocky Shore Communities to Nutrient Additions. Ecosystems 6:577-594

17. Bokn, T.L., Moy, F.E., Christie, H., Engelbert, S., Karez, R., Kersting, K., Kraufvelin, P., Lindblad, C., Marba, N., Pedersen, M.F., and Sorensen, K. (2002) Are Rocky Shore Ecosystems Affected by Nutrient-Enriched Seawater? Some Preliminary Results from a Mesocosm Experiment. Hydrobiologia 484:167-175

18. Kraufvelin, P., Moy, F.E., Christie, H., and Bokn, T.L. (2006) Nutrient Addition to Experimental Rocky Shore Communities Revisited: Delayed Responses, Rapid Recovery. Ecosystems 9:1076-1093

19. Cognie, B., Haure, J., and Barille, L. (2006) Spatial Distribution in a Temperate Coastal Ecosystem of the Wild Stock of the Farmed Oyster Crassostrea Gigas (Thunberg). Aquaculture 259:249-259

20. Moreno, C.A. (2001) Community Patterns Generated by Human Harvesting on Chilean Shores: A Review. Aquatic Conservation-Marine and Freshwater Ecosystems 11:19-30

*literature recommended by expert panel

Sheltered reef

Table SR1. Level of resistance to impacts on extent and quality of sheltered reef habitats to each pressure and resilience following the impact created by each pressure upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	X	NA	NA
Habitat change (to another marine habitat)	L	NA	NA
Physical disturbance	H	L	L
Siltation rate changes	NA	L	M
Temperature change	NA	M	M
Salinity change	NA	L	M
Water flow	NA	M	H
Emergence regime	NA	M	H
Wave exposure changes-local	NA	L	M
Litter	X	X	X
Non-synthetic compounds	NA	M	H
Synthetic compounds	NA	L	M
De-oxygenation	NA	M	M
Inorganic nutrient enrichment	NA	M	L
Organic enrichment	NA	L	L
Introduction of microbial pathogens	NA	H	H
Introduction or spread of non-indigenous species	NA	L	N
Removal of target and non-target species	NA	L	H

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table SR2. Nature and applicability of evidence used to complete Table SR1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	X	X	X	X	X	X	X	X
Habitat change (to another marine habitat)	2	0	0	0	2	***	***	[1, 2]
Physical disturbance	4	0	1	0	3	***	***	[1-4]
Siltation rate changes	2	0	0	0	2	***	***	[1, 2]
Temperature change	4	0	0	2	2	***	***	[3, 5-7]
Salinity change	2	0	0	0	2	***	***	[1, 2]
Water flow	2	0	0	0	2	***	***	[1, 2]
Emergence regime	2	0	0	0	2	***	***	[1, 2]
Wave exposure changes-local	2	0	0	0	2	***	***	[1, 2]
Litter	X	X	X	X	X	X	X	
Non-synthetic compounds	6	2	0	0	4	**	**	[3, 5, 8-11]
Synthetic compounds	5	0	0	0	5	***	***	[3, 5, 10-12]
De-oxygenation	2	0	0	0	2	***	***	[1, 2]
Inorganic nutrient enrichment	6	0	3	1	2	**	***	[3, 5, 13-16]
Organic enrichment	2	0	0	0	2	***	***	[1, 2]
Introduction of microbial pathogens	2	0	0	0	2	***	***	[1, 2]
Introduction or spread of non-indigenous species	2	1	0	0	1	**	***	[5, 17]
Removal of target and non-target species	6	1	1	0	4	***	***	[1-3, 5, 16, 18]

References for sheltered reef (SR) Tables

1.* Hill, J.M. (2008) *Ascophyllum Nodosum* on Very Sheltered Mid Euittoral Rock. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

2.* Hill, J.M. (2008) *Ascophyllum Nodosum* Ecad *Makaii* Beds on Extremely Sheltered Mid Eulittoral Mixed Substrata. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

3. Crowe, T.P., Thompson, R.C., Bray, S., and Hawkins, S.J. (2000) Impacts of Anthropogenic Stress on Rocky Intertidal Communities. Journal of Aquatic Ecosystem Stress and Recovery (Formerly Journal of Aquatic Ecosystem Health) 7:273-297

4. Povey, A. and Keough, M.J. (1991) Effects of Trampling on Plant and Animal Populations on Rocky Shores. Oikos 61:355-368

5. Thompson, R.C., Crowe, T.P., and Hawkins, S.J. (2002) Rocky Intertidal Communities: Past Environmental Changes, Present Status and Predictions for the Next 25 Years. Environmental Conservation 29:168-191

6. Findlay, H.S., Kendall, M.A., Spicer, J.I., Turley, C., and Widdicombe, S. (2008) Novel Microcosm System for Investigating the Effects of Elevated Carbon Dioxide and Temperature on Intertidal Organisms. Aquatic Biology 3:51-62

7. Findlay, H.S., Kendall, M.A., Spicer, J.I., and Widdicombe, S. (2010) Post-Larval Development of Two Intertidal Barnacles at Elevated Co2 and Temperature. Marine Biology 157:725-735

8. Boer, B. (1996) Impact of a Major Oil Spill Off Fujairah. Fresenius Environmental Bulletin 5:7-12

9. Nansingh, P. and Jurawan, S. (1999) Environmental Sensitivity of a Tropical Coastline (Trinidad, West Indies) to Oil Spills. Spill Science & Technology Bulletin 5:161-172

10*. Southward, A.J., Langmead, O., Hardman-Mountford, N.J., Aiken, J., Boalch, G.T., Dando, P.R., Genner, M.J., Joint, I., Kendall, M.A., Halliday, N.C., Harris, R.P., Leaper, R., Mieszkowska, N., Pingree, R.D., Richardson, A.J., Sims, D.W., Smith, T., Walne, A.W., and Hawkins, S.J., *Long-Term Oceanographic and Ecological Research in the Western English Channel*, in *Advances in Marine Biology, Vol 47*. 2005. p. 1-105.

11.* Hawkins, S.J., Gibbs, P.E., Pope, N.D., Burt, G.R., Chesman, B.S., Bray, S., Proud, S.V., Spence, S.K., Southward, A.J., Southward, G.A., and Langston, W.J. (2002) Recovery of Polluted Ecosystems: The Case for Long-Term Studies. Marine Environmental Research 54:215-222

12. Kotrikla, A. (2009) Environmental Management Aspects for Tbt Antifouling Wastes from the Shipyards. Journal of Environmental Management 90:S77-S85

13. Bokn, T.L., Duarte, C.M., Pedersen, M.F., Marba, N., Moy, F.E., Barron, C., Bjerkeng, B., Borum, J., Christie, H., Engelbert, S., Fotel, F.L., Hoell, E.E., Karez, R., Kersting, K., Kraufvelin, P., Lindblad, C., Olsen, M., Sanderud, K.A., Sommer, U., and Sorensen, K. (2003) The Response of Experimental Rocky Shore Communities to Nutrient Additions. Ecosystems 6:577-594

14. Bokn, T.L., Moy, F.E., Christie, H., Engelbert, S., Karez, R., Kersting, K., Kraufvelin, P., Lindblad, C., Marba, N., Pedersen, M.F., and Sorensen, K. (2002) Are Rocky Shore Ecosystems Affected by Nutrient-Enriched Seawater? Some Preliminary Results from a Mesocosm Experiment. Hydrobiologia 484:167-175

15. Kraufvelin, P., Moy, F.E., Christie, H., and Bokn, T.L. (2006) Nutrient Addition to Experimental Rocky Shore Communities Revisited: Delayed Responses, Rapid Recovery. Ecosystems 9:1076-1093

16. Davies, A.J., Johnson, M.P., and Maggs, C.A. (2008) Subsidy by Ascophyllum Nodosum Increases Growth Rate and Survivorship of Patella Vulgata. Marine Ecology-Progress Series 366:43-48

17. Cognie, B., Haure, J., and Barille, L. (2006) Spatial Distribution in a Temperate Coastal Ecosystem of the Wild Stock of the Farmed Oyster Crassostrea Gigas (Thunberg). Aquaculture 259:249-259

18. Moreno, C.A. (2001) Community Patterns Generated by Human Harvesting on Chilean Shores: A Review. Aquatic Conservation-Marine and Freshwater Ecosystems 11:19-30

Maërl

Table MR1. Level of resistance to impacts on extent and quality of maërl habitats to each pressure and resilience following the impact created by each pressure upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	X	NA	X
Habitat change (to another marine habitat)	M	NA	L
Physical disturbance	L	L	L
Siltation rate changes	L	L	L
Temperature change	H	H	H
Salinity change	H	H	H
Water flow	M	M	H
Emergence regime	M	M	M
Wave exposure changes-local	M	M	M
Litter	X	X	X
Non-synthetic compounds	H	H	H
Synthetic compounds	X	X	X
De-oxygenation	M	M	M
Inorganic nutrient enrichment	M	M	M
Organic enrichment	M	M	M
Introduction of microbial pathogens	M	M	M
Introduction or spread of non-indigenous species	M	M	L
Removal of target and non-target species	L	L	L

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table MR2. Nature and applicability of evidence used to complete Table MR1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	X	X	X	X	X	X	X	X
Habitat change (to another marine habitat)	2	0	0	1	1	**	***	[1, 2]
Physical disturbance	12	6	1	1	4	**	***	[1-12]
Siltation rate changes	9	4	1	1	3	**	***	[1, 2, 7-9, 11-14]
Temperature change	2	0	0	2	0	***	***	[1, 15]
Salinity change	1	0	0	1	0	NA	***	[1]
Water flow	1	0	0	1	0	NA	***	[1]
Emergence regime	1	0	0	1	0	NA	***	[1]
Wave exposure changes-local	1	0	0	1	0	NA	***	[1]
Litter	X	X	X	X	X	X	X	X
Non-synthetic compounds	1	0	0	1	0	NA	***	[1]
Synthetic compounds	X	X	X	X	X	X	X	X
De-oxygenation	3	1	0	0	2	**	***	[2, 3, 14]
Inorganic nutrient enrichment	3	1	0	0	2	**	***	[2, 3, 14]
Organic enrichment	3	1	0	0	2	**	***	[2, 3, 14]
Introduction of microbial pathogens	2	0	0	0	2	***	***	[16, 17]
Introduction or spread of non-indigenous species	4	1	0	0	3	***	***	[2, 16-18]
Removal of target and non-target species	6	3	0	1	2	**	***	[1, 4, 5, 10, 12, 19]

References for maërl (MR) Tables

1. Wilson, S., Blake, C., Berges, J.A., and Maggs, C.A. (2004) Environmental Tolerances of Free-Living Coralline Algae (Maerl): Implications for European Marine Conservation. Biological Conservation 120:279-289

2. Grall, J. and Hall-Spencer, J.M. (2003) Problems Facing Maerl Conservation in Brittany. Aquatic Conservation-Marine and Freshwater Ecosystems 13:S55-S64

3. Barbera, C., Bordehore, C., Borg, J.A., Glemarec, M., Grall, J., Hall-Spencer, J.M., De La Huz, C., Lanfranco, E., Lastra, M., Moore, P.G., Mora, J., Pita, M.E., Ramos-Espla, A.A., Rizzo, M., Sanchez-Mata, A., Seva, A., Schembri, P.J., and Valle, C. (2003) Conservation and Management of Northeast Atlantic and Mediterranean Maerl Beds. Aquatic Conservation-Marine and Freshwater Ecosystems 13:S65-S76

4. Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J., and Karakassis, I. (2006) Global Analysis of Response and Recovery of Benthic Biota to Fishing. Marine Ecology-Progress Series 311:1-14

5. Collie, J.S., Hall, S.J., Kaiser, M.J., and Poiner, I.R. (2000) A Quantitative Analysis of Fishing Impacts on Shelf-Sea Benthos. Journal of Animal Ecology 69:785-798

6. Bordehore, C., Ramos-Espla, A.A., and Riosmena-Rodriguez, R. (2003) Comparative Study of Two Maerl Beds with Different Otter Trawling History, Southeast Iberian Peninsula. Aquatic Conservation-Marine and Freshwater Ecosystems 13:S43-S54

7. Hall-Spencer, J., White, N., Gillespie, E., Gillham, K., and Foggo, A. (2006) Impact of Fish Farms on Maerl Beds in Strongly Tidal Areas. Marine Ecology-Progress Series 326:1-9

8. Donnan, D.W. and Moore, P.G. (2003) Special Issue: International Workshop on 'the Conservation and Management of Maerl' - 23-27 February, 2001 - University Marine Biological Station, Millport, Isle of Cumbrae, Scotland - Conclusions. Aquatic Conservation-Marine and Freshwater Ecosystems 13:S77-S78

9. De Grave, S. and Whitaker, A. (1999) Benthic Community Re-Adjustment Following Dredging of a Muddy-Maerl Matrix. Marine Pollution Bulletin 38:102-108

10.* Trigg, C. and Moore, C.G. (2009) Recovery of the Biogenic Nest Habitat of Limaria Hians (Mollusca: Limacea) Following Anthropogenic Disturbance. Estuarine Coastal and Shelf Science 82:351-356

11. Hauton, C., Hall-Spencer, J.M., and Moore, P.G. (2003) An Experimental Study of the Ecological Impacts of Hydraulic Bivalve Dredging on Maerl. Ices Journal of Marine Science 60:381-392

*literature recommended by expert panel

12. Kamenos, N.A., Moore, P.G., and Hall-Spencer, J.M. (2003) Substratum Heterogeneity of Dredged Vs Un-Dredged Maerl Grounds. Journal of the Marine Biological Association of the United Kingdom 83:411-413

13. Pena, V. and Barbara, I. (2008) Maerl Community in the North-Western Iberian Peninsula: A Review of Floristic Studies and Long-Term Changes. Aquatic Conservation-Marine and Freshwater Ecosystems 18:339-366

14. Nelson, W.A. (2009) Calcified Macroalgae - Critical to Coastal Ecosystems and Vulnerable to Change: A Review. Marine and Freshwater Research 60:787-801

15. Steller, D.L., Hernandez-Ayon, J.M., Riosmena-Rodriguez, R., and Cabello-Pasini, A. (2007) Effect of Temperature on Photosynthesis, Growth and Calcification Rates of the Free-Living Coralline Alga Lithophyllum Margaritae. Cienc. Mar. 33:441-456

16.* Jackson, A. (2008) *Phymatolithom Calcareum* Maerl Beds Withj Hydroids and Echinoderms in Deeper Infralittoral Clean Gravel or Course Sand. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

17.* Jackson, A. (2008) *Lithothamnion Glaciale* Maerl Beds in Tide Swept Variable Salinity Infralittoral Gravel. Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme. Plymouth: Marine Biological Association of the United Kingdom. Available from: www.marlin.ac.uk

18. Klein, J.C. and Verlaque, M. (2009) Macroalgal Assemblages of Disturbed Coastal Detritic Bottoms Subject to Invasive Species. Estuarine Coastal and Shelf Science 82:461-468

19. Hall-Spencer, J.M. and Moore, P.G. (2000) Scallop Dredging Has Profound, Long-Term Impacts on Maerl Habitats. Ices Journal of Marine Science 57:1407-1415

Seagrass (*Zostera*)

Table Z1. Level of resistance to impacts on extent and quality of seagrass habitats to each pressure and resilience following the impact created by each pressure and upon cessation of the pressure.

Pressure	Resistance to impact on extent	Resistance to impact on quality	Resilience
Habitat loss (to land)	L	NA	L
Habitat change (to another marine habitat)	N	NA	L-N
Physical disturbance	N	N	L-N
Siltation rate changes	L	L	M
Temperature change	M	H	H
Salinity change	M	M	H
Water flow	M	L	L
Emergence regime	L	L	L
Wave exposure changes-local	M	M	H
Litter	H	M	H
Non-synthetic compounds	H	M	M
Synthetic compounds	H	L	M-L
De-oxygenation	L	L	M
Inorganic nutrient enrichment	M	L	M
Organic enrichment	M	L	M
Introduction of microbial pathogens	M	M	L
Introduction or spread of non-indigenous species	M	M	H
Removal of target and non-target species	M	M	M

Based on Tables 3 and 4 above, H- high, M- medium, L- low and N-none, X- insufficient information, NA- non-applicable.

Table Z2. Nature and applicability of evidence used to complete Table Z1.

	Depth of evidence i.e. number of peer reviewed papers used.	Type of evidence: observational (O) (from field surveys), field experiments (F), lab experiments (L) or review articles (R).				Concordance. *** agree on direction & magnitude of impact; ** agree on direction but not magnitude; * do not agree on direction or magnitude.	Applicability of evidence to Irish context (from Ireland, UK, or similar latitudes in northern Europe (***) or elsewhere (**) or from completely different latitudes, e.g. tropics or polar regions (*).	References (numbers refer to list on next page).
Pressure		**O**	**F**	**L**	**R**			
Habitat loss (to land)	2	1	0	0	1	***	**	[1, 2]
Habitat change (to another marine habitat)	2	1	0	0	1	***	**	[1, 2]
Physical disturbance	5	2	1	0	2	*	**	[1-5]
Siltation rate changes	12	5	1	2	4	***	**	[1, 2, 6-15]
Temperature change	9	3	1	3	2	**	**	[1, 11, 13, 16-21]
Salinity change	2	0	0	1	1	***	**	[1, 11]
Water flow	2	1	0	1	0	*	**	[8, 22]
Emergence regime	1	0	0	0	1	NA	***	[23]
Wave exposure changes-local	1	0	1	0	0	NA	**	[24]
Litter	1	0	0	0	1	NA	**	[1]
Non-synthetic compounds	4	1	0	1	2	**	**	[25-28]
Synthetic compounds	2	0	1	0	1	**	**	[24, 26]
De-oxygenation	4	1	0	2	1	**	**	[8, 11, 13, 19]
Inorganic nutrient enrichment	13	4	2	2	5	**	**	[1, 4, 6, 8-10, 13, 14, 19, 25, 29-31]
Organic enrichment	9	2	0	3	4	***	**	[1, 8, 10, 13, 14, 19, 29, 32, 33]
Introduction of microbial pathogens	1	1	0	0	0	NA	**	[8]
Introduction or spread of non-indigenous species	3	1	0	0	2	**	**	[1, 14, 16]
Removal of target and non-target species	3	0	1	0	2	*	**	[1, 4, 9]

References for Seagrass (*Zostera*) (Z) Tables

1. Boudouresque, C.F., Bernard, G., Pergent, G., Shili, A., and Verlaque, M. (2009) Regression of Mediterranean Seagrasses Caused by Natural Processes and Anthropogenic Disturbances and Stress: A Critical Review. Botanica Marina 52:395-418

2. Almela, E.D., Marba, N., Alvarez, E., Santiago, R., Martinez, R., and Duarte, C.M. (2008) Patch Dynamics of the Mediterranean Seagrass Posidonia Oceanica: Implications for Recolonisation Process. Aquatic Botany 89:397-403

3. Bishop, M.J., Peterson, C.H., Summerson, H.C., and Gaskill, D. (2005) Effects of Harvesting Methods on Sustainability of a Bay Scallop Fishery: Dredging Uproots Seagrass and Displaces Recruits. Fishery Bulletin 103:712-719

4. Duffy, J.E. (2006) Biodiversity and the Functioning of Seagrass Ecosystems. Marine Ecology-Progress Series 311:233-250

5. Creed, J.C. and Amado, G.M. (1999) Disturbance and Recovery of the Macroflora of a Seagrass (Halodule Wrightii Ascherson) Meadow in the Abrolhos Marine National Park, Brazil: An Experimental Evaluation of Anchor Damage. Journal of Experimental Marine Biology and Ecology 235:285-306

6. Moore, K.A. and Wetzel, R.L. (2000) Seasonal Variations in Eelgrass (Zostera Marina L.) Responses to Nutrient Enrichment and Reduced Light Availability in Experimental Ecosystems. Journal of Experimental Marine Biology and Ecology 244:1-28

7.* Williams, S.L. and Mcroy, C.P. (1982) Seagrass Productivity: The Effect of Light on Carbon Uptake. Aquatic Botany 12:321-344

8. Apostolaki, E.T., Tsagaraki, T., Tsapakis, M., and Karakassis, I. (2007) Fish Farming Impact on Sediments and Macrofauna Associated with Seagrass Meadows in the Mediterranean. Estuar. Coast. Shelf Sci. 75:408-416

9. Baggett, L.P., Heck Jr, K.L., Frankovich, T.A., Armitage, A.R., and Fourqurean, J.W. (2010) Nutrient Enrichment, Grazer Identity, and Their Effects on Epiphytic Algal Assemblages: Field Experiments in Subtropical Turtlegrass Thalassia Testudinum Meadows. Mar. Ecol. Prog. Ser. 406:33-45

10. Bastyan, G.R. and Cambridge, M.L. (2008) Transplantation as a Method for Restoring the Seagrass Posidonia Australis. Estuar. Coast. Shelf Sci. 79:289-299

11. Bergmann, N., Winters, G., Rauch, G., Eizaguirre, C., Gu, J., Nelle, P., Fricke, B., and Reusch, T.B. (2010) Population-Specificity of Heat Stress Gene Induction in Northern and Southern Eelgrass Zostera Marina Populations under Simulated Global Warming. Mol. Ecol. 19:2870-2883

*literature recommended by expert panel

12. Cabaco, S., Santos, R., and Duarte, C.M. (2008) The Impact of Sediment Burial and Erosion on Seagrasses: A Review. Estuar. Coast. Shelf Sci. 79:354-366

13. Lee, K.S., Park, S.R., and Kim, Y.K. (2007) Effects of Irradiance, Temperature, and Nutrients on Growth Dynamics of Seagrasses: A Review. Journal of Experimental Marine Biology and Ecology 350:144-175

14. Pergent-Martini, C., Boudouresque, C.F., Pasqualini, V., and Pergent, G. (2006) Impact of Fish Farming Facilities on Posidonia Oceanica Meadows: A Review. Marine Ecology-an Evolutionary Perspective 27:310-319

15.* Moore, K.A., Wetzel, R.L., and Orth, R.J. (1997) Seasonal Pulses of Turbidity and Their Relations to Eelgrass (Zostera Marina L) Survival in an Estuary. Journal of Experimental Marine Biology and Ecology 215:115-134

16.* Keser, M., Swenarton, J.T., Vozarik, J.M., and Foertch, J.F. (2003) Decline in Eelgrass (Zostera Marina L.) in Long Island Sound near Millstone Point, Connecticut (USA) Unrelated to Thermal Input. Journal of Sea Research 49:11-26

17. Abe, M., Yokota, K., Kurashima, A., and Maegawa, M. (2009) High Water Temperature Tolerance in Photosynthetic Activity of Zostera Japonica Ascherson & Graebner Seedlings from Ago Bay, Mie Prefecture, Central Japan. Fisheries Science 75:1117-1123

18.* Thorhaug, A. and Veziroglu, T.N., *Thermal Pollution Effects on an Estuary in a Developing Nation: Impact and Rehabilitation of Seagrass*, in *Studies in Environmental Science*. 1984, Elsevier. p. 407-413.

19. Koch, M.S., Schopmeyer, S., Kyhn-Hansen, C., and Madden, C.J. (2007) Synergistic Effects of High Temperature and Sulfide on Tropical Seagrass. Journal of Experimental Marine Biology and Ecology 344:91-101

20.* Roessler, M.A. (1971) Environmental Changes Associated with a Florida Power Plant. Marine Pollution Bulletin 2:87-90

21.* Jones, G.K., Baker, J.L., Edyvane, K., and Wright, G.J. (1996) Nearshore Fish Community of the Port River Barker Inlet Estuary, South Australia .1. Effect of Thermal Effluent on the Fish Community Structure, and Distribution and Growth of Economically Important Fish Species. Marine and Freshwater Research 47:785-799

22. Backhaus, J.O. and Verduin, J.J. (2008) Simulating the Interaction of Seagrasses with Their Ambient Flow. Estuar. Coast. Shelf Sci. 80:563-572

23. Short, F.T. and Neckles, H.A. (1999) The Effects of Global Climate Change on Seagrasses. Aquatic Botany 63:169-196

24. Bishop, M.J. (2005) Compensatory Effects of Boat Wake and Dredge Spoil Disposal on Assemblages of Macroinvertebrates. Estuaries 28:510-518

*literature recommended by expert panel

25. Balata, D., Bertocci, I., Piazzi, L., and Nesti, U. (2008) Comparison between Epiphyte Assemblages of Leaves and Rhizomes of the Seagrass Posidonia Oceanica Subjected to Different Levels of Anthropogenic Eutrophication. Estuar. Coast. Shelf Sci. 79:533-540

26. Roberts, D.A., Johnston, E.L., and Poore, A.G.B. (2008) Contamination of Marine Biogenic Habitats and Effects Upon Associated Epifauna. Marine Pollution Bulletin 56:1057-1065

27. Dean, T.A. and Jewett, S.C. (2001) Habitat-Specific Recovery of Shallow Subtidal Communities Following the Exxon Valdez Oil Spill. Ecological Applications 11:1456-1471

28.* Thorhaug, A. and Marcus, J. (1987) Oil-Spill Cleanup - the Effect of 3 Dispersants on 3 Subtropical Tropical Seagrasses. Marine Pollution Bulletin 18:124-126

29. Kirkman, H. and Kendrick, G.A. (1997) Ecological Significance and Commercial Harvesting of Drifting and Beach-Cast Macro-Algae and Seagrasses in Australia: A Review. Journal of Applied Phycology 9:311-326

30. Tett, P., Gowen, R., Mills, D., Fernandes, T., Gilpin, L., Huxham, M., Kennington, K., Read, P., Service, M., Wilkinson, M., and Malcolm, S. (2007) Defining and Detecting Undesirable Disturbance in the Context of Marine Eutrophication. Marine Pollution Bulletin 55:282-297

31. Cambridge, M.L., Chiffings, A.W., Brittan, C., Moore, L., and Mccomb, A.J. (1986) The Loss of Seagrass in Cockburn Sound, Western Australia .2. Possible Causes of Seagrass Decline. Aquatic Botany 24:269-285

32. Koch, M.S. and Erskine, J.M. (2001) Sulfide as a Phytotoxin to the Tropical Seagrass Thalassia Testudinum: Interactions with Light, Salinity and Temperature. Journal of Experimental Marine Biology and Ecology 266:81-95

33.* Koch, M.S., Schopmeyer, S.A., Nielsen, O.I., Kyhn-Hansen, C., and Madden, C.J. (2007) Conceptual Model of Seagrass Die-Off in Florida Bay: Links to Biogeochemical Processes. Journal of Experimental Marine Biology and Ecology 350:73-88

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*literature recommended by expert panel

Appendix 1: Legislative context

The Habitats Directive

The EU Habitats Directive (92/43/EEC) was introduced in 1992 and was transposed into Irish law in 1997 by S.I. 94 of 1997. The directive aims to ‘promote maintenance of biodiversity’ by requiring Member States to take measures to (1) maintain or restore natural habitats and wild species at favourable conservation status and (2) introduce robust protection for habitats and species of European importance. As part of the framework to achieve this aim, the directive requires the maintenance and/ or restoration to favourable conservation status of species and habitats. Assessment of conservation status is based on the extent and quality of key habitats (listed in Annex 1 of the Directive) and the range and population dynamics of key species (listed in Annex 2 of the Directive). Implementation of the Directive requires the declaration of Special Areas of Conservation (SACs) to protect listed habitats and species and the Appropriate Assessment of plans or projects proposed to take place within them (see Directive for further details or Crowe et al. 2011 for a summary).

The marine Annex I habitat types which are relevant in the Irish context are: reefs, estuaries, large shallow inlets and bays, mudflats and sandflats not covered by seawater at low tide and, to a lesser extent, sandbanks slightly covered by seawater at all times and sea caves. It is clear that some of these habitat types are geographically extensive, hosting a range of sectoral activity, but do not in themselves constitute an easily discernible single ecological unit, e.g., estuaries, inlets and bays, mudflats and sandflats. It is therefore necessary to identify the component habitats or broad community types for these habitat complexes. A useful framework of habitat types within which to consider issues of natural variability, pressure and recoverability is as follows (Crowe et al. 2011):

1. Gravels
2. Sands
3. Muds
4. Muddy sands/sandy muds
5. Exposed reef
6. Sheltered reef
7. Biogenic communities (e.g. Maërl, seagrass (*Zostera*))

These habitat types occur to varying degrees in the different Annex I habitats described above and each SAC comprises a matrix of habitats.

The Water Framework Directive

The Water Framework Directive (WFD, 2000/60/EC, NS Share 2005) requires an integrated approach to the protection, improvement and sustainable use of rivers, lakes, estuaries, coastal waters and groundwater within Europe. The primary focus of the Directive is to achieve 'good' ecological status for all waters by 2015. Ecological status is divided into five classes (high, good, moderate, poor and bad) and is derived from measurements of biological, hydro morphological and physio-chemical elements. The measurement of the biological elements includes flora, benthic invertebrates and fish.

Under the Directive, water quality management is centered on river basins. Characterisation Reports give an account of each basin, including the identification and description of water bodies followed by classification according to their specific type. Water bodies are assigned to types depending on their physical and biological characteristics (typology). For each type, reference conditions have been speficied which represent the condition of a water body in a relatively pristine or unimpacted state. Characterisation reports also include economic analysis and assessment of the potential of human pressures to prevent attainment of good environmental status by 2015. On this basis, a Programme of Measures is agreed, consisting of policies and strategies, such as monitoring programmes, that are intended to reduce the risk to water bodies and allow them to attain good status.

The WFD covers estuaries (transitional waters) and marine habitats out to 1 nautical mile from the coast. It influences them both directly and by affecting inputs from further upstream within catchments. The typology of transitional waters is based on their hydrology and coastal geomorphology. The typology of coastal waters divides them according to substratum and degree of exposure to wave action, recognising distinctions, for example, between exposed rocky shores and sheltered sandy shores.

The Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD, 2008/56/EC) aims to achieve Good Environmental Status in Europe's seas by 2020. Good environmental status should allow for the *provision of ecologically diverse and dynamic oceans and seas which are clean, healthy and productive.* Member states are required to develop marine strategies that apply an ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status, while enabling the sustainable use of marine goods and services by present and future generations.

The Directive sets out eleven high level descriptors of good environmental status which cover all the key aspects of the marine ecosystem and all the main human pressures on them, including maintenance of biological diversity, control of non-indigenous species, exploitation of fish and shellfish within safe biological limits, maintenance of integrity of food webs, minimisation of eutrophication is minimised, safeguarding of sea floor integrity, control of contaminants, marine litter and energy inputs (including noise). Like the WFD, member states are required to take stock of their marine environments, assess risks to good environmental status and put in place management plans for the achievement of good environmental status.

The MSFD covers the sea and seabed in territorial waters, i.e. extending to 12 nautical miles offshore, and overlaps with the WFD in coastal waters (within 1 nautical mile of the shore), covering the aspects of the environmental status not covered by that Directive.

Appendix 2: Pressures and ecosystem components

The lists of pressures (Table A2.1), and pressures disaggregated by activity causing them (Table A2.2) are given below.

Table A2.1: The list of broad pressure themes and individual pressures relevant for regional assessments carried out in the North-East Atlantic. The list is derived from the OSPAR/UKMMAS assessment matrix (Version 9 September 2008) and taken from a report by Robinson et al (2008).

Pressure theme	**Pressure**
Hydrological changes – (inshore/local)	Temperature changes – local
	Salinity changes – local
	Water flow (tidal and current) changes – local
	Emergence regime changes (sea level) – local
	Wave exposure changes – local
Pollution and other chemical changes	Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water)
	Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals)
	Radionuclide contamination

	De-oxygenation Nitrogen and phosphorus enrichment Organic enrichment
Other pressures	Litter
Species-level pressures (condition)	Underwater noise Visual disturbance (behaviour) Barrier to species movement (behaviour, reproduction) Introduction of microbial pathogens (disease) Introduction or spread of non-indigenous species & translocations (competition)
Species-level changes (distribution, population size)	Removal of target species (lethal) Removal of non-target species (lethal) Death or injury by collision
Habitat damage	Siltation rate changes Habitat structure changes – abrasion & other physical damage Habitat structure changes – removal of substratum (extraction)
Habitat loss	Habitat change (to another substratum) Habitat loss (to land)

Table A2.2: The list of pressures relevant to an assessment of the key pressures on marine ecosystem components in the North-East Atlantic, derived from the OSPAR/UKMMAS assessment matrix (Version 9 September 2008). Here pressures are sorted by the activity contributing to the pressure and then by pressure theme (Robinson et al. 2008).

Pressure themes	Pressure type	Main activities contributing to Pressure
Species-level pressures (condition)	Introduction or spread of non-indigenous species & translocations (competition)	Aquaculture
Species-level pressures (condition)	Introduction of microbial pathogens (disease)	Aquaculture
Pollution and other chemical changes	De-oxygenation	Aquaculture
Pollution and other chemical changes	Nitrogen and phosphorus enrichment	Aquaculture
Habitat loss	Habitat change (to another substratum)	Beach replenishment
Hydrological changes – (inshore/local)	Water flow (tidal and current) changes – local	Coastal infrastructure
Hydrological changes – (inshore/local)	Wave exposure changes – local	Coastal infrastructure
Habitat damage	Siltation rate changes	Coastal infrastructure
Hydrological changes – (inshore/local)	Emergence regime changes (sea level) – local	Coastal infrastructure – barrages
Species-level pressures (condition)	Barrier to species movement (behaviour, reproduction)	Coastal infrastructure - barrages, causeways, weirs, sluices
Hydrological changes – (inshore/local)	Salinity changes - local	Coastal infrastructure - barrages, causeways, weirs, sluices
Habitat loss	Habitat loss (to land)	Coastal infrastructure - defence & land claim
Habitat loss	Habitat change (to another substratum)	Coastal infrastructure - marinas, harbours
Species-level changes (distribution, population size)	Removal of non-target species (lethal)	Fishing - benthic trawling
Species-level changes (distribution, population size)	Removal of target species (lethal)	Fishing - benthic trawling

Pressure themes	Pressure type	Main activities contributing to Pressure
Habitat damage	Habitat structure changes – abrasion & other physical damage	Fishing - benthic trawling
Species-level changes (distribution, population size)	Removal of non-target species (lethal)	Fishing – dredging
Species-level changes (distribution, population size)	Removal of target species	Fishing – dredging
Habitat damage	Habitat structure changes – abrasion & other physical damage	Fishing – dredging
Species-level changes (distribution, population size)	Removal of non-target species (lethal)	Fishing - pelagic trawling
Species-level changes (distribution, population size)	Removal of target species (lethal)	Fishing - pelagic trawling
Species-level changes (distribution, population size)	Removal of non-target species (lethal)	Fishing - potting/creeling
Species-level changes (distribution, population size)	Removal of target species (lethal)	Fishing - potting/creeling
Habitat damage	Habitat structure changes – abrasion & other physical damage	Fishing - potting/creeling
Species-level changes (distribution, population size)	Removal of non-target species (lethal)	Fishing - set netting
Species-level changes (distribution, population size)	Removal of target species (lethal)	Fishing - set netting
Species-level changes (distribution, population size)	Removal of target species (lethal)	Fishing - shellfish harvesting
Pollution and other chemical changes	Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water)	Land-based pollution
Pollution and other chemical changes	Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals)	Land-based pollution
Pollution and other chemical changes	De-oxygenation	Land-based pollution
Pollution and other chemical changes	Nitrogen and phosphorus enrichment	Land-based pollution
Other pressures	Litter	Litter

Pressure themes	Pressure type	Main activities contributing to Pressure
Habitat damage	Habitat structure changes – removal of substratum (extraction)	Navigational dredging (capital, maintenance)
Habitat loss	Habitat change (to another substratum)	Navigational dredging (capital, maintenance) - dredge disposal
Hydrological changes – (inshore/local)	Water flow (tidal and current) changes – local	Offshore infrastructure
Species-level pressures (condition)	Underwater noise	Offshore infrastructure – wind turbines
Species-level pressures (condition)	Visual disturbance (behaviour)	Offshore infrastructure – wind turbines
Species-level changes (distribution, population size)	Death or injury by collision	Offshore infrastructure – wind turbines and other constructions
Habitat loss	Habitat change (to another substratum)	Offshore infrastructure: wind turbines, oil & gas platforms
Pollution and other chemical changes	Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water)	Oil & gas industry
Species-level pressures (condition)	Introduction or spread of non-indigenous species & translocations (competition)	Other means of non-native introduction
Hydrological changes – (inshore/local)	Temperature changes – local	Power stations
Habitat damage	Habitat structure changes – removal of substratum (extraction)	Sand & gravel extraction
Habitat damage	Siltation rate changes	Sand & gravel extraction
Species-level pressures (condition)	Underwater noise	Seismic survey (military, exploration, construction)
Species-level changes (distribution, population size)	Death or injury by collision	Shipping
Pollution and other chemical changes	Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water)	Shipping

Pressure themes	Pressure type	Main activities contributing to Pressure
Species-level pressures (condition)	Introduction or spread of non-indigenous species & translocations (competition)	Shipping (ballast water, on hulls)
Habitat damage	Habitat structure changes – abrasion & other physical damage	Shipping (anchoring)
Habitat damage	Habitat structure changes – abrasion & other physical damage	Shipping (anchoring)
Species-level pressures (condition)	Introduction or spread of non-indigenous species & translocations (competition)	Terrestrial pest control
Species-level changes (distribution, population size)	Death or injury by collision	Tourism/recreation (water sports/sailing)
Species-level pressures (condition)	Visual disturbance (behaviour)	Tourism/recreation
Habitat damage	Habitat structure changes – abrasion & other physical damage	Tourism/recreation (anchoring)
Habitat damage	Habitat structure changes – abrasion & other physical damage	Tourism/recreation(trampling)
Hydrological changes – (inshore/local)	Water flow (tidal and current) changes – local	Water abstraction (freshwater catchment)

Appendix 3 Search terms and outputs

ISI Web of Science

	Habitat Search Terms											
	gravel*, cobble*		**Sand, sediment***		**Mud, silt, sediment***		**muddy sand, sandy mud, sediment***		**seagrass*, *Zostera*, *Sabellaria*, anthozoa, *Serpula*, *Sabella*, *Neopentadactyla*, Maërl, maerl, bivalve, mussel, oysters, *Pachycerianthus, Virgularia***		**rocky shore, hard bottom, hard substratum, rocky reef, intertidal reef, subtidal reef, rock***	
Pressure search terms	**Useful hits**	**Total Hits**	**Useful hits**	**Total Hits**	**Useful hits**	**Total Hits**	**Useful hits**	**Total Hits**	**Useful hits**	**Total Hits**	**Useful hits**	**Total Hits**
acoustic, aggregate*, alien*, angling, anoxia, aquaculture, barrier, bottom trawl*, by-catch, construction, copper, current*, disease*, disturbance, disturbance, dredge*, drugs, endocrine disru*, eutrophication, gillnet*, heavy metals, hook*, hydrocarbon*, hypoxia, lead, litter, nitrate*, nitrite*, noise, non-native, nutrient*, off-road vehicles, oil, organic matter, otter trawl*, PAH*, pathogen*, PCB*, pesticide*, pharmaceuticals, phosphate*, plastic*, reclamation*, renewable*, salinity, scour, sea defence*, sea level, sedimentation, storminess, sulphate*, sulphite*, trampling, tributyltin, turbidity, warming, wave*, wind farm*, wind, turbine*, zinc AND marine, estua*, coast, shallow.	65	961	210	1994	218	2405	42	587	183	2447	194	3430

Aquatic Science and Fisheries Abstracts

	Habitat Search Terms	
	gravel*, cobble*, sand, sediment*, mud, silt, sediment*, muddy sand, sandy mud, seagrass*, *Zostera*, *Sabellaria*, anthozoa, *Serpula*, *Sabella*, *Neopentadactyla*, Maërl, maerl, bivalve, mussel, oysters, *Pachycerianthus, Virgularia*, rocky shore, hard bottom, hard substratum, rocky reef, intertidal reef, subtidal reef, rock*	
Pressure search terms	**Useful hits**	**Total hits**
acoustic, aggregate*, alien*, angling, anoxia, aquaculture, barrier, bottom trawl*, by-catch, construction, copper, current*, disease*, disturbance, disturbance, dredge*, drugs, endocrine disru*, eutrophication, gillnet*, heavy metals, hook*, hydrocarbon*, hypoxia, lead, litter, nitrate*, nitrite*, noise, non-native, nutrient*, off-road vehicles, oil, organic matter, otter trawl*, PAH*, pathogen*, PCB*, pesticide*, pharmaceuticals, phosphate*, plastic*, reclamation*, renewable*, salinity, scour, sea defence*, sea level, sedimentation, storminess, sulphate*, sulphite*, trampling, tributyltin, turbidity, warming, wave*, wind farm*, wind, turbine*, zinc AND marine, estua*, coast, shallow.	205 (of 2500 examined so far[1])	33728

[1] Due to time constraints only a fraction of the literature returned by the Aquatic Science and Fisheries Abstracts database was assessed.