A framework for managing sea bed habitats in near shore Special Areas of Conservation

A report by

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All of those involved have extensive experience of research and consultation at the interface between science and environmental policy and management. The group also includes individuals with particular expertise in each of the focal habitats and conservation units of this report. Brief biographic details of authors and consultees are provided in Appendix 1.

Executive summary

The EU Habitats Directive aims to promote maintenance of biodiversity. As part of the framework to achieve this, the Directive requires the restoration or maintenance of favourable conservation status in habitats listed in Annex I. The implementation of the Directive requires the designation of key sites containing these habitats as Special Areas of Conservation (SACs). Plans or projects proposed to take place in SACs are subject to appropriate assessment of their implications for the site by reference to its conservation objectives. In broad terms, the primary conservation objective of any SAC is to restore or maintain favourable conservation status. To guide the setting and implementation of operational site-specific conservation objectives, the Article 17 framework was used as a reference point to explore criteria for determining whether a site was in favourable (green), unfavourable-inadequate (amber) or unfavourable-bad (red) status. For a number of parameters, including the area of habitat and the quality of its specific structures and functions, the framework provided guideline percentages of change to mark the threshold for transition between green and red status, but not for the transition between green and amber status.

The main aims of the current project were: (1) to recommend a framework for setting and implementing site-specific conservation objectives by identifying threshold changes in extent and quality of selected marine Annex I habitats in SACs. The framework was to take account of natural variation in these parameters and to be based on scientific understanding of the ecology of the habitats; (2) review available evidence of sectoral impacts of human activities on the focal habitats as a guide to appropriate assessment.

The main focal habitats were: reefs, estuaries, large shallow inlets and bays, mudflats and sandflats not covered by seawater at low tide. Within these habitats, we distinguished a number of conservation units with distinct physical and biological characteristics, specifically gravels, sands, muds, muddy sands/sandy muds, biogenic communities (maërl, seagrass), exposed reefs and sheltered reefs. While recognising that these conservation units can be further sub-divided based on their biological communities, these units were considered the most stable and significant entities upon which objective setting and considerations of sectoral pressures should initially focus.

Our review of the scientific literature combined with a workshop of invited experts and a series of meetings and consultations led us to the following conclusions with regard to the setting and implementation of conservation objectives:

1. The framework recommended by the EC working group for the setting of conservation objectives fails to recognise important differences between terrestrial and marine systems and is therefore not readily applicable to marine conservation units.
2. Specific percentage thresholds of change in extent or quality of near shore marine habitats cannot be scientifically supported at this time. This conclusion was reached by (a) developing a logical process for identifying thresholds of change taking account of natural variation and (b) identifying two key elements that would be required to support such a process and for which insufficient evidence is currently available, specifically (i) an empirical basis for defining relevant envelopes of natural variation and (ii) an ecologically defensible rationale for determining acceptable thresholds of change outside envelopes of natural variation.

We therefore recommend:

1. A critical review of the existing Article 17 reporting framework, taking account of important differences between marine and terrestrial habitats. Such a review should take place at the level of European seas rather than within a single member state.
2. A scientific basis for percentage thresholds of change in extent and quality of near shore marine habitats will require relevant data and understanding to (a) define envelopes of natural variation in appropriate biotic variables and (b) develop objective criteria for setting ecologically meaningful deviations from those envelopes, e.g. based on tipping points and thresholds.
3. The following key knowledge gaps need to be filled: (a) datasets with the appropriate combination of spatio-temporal coverage and relevance to Ireland to quantify natural variation in extent and quality of conservation units (b) an agreed set of appropriate biotic variables that can be sampled to identify and interpret changes in conservation status cost-effectively (c) an ecological rationale for selecting thresholds of change, e.g. based on improved understanding of tipping points in marine ecosystems.
4. Include the monitoring of pressures as well as biotic variables in any implementation framework, such that biotic monitoring can be targeted to areas under greatest anthropogenic pressure and, if degradation occurs, the relevant human activities can be identified and restricted.
5. Until relevant data and understanding are available, prioritise protection of conservation units considered of high conservation value, either intrinsically or due to their provision of important ecosystem services, e.g. seagrass, maërl, feeding habitats for protected bird species. Thereafter, efforts to protect biological diversity should focus at broad levels, considering variation among sites, habitats, assemblages and species.

6. It is recognised that percentage changes may need to be defined to support spatial management of SACs on an interim basis (pending 1 above), and under such circumstances it would be necessary to base them on expert opinion, pragmatism or other criteria, such as social acceptability, all of which are arbitrary to some degree.

Our assessment of potential impacts of pressures associated with human activities involved a systematic review of the literature and consultation with appropriate experts. The first step was to map pressures to sectors of human activity. We then categorised the resistance of each conservation unit to potential impacts of each pressure on extent and quality and assessed the likely time to recovery (resilience). Our findings are summarised as a series of tables, which include details of the extent, nature, quality and applicability in an Irish context of the evidence that underpins each entry.

We emphasise that the tables should serve as a guide only and that their applicability to any specific situation should be informed by appropriate expert judgement during the assessment process. 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. It should also be noted that systems with low resilience may be particularly vulnerable to multiple pressure events as they spend long periods in a degraded (recovering) state.

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Chapter 1: Introduction

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 habitats listed under Annex I. Under Article 17, each Member State must report to the European Commission on the national conservation status of listed habitats and species every six years.

Article 1 of the directive states that the conservation status of a natural habitat is defined by the sum of the influences acting on it and its typical species that may affect its long-term natural distribution, structure and function, as well as the long-term survival of its typical species within the territory. The conservation status of a natural habitat will be taken as favourable when:

- its natural range and areas it covers within that range are stable or increasing, and
- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and
- the conservation status of its typical species is favourable as defined below.

The conservation status of a species means the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations within the territory referred in Article 2, and will be taken as favourable when:

- population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and
- the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and
- there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

In practise, it is necessary to develop more detailed criteria against which conservation status can be assessed. A general evaluation matrix was therefore developed during the 2006 Article 17 reporting cycle by a European Commission expert working group drawn from Member States to guide this process (Table 1).

Table 1. General evaluation matrix for assessing conservation status of a habitat type within a Member State (from European Commission (2006) Assessment, monitoring and reporting under Article 17 of the Habitats Directive: Explanatory Notes & Guidelines).

Parameter	**Conservation Status**			
	Favourable ('green')	***Unfavourable – Inadequate* ('amber')**	**Unfavourable - Bad ('red')**	***Unknown (insufficient information to make an assessment)***
Range[1]	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference range'	Any other combination	Large decrease: Equivalent to a loss of more than 1% per year within period specified by MS OR More than 10% below 'favourable reference range'	*No or insufficient reliable information available*
Area covered by habitat type within range[2]	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference area' AND without significant changes in distribution pattern within range (if data available)	Any other combination	Large decrease in surface area: Equivalent to a loss of more than 1% per year (indicative value MS may deviate from if duly justified) within period specified by MS OR With major losses in distribution pattern within range OR More than 10% below 'favourable reference area'	*No or insufficient reliable information available*
Specific structures and functions (including typical species[3]**)**	Structures and functions (including typical species) in good condition and no significant deteriorations / pressures.	Any other combination	More than 25% of the area is unfavourable as regards its specific structures and functions (including typical species)[4]	*No or insufficient reliable information available*
Future prospects (as regards range, area covered and specific structures and functions)	The habitats prospects for its future are excellent / good, no significant impact from threats expected; long-term viability assured.	Any other combination	The habitats prospects are bad, severe impact from threats expected; long-term viability not assured.	*No or insufficient reliable information available*

[1] Range within the biogeographical region concerned (for definition, see Annex F, further guidance on how to define range (e.g. scale and method) will be given in a foreseen guidance document to be elaborated by ETC-BD in cooperation with the SWG.

[2] There may be situations where the habitat area, although above the 'Favourable Reference Area', has decreased as a result of management measures to restore another Annex I habitat or habitat of an Annex II species. The habitat could still be considered to be at 'Favourable Conservation Status' but in such cases please give details in the Complementary Information section ("Other relevant information") of Annex D.

[3] A definition of typical species will be elaborated in the frame of the guidance document by ETC-BD in cooperation with the SWG.

[4] E.g. by discontinuation of former management, or is under pressure from significant adverse influences, e.g. critical loads of pollution exceeded.

Conservation objectives

The implementation of the Habitats Directive requires the designation of key sites as Special Areas of Conservation (SACs) for the protection of natural habitats and the development of conservation objectives that ensure such habitats within these sites contribute to favourable conservation status nationally. Although Table 1 refers primarily to the overall stock of each protected habitat within a Member State, it can be taken that its principles also apply to individual sites and can be used as a basis for developing site-specific conservation objectives, particularly in relation to ‘specific structures and functions’. Although percentage values have been provided as a guide to the deterioration that would constitute a transition to Unfavourable-Bad (red) conservation status, none are given in relation to the transition from Favourable (green) to Unfavourable-Inadequate (amber).

Appropriate assessment

Under Article 6(3) of the directive, any plan or project not directly connected with or necessary to the management of an SAC but likely to have a significant effect on it, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in reference to its conservation objectives. The competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned. This requires consideration of potential changes to both the extent (area) and quality (structure and functioning) of a habitat in response to a pressure, or combination of pressures, arising from specified human activities (plans or projects).

A framework for conservation objectives and appropriate assessment in Ireland

In December 2007, the European Court of Justice (ECJ) Case C418-04 ruled that Ireland had systematically failed to carry out proper assessment of aquaculture projects situated in Special Protection Areas (SPAs) for birds or likely to have effects on SPAs and emphasised the importance of prior appropriate assessment utilising relevant expertise of a plan or project against site-specific conservation objectives. Since this ruling pointed to an implementation failure under Article 6(3) of the Habitats Directive, by extension, it equally applied to SACs, including those in marine habitats that are the focus of this report.

Whilst the framing of site-specific conservation objectives is an important ongoing response by Ireland to the ECJ Ruling, it is to the benefit of both conservation and development interests that clarity is brought to the application of such objectives within the appropriate assessment process. The understandable ambition to maximise development and use of SACs in the current economic climate must be complemented by a regulatory framework that delivers Ireland’s legal obligations and clarifies to the extent possible, “Under what circumstances does the net effect of site uses result in unfavourable conservation condition?" The natural dynamics of habitats and their species over space and time, their resistance to specific pressures and the likely nature of recoverability in space and time thereafter are essential considerations to guide good regulatory processes. To that end, this study undertook to:

1. Review available scientific knowledge relating to natural variation in extent and quality for prescribed conservation units (or receiving environments),
2. Prepare tangible and specific recommendations for acceptable levels of impact to area and/or quality of specified conservation units in terms of percentage reductions, taking account of natural levels of variation, and from which the conservation units should be capable of recovery,
3. Subject to availability of information, prepare a draft review of the chemical, physical and biological tolerances and sensitivities for such conservation units in terms of:
    - potential impacts on extent (at the scales of coastal features and habitats) of key pressures / sectors;
    - potential impacts on quality (within habitat) – including sub-lethal effects – of key pressures / sectors;
    - potential for and timescale of recovery (i.e. resilience);
    - cumulative and interactive effects;
    - tipping points / threshold values;
    - quality of evidence and applicability in an Irish context.

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 current review was compiled to a short deadline and 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.

Focal habitats and conservation units

Natural habitats can be defined as terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features. Annex I of the Habitats Directive lists habitat types which require designation as SAC's. 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 immediately apparent 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.

Identification of conservation units

A wide range of environmental and biological factors act to shape marine benthic habitats and their ecology. Hydrodynamic and geophysical processes create a physical habitat that interacts with its surrounding environment to influence the composition of ecological communities. The following is recommended as a useful framework of habitat types, or conservation units, within which to consider issues of natural variability, pressure and recoverability:

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

These conservation units occur to varying degrees in the different Annex I habitats described above and each SAC comprises a matrix of conservation units. Given the prominence in hierarchical classification schemes of physical habitat type, and its strong influence on fauna and flora, these units were considered the most stable and significant entities upon which objective setting and considerations of sectoral pressures might initially focus. Nevertheless, we recognise that there can be considerable variation in biological communities within these conservation units and that this needs to be taken into account during assessment.

Chapter 2: Setting and implementation of conservation objectives

In broad terms, the conservation objective for any SAC is to contribute to the favourable conservation status of the Annex I habitats within it. The Habitats Directive defines favourable conservation status in terms relating to the extent of habitats, the quality of their structures and functioning and their key species (see Introduction). The challenge is to define favourable conservation condition at a site operationally, such that decisions affecting the SAC can be made against objective criteria and site monitoring can be undertaken to determine whether favourable condition has been maintained. An EC working group has generated a framework to report on favourable conservation status of habitats as required under Article 17 of the directive, which includes percentage changes in extent and quality of habitats that constitute changes from green to red status (Table 1). Accordingly, the brief for the current project stipulated that levels of degradation that would constitute a shift from green to amber conservation status contributing to this framework should be defined in terms of percentage reductions in extent and/or quality of conservation units.

We would argue, however, that the Article 17 reporting framework recommended by the EC working group (Table 1) fails to recognise important differences between terrestrial and marine systems and is therefore not readily applicable to conservation of marine habitats. In particular, many marine systems are ecologically ‘open’ systems and substantially influenced by oceanographic and hydrodynamic processes. These often act remotely from the focal site and contribute to high levels of natural variation observed at spatial and temporal scales different from those exhibited by terrestrial systems (Steele 1985, 1991). In addition, many marine habitats are submerged and inaccessible, making it very difficult to quantify changes in extent and quality with the necessary accuracy and precision. This is in contrast to most terrestrial habitats in which important changes tend to occur over longer timescales and are comparatively easily observed and quantified. Finally, there is rarely sufficient evidence to provide a defensible ecological rationale for what would constitute acceptable or unacceptable percentage changes at particular sites, leaving the framework open to challenges on scientific grounds.

The research and consultation undertaken in the current project have led us to the conclusion that specific percentage thresholds for change in extent or quality of nearshore marine habitats cannot be scientifically supported at this time. In this chapter, we present the basis for this conclusion in detail and suggest alternative approaches. We start by presenting a logical process for setting percentage-based conservation objectives under the current framework. We then identify elements of ecological evidence and understanding from a monitoring (or quantitative) perspective that would be required to underpin such a process but are currently lacking. Finally, we suggest pragmatic interim approaches to setting and implementing conservation objectives to support spatial management approaches.

A logical process for setting percentage-based conservation objectives

The extent and quality of all habitats varies considerably in space and time. Marine habitats are particularly prone to such variation. Habitats or conservation units which are varying naturally must be considered to have favourable conservation status. For the purposes of defining and implementing conservation objectives it is therefore important to understand the extent to which the units under consideration vary under natural conditions. For example, a conservation objective stating that there should be no reduction in extent of a seagrass bed in excess of 1% per year will be difficult or impossible to implement if the extent of the seagrass bed varies naturally by ±5%. We therefore propose that the following process for setting and implementing conservation objectives would be a logical solution, if the solution is required to involve percentage-based thresholds:

1. Define an envelope of natural variation for selected biotic variables in the conservation unit in question based on existing data (Figure 1).
2. In each reporting period, take an appropriate number of samples of selected biotic or abiotic variables and for each sample, assess whether it fits within or outside the envelope of natural variation.
3. Determine the proportion of samples that fall outside the envelope of natural variation (Figure 1). If this proportion is above a pre-determined threshold value, an investigation should be undertaken to assess the likely cause for this result. Under the existing framework (Table 1), if >25% of samples are of unfavourable status, the overall status is 'unfavourable – unacceptable' (red). However, in some cases, samples may fall outside the envelope in association with extreme natural events (e.g. severe storms or floods) and this should be taken into account when interpreting outcomes. In cases where no natural events can be linked with the changes, anthropogenic causes must be considered and appropriate management steps taken. This process would be greatly helped if human pressures are monitored in conjunction with biotic variables.
4. Periodically re-assess the envelope of natural variation based on new data, such that the baseline remains appropriate (see Chapter 3).

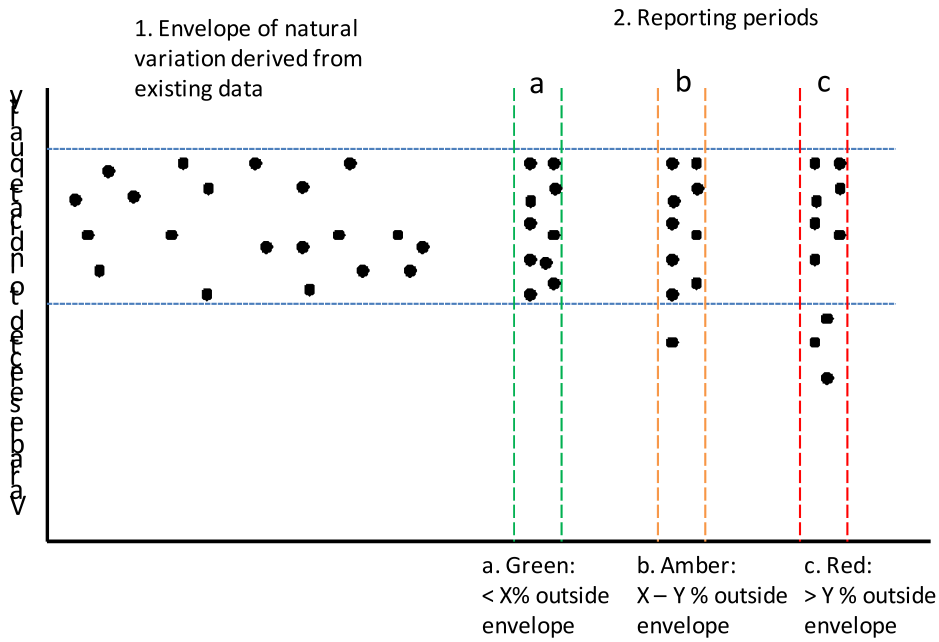

Figure 1. Schematic representation of a framework for setting and monitoring conservation objectives in terms of the proportion of samples falling outside an envelope of natural variation. An envelope of natural variation is indicated by the dashed horizontal lines (blue). The three pairs of vertical dashed lines represent hypothetical reporting periods for which monitoring revealed (a) green, (b) amber and (c) red status. 'X' and 'Y' are threshold values for these transitions. See text for detailed explanation.

Two key elements required to underpin such a framework are:

(a) An empirical basis for defining envelopes of natural variation, ultimately on a site-specific basis, but at least specific to habitats within defined geographic areas.
(b) An ecologically defensible rationale for specifying threshold proportions of samples falling outside the envelope of natural variation that would signal declines from green to amber to red status (i.e. the values for 'X' and 'Y' in Figure 1). Again, such thresholds may vary considerably under different environmental contexts and should ultimately be site-specific.

Below, we argue that there is insufficient evidence to support either of these elements.

Challenges in defining envelopes of natural variation

Data availability

Within this project, the intention was to find and collate data from temporal studies with a view to quantifying the extent of natural variation that should be accounted for when setting conservation objectives. Extensive searches were made within the data holdings of the Plymouth Marine Laboratory and Primer-E, the Marine Biological Association of the United Kingdom and the UK National Marine Biological Library, and databases developed during

European projects, particularly the EU Network of Excellence on Marine Biodiversity and Ecosystem Functioning (MARBEF) and its responsive mode subprojects such as LargeNET. Literature searches were made using the Web of Science and Google Scholar. The aim was to find raw data, relevant to features which could be the target of marine conservation objectives in Ireland, from anywhere on the continental shelf of the North-East Atlantic. Some datasets were available to us, such as abundances of sediment fauna collected at a range of sites off the North-East coast of England from 1973 to 1996 (Warwick et al. 2002), and from the Baie de Morlaix in France from just prior to the Amoco Cadiz oil-spill to ~4 years later (Dauvin 1984). Data from sediments in the Skomer Marine Nature Reserve, within the Pembrokeshire SAC in the UK were also examined in this project. The existence of other datasets was determined (e.g. see Frost et al. 2006), including data from several monitoring programmes in SACs and elsewhere in Europe, although the data could not be accessed in an appropriate form within the time-frame of this project. None of them, however, had the combination of spatio-temporal coverage and relevance to Ireland required for them to be used to set, quantitatively, levels of natural variation which could be built into robust and defensible conservation objectives.

This outcome is perhaps not unexpected. Gray and Elliott (2009) identify three general patterns of temporal variability in marine benthic systems. Some species tend to maintain population numbers relatively constant through time and may be said to be persistent; many organisms undergo repeatable cycles, which may be annual or longer term with periods from 6-7 to >30 years; there may be changes in response to longer-term processes which may or not be cyclical such as variation in the North Atlantic Oscillation. These patterns may be regarded as stable as changes are to some extent predictable, but may only be understood if we have monitoring data at the appropriate temporal and spatial scales. The variability of populations is influenced by variation in recruitment (and the processes underlying that variation): some species recruit regularly, while others have highly successful pulses of recruitment followed by long periods with no recruitment at all. Whether the latter may be considered stable or not depends on the repeatability of the cycles and the scale at which variation is considered. Gray and Elliott (2009) state that insufficient information is available on this, and go on to say 'In fact, so little data is available on long-term cycles and variations in recruitment that the patterns described above may in time prove not to be typical at all. Understanding recruitment variability and the factors causing that variability is one of the central problems in understanding long-term fluctuations in benthic communities.' It should also be noted that not only species and populations exhibit variation on many temporal scales: assemblages also do. Thus repeat surveys of the same place might detect very similar assemblages, but they will not be identical. They might detect very different assemblages which form parts of a natural successional cycle (e.g. mussels, barnacles or algae, on rocky shores). In terms of setting objectives, consideration needs to be made of the degree of change that might be considered trivial, as opposed to the degree of change that might be of concern.

There have been many collations of data and information within Europe and European nations which have aimed to incorporate natural variability into frameworks of conservation objectives. The general conclusion has been that sufficient data of adequate quality do not yet exist for the purpose of determining numerical limits or ranges for natural variation. As one example, within OSPAR (2008) there are many statements highlighting the lack of relevant data and information, such as: little is known about changes in maërl beds in relation to natural variability; rates of development of *Modiolus* reefs are not known; the degree to which *Modiolus* population structure, physical nature of the reefs, or the associated community structure might vary does not appear to have been studied; a better knowledge of the natural variation in extent, density and population structure of *Sabellaria spinulosa* reefs is required; research into the stability, rate of establishment, and recovery of damaged reefs will be important as will better knowledge of the natural variation in extent, density and population structure of *S. spinulosa* reefs; although there are many studies on seagrass beds in particular locations there are still aspects for which there is a poor understanding; the lack of long-term observational studies of sublittoral sediments means little is known about changes that might be the result of natural variability.

Measuring and interpreting benthic change

Conservation objectives consider two main components of conservation units: extent and quality. Although changes in extent of a feature may not appear to be difficult to determine, it may be difficult to do in practice, not just because the sampling and mapping required may be difficult to do underwater, but also because the feature may appear or disappear depending on how it is defined. For example, when do patchy populations of a reef-forming species such *Sabellaria spinulosa* become a reef? When conditions are favourable, dense aggregations may be found, forming reefs up to about 60 cm high and several hectares in area, and these are considered of great conservation value as biogenic reefs. Although reefs may persist in an area for many years, individual clumps may regularly form and disintegrate. For such species it is necessary to develop a definition of what it is that constitutes a reef, as the species is widespread in sediments without forming reefs, and it is the reef structure that is considered valuable. OSPAR (2008) give such a definition: in mixed substrata habitats, comprised variously of sand, gravel, pebble and cobble, the *Sabellaria* covers 30% or more of the substrata and needs to be sufficiently thick and persistent to support an associated epibiotic community which is distinct from surrounding habitats; on rocky habitats of bedrock, boulder and cobble, the *Sabellaria* covers 50% or more of the rock and may form a crust or be thicker in structure. In some areas, these two variations of reef type may grade into each other. Such a definition is fine until one imposes a particular limit on extent. If cover of *Sabellaria* on rock drops from 52% to 48% (should it be possible to measure it with such accuracy) the reef may be said to have disappeared, whereas in truth it may be evidence of a decline of concern, simple natural decline, or sampling error. Similarly, does the extent of a seagrass bed refer to the rhizome mat within the sediment (which may be impossible to map accurately) or the appearance of blades above the sediment surface (the aspect of the feature considered to deliver most ecosystem functioning but which may appear or disappear seasonally)?

Setting objectives relating to quality, however, is even more difficult to do in quantitative terms. The nature, direction, degree and interpretation of changes depend, critically, on how quality is defined and determined. In order to set a quantitative limit to change observations must be subjected to some sort of numerical treatment. For example, measures of diversity may be calculated and used in the definition of quality, using a conceptual model that diversity declines in a system under stress, as sensitive species are lost. Some species may increase or even become dominant, reducing evenness. Such a model could be used to define objectives along the lines "diversity should not be more than 10% less than baseline" which could then form the basis of a monitoring programme. The problem is that the model may not accurately predict how communities will respond to a change in pressure. Figure 2 illustrates how a range of measures of diversity actually increased following the Amoco Cadiz oil-spill, a situation which cannot be considered to represent an improvement in environmental condition.

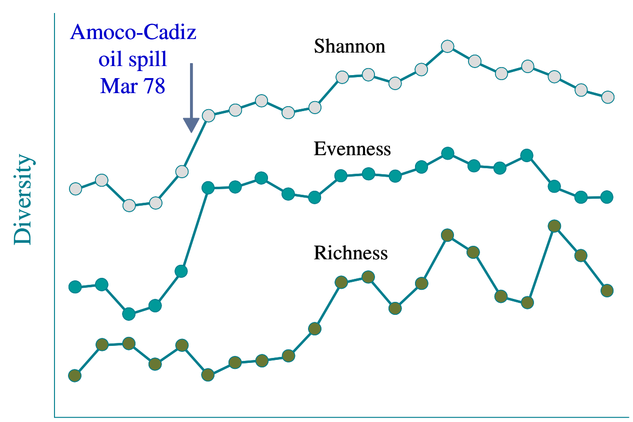

Figure 2. Relative changes in infaunal diversity in the Baie de Morlaix following the Amoco Cadiz oil-spill (based on Dauvin, 1984).

Very different indications of change may be apparent if alternative numerical treatments are applied to the same data. Figure 3 shows that while the number of species in samples from off the coast of North-East England varied widely from year to year, with no clear pattern, Shannon diversity (primarily an evenness measure) showed a clear step-wise increase in the mid-1980s. Further analyses (Warwick et al. 2002) were required to determine that this change represented a decline in environmental condition, being driven by the practical disappearance of a previously abundant species.

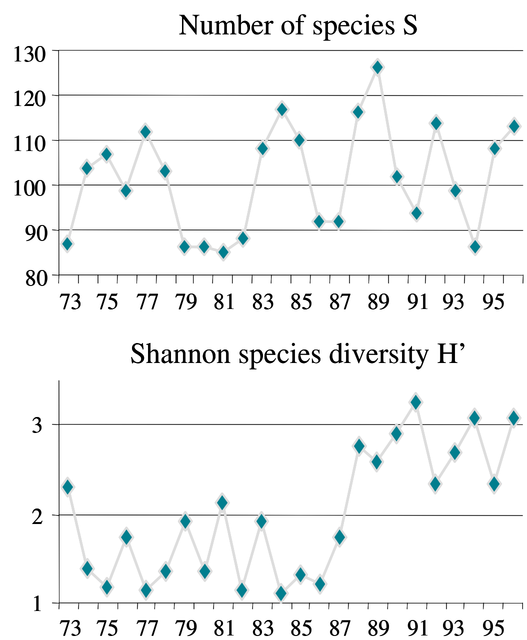

Figure 3. Changes in diversity off the coast of North-East England 1973-1996 (based on Warwick et al. 2002).

A classic marine example of the difficulties in setting and then monitoring a simple quantitative objective is the failure of the monitoring of Norwegian oil platforms to detect change, when changes were in fact happening (Gray et al. 1990). A simple objective of the type "there should be no changes in sediment communities beyond 500 m from oil-platforms" was being monitored using simple numerical treatments (calculation of diversity measures) of the monitoring data. Using this approach, no evidence of change was apparent. Application of alternative numerical methods, namely sensitive multivariate analyses, to the same data showed that objectives were not being complied with as there were clear changes in communities up to several kilometres from the installations. This finding led to major changes in the industry and the way in which monitoring was carried out.

The question then is: how to take account of natural variation within conservation objectives without having a clearly defensible method for setting numerical limits? The simplest approach is to phrase objectives in a way that acknowledges that variation occurs, while allowing expert judgement to play a role in determining the cause and consequences of that variation. An analysis of infaunal benthic data from a monitoring programme in the Skomer Marine Nature Reserve in Wales shows dramatic changes in abundance and community structure between 2003 and 2006, with declines in species numbers in the order of 50%. The 2006 survey took place in the autumn following the Sea Empress oil spill, and it would be easy to conclude that the spill had severely impacted the reserve. In fact, close examination of the data (which species had declined), analysis of data from continued monitoring (on a 3 year cycle), and a detailed examination of environmental factors (major storms in the Skomer area preceding the monitoring survey) led to the conclusion that the observed changes were naturally-driven. An overarching objective of the type "variation of 10% may be considered natural" would have been of no use in such a situation.

Taking this thinking further, while variation is an expected integral feature of well-functioning dynamic marine systems, not all variation is equally important or of equal conservation concern. Small variations in some features may be important, large variation in others may not. For example maërl beds are slow growing and long-lived, so small declines in the extent of a maërl bed should be of concern. Changes in a sedimentary system following major storms may be large, even encompassing the complete burial of biogenic reefs, but are part of the natural order. Numerically equivalent changes in a sheltered sediment system for which no cause is apparent should be of concern. With this in mind, the setting of acceptable numerical ranges within conservation objectives, if it must be done, should be site- and feature-specific.

Statistical power to detect change

A further consideration is that of statistical power. Setting a conservation objective with numerical bounds implies that changes in conservation status may be detected accurately. The statistical power of a survey, which is the probability that a predefined change will actually be detected, depends on natural variability against which change is to be detected, the amount of sampling effort (numbers of replicate samples) and the amount of change to be detected. Focusing on a range of sublittoral sediments ranging from clean coarse gravels to muddy sands (reference stations from UK aggregate extraction areas), power analysis shows that for many biotic variables the degree of sampling effort required for the detection of small changes (<10%) is prohibitive (100s to 1000s of samples required to detect the change 80% of the time). Only if changes in the order of 50-75% are to be detected with any degree of certainty does the required sampling effort begin to be practical. Similar results are reported by Rogers et al. (2008), looking at a range of benthic groups in offshore sediments sampled by a range of different methods (see Figure 4). Depending on the group (epifauna, infauna, meiofauna) and the sampling method (trawls, grabs, cores) very different numbers of samples would be required to detect a single objective of the type "change in species numbers of 10%. Again, setting simple limits for different components of the biota on the basis of limited studies is unlikely to be useful, and even if such limits are set they may not be enforceable. It is easy to incorporate statements into objectives of the form "variation of <5% is considered natural" but it may then be impossible to determine whether such changes occur or not.

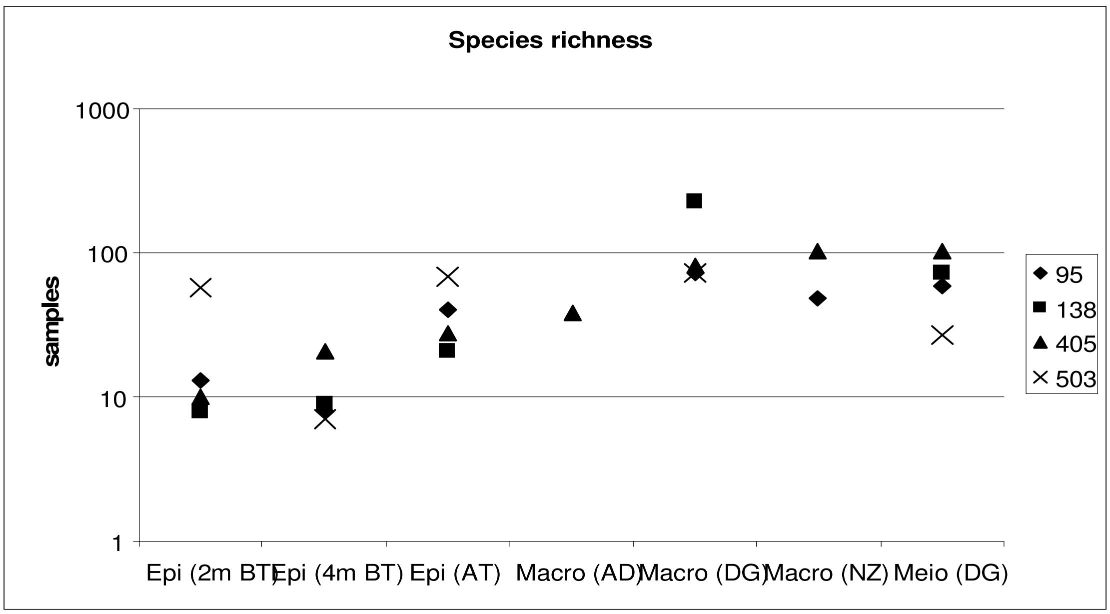

Figure 4. Numbers of samples required per treatment to detect a 10% difference in numbers of species 80% of the time at 4 offshore sites (95, 138, 405, 503) in the Irish Sea for a range of faunal components (Epi – epifauna; Macro – macrofauna; Meio – meiofauna) collected using different gears (see Rogers et al. 2008 for full details and other examples).

Selecting appropriate biotic variables

Notwithstanding the arguments made in the previous sections, some form of monitoring will be required to determine the conservation status of SACs. Clearly, the choice of variables to sample is critical to the likely validity of inferences made and determining the cost of the process. A detailed review of relevant variables is beyond the scope of the current contract. We recommend consideration of the following points, however:

(a) Abundance of individual taxa and traditional indices of diversity (species richness, Shannon diversity, etc.) are extremely variable through time and extremely costly to quantify because of the time and expertise required to process samples. It is therefore necessary to consider response variables that vary less and are cheaper to sample, but contain sufficient information to judge the status of conservation units.
(b) Biotic indices, such as IQI (Cusack et al. 2008) and M-AMBI (Muxika et al. 2007) are somewhat less costly to measure and vary less because they are less sensitive to fluctuations of individual taxa.
(c) Functional diversity metrics such as biological trait analysis (BTA) are less confounded over large temporal and spatial scales than traditional taxon-based approaches (Menezes et al. 2010) and have the potential to be a reliable, cost-effective, proxy of ecosystem functioning (Bremner et al. 2003, 2006, Frid et al. 2008).
(d) High level indicators derived from low cost sampling techniques could be used as a primary monitoring tool, e.g. using remote sensing or aerial photography (e.g. involving low cost platforms such as remote controlled aircraft or aircraft already employed on a compatible task).
(e) Chemical and physical proxies of biodiversity such as sediment profile imaging (SPI) (Solan & Kennedy, 2002), measuring the depth of the redox layer in sedimentary habitats act as a good proxy for bioturbation activity. Turbidity or shoot density (Cabaco et al. 2007, Ferwerda et al. 2007) in seagrass beds offer a rapid assessment method and shoot density could be calculated from photographs taken during a walk-through of the site.
(f) It may be necessary to ground-truth high level indicators against detailed biological data to be sure they reliably correspond to relevant changes. Furthermore ground-truthing of biotic indices may be required, particularly if they are to be applied in conservation units other than those in which they were developed (e.g. Crowe et al. 2004, Fitch and Crowe, 2010).
(g) In many situations, sampling a number of variables may be more informative than selecting only one. Particular variables may be more relevant to detecting impacts of particular stressors, so it may be appropriate to select different variables for different sites depending on the pressures present.
(h) Given the difficulties described above for defining rigid quantitative conservation objectives, a more qualitative or semi-quantitative approach may be appropriate. Assessment of key biological, physical and/or chemical processes underpinning favourable conservation status could be undertaken by appropriately trained operators taking a check-list approach – visiting sites and looking for key features of the environment indicative of health or degradation (e.g. blooms of green algae, sulphur

smells indicating anoxic sediments, etc.) or through rapid visual assessment of benthic samples at the sampling locations (e.g. clearly high abundances of indicator taxa such as *Capitella*).

(i) Anchoring extent-based conservation targets (or objectives) around physically defined conservation units as proposed in the current study reduces some of the variability issues referred to above compared to focusing at the biotope level.

(j) There is considerable scope to draw on conclusions of working groups for other directives. Indeed, the cost-effectiveness of monitoring for compliance with the Habitats Directive could be improved by linking it where possible with monitoring for compliance with other directives, such as the Water Framework Directive and the Marine Strategy Framework Directive. It is recognised, however, that differences in the aims of monitoring for different directives can reduce their compatibility.

The appropriate number of monitoring samples to collect will be dictated to some degree by the extent of the conservation unit, the degree of spatial resolution required and the cost of collecting and processing samples. However, given that proportions of sample points will need to be calculated, the number should be sufficiently large that individual sample points do not have undue influence on the outcome.

Monitoring human pressures

Incorporating monitoring of human activities and associated pressures into the framework would be highly beneficial as it would facilitate interpretation of causes of deviations from favourable conservation status and appropriate management responses (e.g. in terms of identifying which activities need to be managed or restricted). Given limited budgets for monitoring, the comparatively expensive monitoring of biota should be targeted within a given reporting period towards areas that have recently experienced changes in the pressures acting on them, e.g. due to new licensing of aquaculture or granting of planning permission for developments, particularly where there is uncertainty about potential environmental impacts. Interpreting changes in potentially impacted areas can be informed by comparison with baseline data or with data from other areas with similar characteristics but which have not been subjected to recent anthropogenic change.

Challenges in determining thresholds of change

Without an underlying rationale, selecting threshold of change beyond an envelope of natural variation to define transitions from green to amber to red status is not a scientific question but a societal choice. By what rationale should 10, 15 or 25% be chosen? In principle, an ecological rationale for defining threshold percentages of change could be developed on the basis of permitting changes from which it is known that the system can reliably recover. In population biology, a Minimum Viable Population size can be identified, below which a particular population is generally not sustainable (Soulé, 1987). Management to conserve populations can take this information into account when setting thresholds for taking action. The conceptual basis for defining Minimum Viable Populations is well developed. There is no equivalent understanding in relation to habitats and ecosystems.

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).

While acknowledging the Habitats Directive is concerned primarily with habitat protection rather than sustainable habitat change, information concerning such tipping points is an important consideration towards developing recommended limits to degradation in SACs. However, at this point in time, tipping points are not sufficiently well understood to permit their prediction in advance. As such, there is no ecological basis for specifying acceptable percentage changes to the extent or quality even in general terms, let alone for specific conservation units under specific circumstances. If percentage changes are to be defined, it would be necessary to base them on expert opinion, pragmatism or other criteria, such as social acceptability, all of which are arbitrary to some degree. Without adequate ecological knowledge, arbitrarily set thresholds could endanger some habitats by being set too high or unnecessarily restrict economic activity in others by being set too low.

Interim approaches

Pending a review of the current framework, practical steps need to be taken to safeguard the most important and vulnerable conservation units in SACs, without preventing acceptable levels of human activity. In the short term, a process of prioritising habitats for protection should be undertaken. For certain high value conservation units (e.g. seagrass or maërl beds, bird feeding areas, etc), we would argue that no deterioration in extent should be considered acceptable, particularly if it is effectively irreversible. Activities likely to cause loss of extent of such habitats should be subject to particular management. Thereafter, focusing general conservation strategies at broad physical, chemical and biological levels (e.g. estuarine sand communities, marine mud communities, etc) would afford protection to some of the primary drivers of biological diversity in marine systems.

The prioritisation of habitats for protection in both the short and longer term should take account of ecosystem services, such as nutrient cycling, provision of food and clean water, regulation of flooding or specified cultural or aesthetic benefits (Millennium Ecosystem Assessment, 2005). International conservation efforts are moving strongly in this direction, because such a focus makes explicit the link between ecosystem health and human well-being, thus improving political and social engagement (Raffaelli and Frid, 2010). It should be noted that the link between changes in the structure of ecosystems (e.g. in terms of extent and quality of habitats and biological assemblages) and their functioning and provision of services is not always well understood (e.g. Stachowicz et al. 2007). In some cases, a substantial structural change can have limited functional consequences (e.g. when other species are able to compensate functionally for those lost or reduced in abundance); in others slight structural changes can have dramatic functional consequences (e.g. seagrass can be a major contributor to carbon sequestration so reductions in density or extent can dramatically alter carbon budgets for coastal areas). Key ecosystem services for coastal marine SACs may include maintaining water quality or providing food for protected bird species.

Conclusions and recommendations

In conclusion, not enough data are available to set quantitative limits for conservation objectives that account for natural variability. Variability by its nature demands interpretation on a case by case basis, and the setting of objectives needs to consider the consequences of different amounts of variation for particular sites, habitats, assemblages and species. Observed variation, and the amount of variation, depends on what is being measured and how it is being interpreted. Different treatments of the same data can lead to very different interpretations, and objectives should be set in such a way that sensible and practical programmes may be put in place to support decision-making and determine compliance.

We recommend:

1. A critical review of the existing Article 17 reporting framework, taking account of important differences between marine and terrestrial habitats. Such a review should take place at the level of European seas rather than within a single member state.
2. A scientific basis for percentage thresholds of change in extent and quality of near shore marine habitats will require relevant data and understanding to (a) define

envelopes of natural variation in appropriate biotic variables and (b) develop objective criteria for setting ecologically meaningful deviations from those envelopes, e.g. based on tipping points and thresholds.

3. The following key knowledge gaps need to be filled: (a) datasets with the appropriate combination of spatio-temporal coverage and relevance to Ireland to quantify natural variation in extent and quality of conservation units (b) an agreed set of appropriate biotic variables that can be sampled to identify and interpret changes in conservation status cost-effectively (c) an ecological rationale for selecting thresholds of change, e.g. based on improved understanding of tipping points in marine ecosystems
4. Include the monitoring of pressures as well as biotic variables in any implementation framework, such that biotic monitoring can be targeted to areas under greatest anthropogenic pressure and, if degradation occurs, the relevant human activities can be identified and restricted.
5. Until relevant data and understanding are available, prioritise protection of conservation units considered of high conservation value, either intrinsically or due to their provision of important ecosystem services, e.g. seagrass, maërl, feeding habitats for protected bird species. Thereafter, efforts to protect biological diversity should focus at broad levels, considering variation among sites, habitats, assemblages and species.
6. It is recognised that percentage changes may need to be defined to support spatial management of SACs on an interim basis (pending 1 above), and under such circumstances it would be necessary to base them on expert opinion, pragmatism or other criteria, such as social acceptability, all of which are arbitrary to some degree.

Chapter 3: Indicative assessment of potential sectoral pressures

Appropriate 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 conservation unit recover from the impact?' These must be considered both in terms of extent and quality of conservation units. For each of the focal conservation units, we therefore undertook to address these questions for the range of applicable sectors of human activities and the pressures they exert.

A standard list of anthropogenic pressures as set out under OSPAR and refined from Robinson et al. (2008) was compiled for use in this report (see Table A2.1, Appendix 2). Each sector of human activity results in one or more of the described pressures. From the comprehensive list it was agreed that some pressures of limited relevance would be 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 2a). The association of pressures with sectors is based on Robinson et al (2008) (see Table A2.2, Appendix 2).

Table 2a. 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 and tourism	Energ
		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 2b. Explanatory notes for the sectors and sub-sectors in Table 2a. 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.

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 conservation unit, summarising their susceptibility to the pressures described above (Table 2a 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. No major changes were recommended to any entries, though advice was given on additional literature to consult. Due to the large volume of literature returned from searches it has not been possible to include details from every paper in the report within the timeframe of the contract. Details of the concepts and rationale underpinning the Tables are provided below.

Susceptibility of conservation units to impact – resistance stability

The degree to which a particular conservation unit is impacted by a particular pressure varies depending on the conservation unit and the pressure involved. In other words, different conservation units 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 3 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 3. The resistance categories used to complete tables for each conservation unit (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 conservation units 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 conservation units. The current review recognises that different pressures cause different changes in the structure and functioning of conservation units, 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 4) 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 4. The resilience categories used to complete tables for each conservation unit (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 conservation unit generally has capacity to recover should not necessarily be used to justify causing damage to it.

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 5). 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 5. 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.

Temporal accumulation of impact – shifting baselines

Ideally, in a given habitat, the baseline from which the ecological quality of a habitat should be measured is from un-impacted natural conditions. It should, however be noted that a pressure or combination of pressures may have (and in many instances are likely to have) caused a shift away from such conditions.

Where un-impacted baseline data are available for selected quality criteria, then future quality threshold values may be set against such data. In a given monitoring period, it is vital to be conscious of the baseline from which any impact on a quality criterion for a habitat is being measured, and the timescale over which the assessment is being carried out. For instance, in the Habitats Directive baselines for SACs were required from the time of legal transposition (i.e. from 1994 values). Whilst data concerning habitat range and extent may be derived for 1994, the baseline for habitat structure and function may need to rely on data derived from the first relevant survey event after 1995 in association with best expert judgement as to appropriate thresholds. It is certainly possible that an improvement in some baseline quality criteria over time may have occurred in some areas. However, it is also possible that an area was not functioning appropriately and/or coping with resident or subsequent pressures.

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 conservation units 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 conservation unit 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.

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.

Summary Tables

Below are the Tables summarising the findings of the review. They are grouped by conservation unit. For each conservation unit, 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 conservation unit 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 conservation unit 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 conservation units of the same type may also be influential. For example, the ‘gravels’ conservation unit 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 conservation units 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 conservation unit. For most conservation units, ‘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 conservation units 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 conservation units 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.

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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]

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*literature recommended by expert panel

*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]

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*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]

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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]

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*literature recommended by expert panel

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.

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)	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]

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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.

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)	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]

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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]

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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.

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).				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).
		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]

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Appendix 1 Brief biographic details of authors and consultees

Dr Tasman P. Crowe is Head of Research and Innovation in the School of Biology and Environmental Science at University College Dublin. His research has included studies of individual and combined impacts of a range of stressors on marine benthic habitats, particularly rocky shores, and field-based testing of biomonitoring tools. He has also worked on fishery management, stock enhancement, design of networks of marine protected areas and on the experimental evaluation of consequences of biodiversity loss for ecosystem functioning. He is a member of the National Platform for Biodiversity Research and has published over 40 peer-reviewed papers and three book chapters.

Dr Jayne E. Fitch is a postdoctoral research assistant in the School of Biology and Environmental Science at University College Dublin. She has expertise in the impacts of multiple environmental and anthropogenic pressures in benthic ecosystems and the monitoring and management of marine ecosystems. She has 2 peer-reviewed publications.

Professor Chris L. J. Frid is Professor of Marine Biology and Head of the School of Environmental Sciences at the University of Liverpool. He has expertise in the dynamics of marine systems - the role of intrinsic and extrinsic drivers and the role of human impacts. Prof. Frid is a member ICES Working Group on The Ecosystem Effects of Fishing Activities, has provided advice on marine management to industry, the European Parliament, European Commission and UK government agencies. He has written 90 peer-reviewed papers and 18 books/book chapters.

Dr Paul Somerfield is principal investigator in the Marine Life Support Systems programme at Plymouth Marine Laboratory. He has expertise in the ecology of marine communities, non-parametric multivariate methods for analysis of data, application of macroecological and meta-analytical approaches in the marine environment, spatial distribution of marine organisms, sampling methods for the study of marine communities. Dr. Somerfield is a member of the ICES Benthic Ecology Working Group and the Royal Statistical Society Panel on Statistics for Ecosystem Change. He has written over 80 peer-reviewed papers.

Professor Mike Elliott is Professor of Estuaries and Coastal Science and is Director of the Institute of Estuarine and Coastal Sciences at the University of Hull. He has expertise in the science and management of estuaries and coastal areas, marine and estuarine pollution and the effects of human activities on biological systems; policy and legislative aspects of estuaries and coasts. Prof. Elliott is a member of the Marine Conservation Zone Science Advisory Panel. He has written more than 140 peer-reviewed and 10 books/ book chapters.

Professor Stephen J. Hawkins is Professor of Marine Ecology and Dean of the Faculty of Natural and Environmental Sciences at the University of Southampton. He has expertise in experimental coastal ecology, rocky shore ecology, restoration of degraded coastal ecosystems, recovery of polluted shores and estuaries, shellfisheries, impacts of scallop dredging on benthos, long term change in relation to climate using rocky-shore indicators, ecology and design of sea defences. Prof. Hawkins has written more than 140 peer-reviewed publications and a number of books and book chapters.

Professor David M. Paterson is Professor of Coastal Ecology and Head of the School of Biology at St Andrews University. He has expertise in the ecology and dynamics of coastal and estuarine systems, the biodiversity and functional ecology and dynamics of coastal systems and the resilience of coastal systems in the face of global change, their functional variability and the services they provide. Prof. Paterson is External scientific adviser to the Danish national programme. He has written more than 100 peer-reviewed publications and 13 books/book chapters.

Professor David G. Raffaelli is Professor of Environmental Science at the University of York. He has expertise in marine food web dynamics; the relationships between catchment land-use, water quality and impacts on coastal receiving systems; the application of manipulative field experiments to large-scale conservation and management issues, biodiversity, ecosystem functioning and ecosystem services; the influence of species body-size in community dynamics; the issues of communication in environmental debate; inter-disciplinary approaches to environmental management. Prof. Raffaelli has written more than 100 peer-reviewed publications and 17 books/ book chapters.

Dr Pádraig Whelan is a lecturer in the Department of Zoology, Ecology and Plant Science and at University College Cork. He has expertise in protected area management, the impact and control of introduced species and the biology, ecology and distribution of *Zostera marina* in Ireland. Dr Whelan has written more than 25 peer-reviewed papers and 4 books/ book chapters.

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

	Conservation Unit 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

	Conservation Unit 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[5])	33728

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