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Development of JNCC Marine Ecosystem Services Optimisation models

Tillin, H.M., Langmead, O., Pegg, S., Carr, S., Gibson- Hall, E., La Bianca, G., Luff, A., Keen, P.W., Wilding, C., Nicholson, J.C., Ivory P. & van Rein, H.

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Summary

The benefits that humans derive from marine ecosystems through the provision of foods such as fish, crabs and scallops and other less tangible goods, including opportunities for recreation, are increasingly being recognised. Human well-being is further indirectly supported by the processes and functions of ecosystems that regulate and maintain the natural environment, such as the absorption of flood waters by coastal saltmarshes, waste breakdown that maintains environmental quality and the provision of nursery habitats for commercially harvested species. These direct and indirect benefits are termed ecosystem services.

Human activities that take place in coastal and marine environments can alter the provision of ecosystem services through depletion and degradation of natural assets. To ensure that uses and benefits are sustained, environmental managers and policy makers are seeking to develop tools to manage human demands and pressures and support decision making.

JNCC has previously commissioned the development of five conceptual ecological models (CEMs) which represent broad marine, sublittoral habitats (mud, sand, coarse and mixed sediments and rock) in the UK to support marine management, including indicator selection. The CEMs demonstrate the ecological links, drivers and ecosystem functions which occur in shallow sublittoral habitats, the relative magnitude of influence of ecological components and the confidence in these links. Using the existing CEMS, JNCC developed initial marine ecosystem service models using Bayesian Belief Networks to link the ecological components identified in the CEMS to the delivery of ecosystem services. The aim of the current project was to further develop and test these initial proof-of-concept MESO models, to improve confidence in the model relationships as well as increase the usability of the models for managers by creating a user interface.

The current project examined how both the pressures resulting from human activities and their impacts on ecosystem services could be incorporated in the models. To support the decision-making, we reviewed evidence for human activity-pressure links and their impacts on the marine environment. A further review of the relation of each model component to ecosystem services was also undertaken. To our knowledge this is the first attempt to link ecosystem components in terms of the grouping of functionally similar species into functional groups (bio-assemblages), with their capacity to provide ecosystem services. This takes the association between the ecological component down to a much more detailed level in terms of the functions being undertaken by the ecological assemblage that support the intermediate and final ecosystem services. The strength of the linkages is supported by information relating to the life history and biological traits of the species and thus a much more robust approach than expert opinion at the scale of biotopes comprised of many different functional groups.

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1 Introduction

1.1 Project Background

There is increasing recognition of the benefits that humans derive from ecosystems through the provision of foods such as fish, crabs and scallops and other less tangible goods, including opportunities for recreation. Human well-being is further indirectly supported by the processes and functions of ecosystems that regulate and maintain the natural environment, such as the absorption of flood waters by coastal saltmarshes, waste breakdown that maintains environmental quality and the provision of nursery habitats for the commercially harvested species. These direct and indirect benefits are termed ecosystem services.

Human activities that take place in coastal and marine environments can alter the provision of ecosystem services through depletion and degradation of natural assets. To ensure that uses and benefits are sustained, environmental managers and policy makers are seeking to develop decision support tools to manage human demands and pressures. To support marine management, including indicator selection, JNCC has previously commissioned the development of five conceptual ecological models (CEMs) which represent broad marine, sublittoral habitats (mud, sand, coarse and mixed sediments and rock) in the UK. The CEMs diagrammatically demonstrate:

- ecological links, drivers and ecosystem functions which occur in shallow sublittoral habitats;
- relative magnitude of influence of the ecological components included in the model; and
- the confidence in these links.

JNCC has explored the use of the CEMs as the basis for developing marine ecosystem service models. The initial marine ecosystem service optimisation (MESO) model used a Bayesian Belief Network (hereafter the models are referred to as referred to as MESO BBN models). The MESO BBN models simulate the probable effects of stressors (i.e. pressures) on the provision of ecosystem services, including intermediate (supporting services) and final ecosystem services supplied by the habitat. JNCC commissioned this project to further develop the MESO BBN as outlined in the project aims and objectives.

1.2 Project Aims and Objectives

JNCC commissioned the Marine Biological Association of the UK and AVS Limited to further develop MESO BBN models based on the five broad habitat type CEMs. The partially developed MESO BBN models supplied to the project team were made up of nodes and edges that represent ecological components, pressures and ecosystem services (nodes) and the links (edges) between these. The aims of the current project were to:

- further develop and test the initial proof-of-concept MESO BBN model and to evaluate the incorporation of nodes representing pressures and ecosystem service to the existing ecological component nodes identified in the CEM;
- improve confidence in the model relationships by reviewing evidence for the links (edges) and identifying how these could be parameterised; and finally,
- increase the usability of the MESO BBN models so that the models become operational and accessible to decision makers by creating a user interface.

The objectives to deliver this work are set out below.

1.2.1 Ecological Objectives

To underpin further development of the MESO BBN, evidence was required on the effects of pressures caused by human activities on the components of marine ecosystems that support and provide ecosystem services. The response of the bio-assemblages within the CEM to human pressures was identified as a particular evidence gap. The links between ecological components within the CEM and ecosystem services also required further elucidation as most work to date has focussed on habitats that supply services not the individual parts. The methodology and key findings and outputs for the ecological objectives are outlined in chapters 2 and 3.

Objective 1. Undertake a literature review to consolidate and summarise evidence of effects of anthropogenic pressures on the functioning of sublittoral sand, mixed sediments, mud, coarse sediments and rock.

Objective 2. Undertake a literature review to consolidate and summarise evidence of effects of anthropogenic pressures on conservation objective attributes for sublittoral sand, mixed sediments, mud, coarse sediments and rock.

Objective 3. Undertake literature review to consolidate and summarise evidence of provision of ecosystem services (intermediate and final) from sublittoral sand, mixed sediments, mud, coarse sediments and rock.

1.2.2 BBN Modelling Objectives

The methodology and key findings and outputs for the BBN modelling objectives are outlined in chapter 4. This chapter also provides a brief introduction to BBN models.

Objective 4. Create manually invoked mechanisms (e.g. scripts) to run BBN models in R (or another suitable programming language) based on JNCCs initial R script and the original VBA scripts in Excel. These must be able to run the existing five MESO models, ingest new data, test stressor scenarios and create outputs.

Objective 5. Create a user-friendly interface that consolidates all manually invoked mechanisms (e.g. scripts) and operational files (e.g. look up tables) into one place.

Objective 6. Create a package with ‘functions’ using the manually invoked mechanisms (e.g. scripts) from the primary objectives (e.g. R package if R scripting language used)

Objective 7. Expand the capabilities of the user-friendly interface from Objective 5 so that it operates with all MESO models (twenty-five in total) from all 5 marine benthic habitats (sublittoral sand, sublittoral rock; sublittoral coarse sediment; sublittoral mixed sediment and sublittoral mud).

1.3 Project Report Outline

This report provides a high-level description of the project findings and methodological approaches. More detailed technical evidence is presented in the report appendices and accompanying Excel spreadsheets (see Section 1.4). As the project was separated into distinct ecological and BBN modelling objectives, we have reported on these separately. The BBN objectives are therefore presented as a standalone chapter (Chapter 4). The report consists of the following Chapters.

Chapter 1. consists of this introductory section, which outlines the project background, project aims and objectives, report outline and outputs.

Chapter 2. Ecological objectives: methodology. This chapter briefly introduces the CEM and the ecological components within these that underpin this project. The chapter outlines the methodology to address Objectives 1-3. The ecosystem service, pressure and conservation objective attribute frameworks adopted by this project are described and the literature review methodology and prioritisation are discussed. The evidence gathered from the review was used to assess the links between ecological components identified in the CEM models and links to ecosystem services, pressures and conservation objective attributes. Summary proformas for these are represented in this report they identify:

- Appendix 8: Pressure proformas: pressure description and benchmark and a summary of the reviewed activities contribution to the pressure (where relevant) and the confidence in this relationship;
- Appendix 9: Conservation objective attribute proformas: a description of the attribute and sub-attribute and the likely relationship between activities and pressures and impacts; and
- Appendix 10: A description of the ecosystem service and the evidence to link delivery of the service to the ecological components identified within the CEM.

Chapter 3. Ecological objectives: summary of key findings and outputs.

Chapter 4. Bayesian Belief Network models. This chapter provides an introduction to BBNs and described work undertaken to fulfil the modelling objectives.

Chapter 5. discusses the key evidence gaps and data limitations.

Chapter 6. provides the final report summary and conclusions.

1.4 Project Outputs

The project outputs consist of this final report and the pressure, conservation objective attribute and ecosystem service proformas (Appendices 8, 9, and 10 respectively). The proformas describe the following:

Outputs supplied separately include:

- ecosystem service review Excel spreadsheet;
- pressure and conservation objective attribute review spreadsheet;
- pressure- sensitivity assessment reviews for sand, coarse, mud, mixed and rock habitats; and
- BBN Model viewer and scripts.

2 Ecological objectives: methodology

2.1 Background: CEM Model Overview

The conceptual ecological models (CEMs) were developed for five broad habitats by previous projects commissioned by JNCC (see Table 1 for references). The CEMs are diagrammatic representations of the influences and processes that occur within an ecosystem. The CEMS are based on literature review and each model is accompanied by a report and technical appendices including details of the literature review and confidence assessments.

Each CEM consists of a number (approximately fifty) of ecological components that represent different taxa, structural and / or functional aspects of the habitat, such as functional groups of taxa (e.g. burrowing fauna), abiotic factors (e.g. sediment type) or processes (e.g. sediment mobility). Characteristic species within habitats were assigned to functional groups based on species traits for representation within each CEM. These functional groups are referred to as bio-assemblages within this project and throughout this report.

The CEMs contain habitat sub-models to represent the interactions between bio-assemblages with a similar function (e.g. all predators and scavengers, or all filter-feeders *etc*.), within a marine benthic habitat. Table 1 (below) shows the number of sub-models from each of the five JNCC CEMs of marine benthic habitats

Table 1. Summary of CEM models, number of sub-models and references.

Model	No of Sub-models	Reference
Shallow sublittoral sand	4	Coates *et al.* 2016
Sublittoral rock	7	Alexander *et al.* 2015
Shallow sublittoral coarse sediment	4	Alexander *et al.* 2014
Shallow sublittoral mixed sediment	5	Alexander *et al.* 2016
Shallow sublittoral mud	5	Coates *et al.* 2015

The models are split into 7 levels and take spatial and temporal scale into account through their design, as well as the magnitude and direction of influence between interacting ecological components. The 7 levels include regional to global drivers, water column processes, local inputs/processes at the seabed, habitat and bio-assemblage, output processes, local ecosystem functions, and regional to global ecosystem functions. Each sub-model is accompanied by an associated confidence model which presents confidence in the links between each model component.

1. Regional to Global Drivers – high level influencing inputs to the habitat which drive processes and shape the habitat at a large-scale, e.g. water currents, climate, *etc*. These are largely physical drivers which impact on the water column profile. (Regional to Global Drivers are not included within BBN)

2. Water Column Processes – processes and inputs within the water column which feed into local seabed inputs and processes, e.g. suspended sediment, water chemistry and temperature, *etc*.

3. Local Processes/Inputs at the Seabed – localised inputs and processes to the ecosystem which directly influence the characterising fauna of the habitat, e.g. food resources, recruitment, *etc*.

4. Habitat and Bio-assemblage – the characterising fauna and sediment type(s) which typifies the habitat. For the sub-models, fauna are broken down into functional groups and sub-functional groups as necessary. Example taxa characterising each group are named in the models, however for the full list of fauna related to each grouping, please see the separate Excel spreadsheets for the pressure sensitivity information.

5. Output Processes – the specific environmental, chemical and physical processes performed by the biological components of the habitat, e.g. biodeposition, secondary production, *etc*.

6. Local Ecosystem Functions – the functions resulting from the output processes of the habitat which are applicable on a local scale, whether close to the seabed or within the water column, e.g. nutrient cycling, habitat provision.

7. Regional to Global Ecosystem Functions – ecosystem functions which occur as a result of the local processes and functions performed by the biota of the habitat at a regional to global scale, e.g. biodiversity enhancement, export of organic material.

The models indicate that whilst the high-level drivers which affect each functional group are largely similar, the output processes performed by the biota and the resulting ecosystem functions vary both in number and importance between groups (Coates *et al.* 2016). Confidence within the models overall was generally high, reflecting the level of information gathered during the literature review.

2.2 Ecological Components

The ecological components identified in the original CEM work were assessed for feasibility of incorporation within the MESO BBN models as nodes. The ecological component nodes for each broad habitat were supplied by JNCC as an Excel spreadsheet. These nodes formed the basis of the literature review and the links with pressures, conservation objective attributes and sub-attributes, and ecosystem services are presented in the summary tables (supplied separately). The bio-assemblage nodes identified for each CEM underpin the pressure sensitivity assessments for the biota and were a key model input.

Some updates to taxonomy have taken place during the development of the CEMs, and subsequently, so that there may be differences in nomenclature between models. Largely we have not updated these but retained the original CEM names to prevent confusion when referring to the original reports. The changes identified are shown below in Table 2. Identifying name changes was important as searches were conducted for information both on currently accepted name and previous name where necessary.

Table 2. Changes in species nomenclature identified in this project.

Current accepted name	Previous name or synonym
Acrocnida brachiata	*Amphiura brachiata/Ophiura brachiata/Ophiocoma brachiata*
Apseudopsis latreilli	*Apseudes latreilli*
Crassicorophium crassicorne	*Corophium crassicorne*
Crisularia plumosa	*Bugula plumosa*
Ennucula tenuis	*Nuculoma tenuis*
Kurtiella bidentata	*Mysella bidentata*
Limecola balthica	*Macoma balthica*
Novocrania anomala	*Neocrania anomala*
Parexogone hebes	*Exogone hebes*
Philine quadripartita	*Philine aperta*
Phyllodoce maculata	*Anaitides maculata*

Saccharina latissima	*Laminaria sachharina*
Spiobranchus triqueter	*Pomatoceros triqueter*
Thracia phaseolina	*Thracia papyracea*
Venerupis corrugata	*Venerupis senegalensis*

2.3 Human activity- pressure framework (Objective 1)

Activities in the marine environment result in a number of pressures which may result in an impact on environmental components that are sensitive to the pressure. A pressure is defined as 'the mechanism through which an activity has an effect on any part of the ecosystem' (Robinson *et al.* 2008). Pressures can be physical (e.g. sub-surface abrasion), chemical (e.g. organic enrichment) or biological (e.g. introduction of non-native species).

An activity may give rise to more than one pressure. Therefore, rather than assessing the impact of activities as a single impact, the pressure-based approach supports clearer identification of the pathway(s) through which impacts on a feature may arise from the activity. Conversely, the same pressure can also be caused by a number of different activities. To be meaningful and consistent, sensitivity to a pressure should be measured against a defined pressure benchmark.

The anthropogenic pressure framework used in this project is based on the list of marine pressures and their descriptions published within OSPAR agreement 2014-2021, 'OSPAR Joint Assessment and Monitoring Programme (JAMP) 2014-2021 (ICG-C 2011). The pressure descriptions and benchmarks used in the accompanying Excel spreadsheets and sensitivity assessments were taken from Tyler-Walters *et al.* (2018).

Not all pressures within this framework are relevant to benthic habitats and the ecological components in the CEM. In addition, there are issues assessing some pressures as the evidence base is limited. As a result, a number of pressures were excluded from the assessment at the beginning of the review and these pressures were excluded on the basis of the rationale below (from Tillin & Tyler-Walters 2014):

- There is a paucity of research concerning the effects of underwater noise on marine invertebrates. While it is generally believed that invertebrates are relatively insensitive to these pressures, compared to other marine receptors such as marine mammals and fish, the evidence base for this is poor and currently, it is almost impossible to draw clear conclusions on the nature and levels of man-made sound that have potential to cause effects upon fish and invertebrates (Hawkins *et al.* 2015).

- There is a lack of good quantitative data and an absence of studies concerning the effects of litter on marine invertebrates and Rochman *et al.* (2016) came to the conclusion from a recent review that the quantity and quality of research requires improvement to allow the risk of ecological impacts of marine debris to be determined with precision.

- Potential effects from electromagnetic fields have been identified for a range of invertebrate species. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds. The significance of the response reactions on both individual and population level is uncertain, if not unknown.

- There is very limited information on the effects of the introduction of light on marine invertebrates. Tasker *et al.* (2010) excluded this pressure when developing indicators relating to the introduction of energy for the purposes of the Marine Strategy

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

- Radionuclide contamination is often detected, and bioaccumulation noted in some species (Cole *et al.* 1999) but information on specific effects is limited.

- The effects of more recent pollutants such as nano particulates on marine species continue to be studied, while novel endocrine disruptors have been shown to affect inshore shellfish through depressed reproduction (Langston *et al.* 2007), but information on population effects is lacking.

The anthropogenic pressures included were selected based on relevance, with selection informed by previous reviews on pressures (Tillin & Tyler-Walters 2014). The final sub-set of pressures incorporated within the review and models was agreed with JNCC (see Table 3 below). We suggested that the contaminant pressures that are difficult to assess could potentially be addressed through a 'generic scenario'. This pressure scenario would assess a generic change in environmental quality and would be based on changes in the ecological bio-assemblages based on the AMBI index that has been applied across a range of stressors (Muxica *et al.* 2005).

Table 3. Final List of Pressures assessed and included in the MESO BBN, the pressure proformas are provided in Appendix 8.

Pressure theme	Included in MESO BBN	Pressure Proforma
Physical change (reversible)	Habitat structure changes - removal of substratum (extraction)	1
	Abrasion/disturbance of the substratum on the surface of the seabed	2
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	3
	Smothering and siltation changes (depth of vertical sediment overburden) (light and heavy)	4
	Changes in suspended solids (water clarity)	5
Physical loss (permanent change)	Physical change (to another seabed type)	6
	Physical change (to another sediment type)	7
Biological Pressures	Removal of non-target species	No proforma
	Removal of target species*	No proforma
Hydrological changes (inshore/local)	Wave exposure changes - local	No proforma
Pollution and other chemical changes	Generic modelled scenario based on AMBI where impacts focus on changes in bio-assemblage.	No proforma
*Assessed as an ecosystem service within the BBN MESO not a pressure		

2.4 Conservation objective attribute Framework (Objective 2)

In the context of this project, conservation objectives set out the broad management ecological aims to conserve a marine feature, such as sandbanks or moderate energy circalittoral rock for example. The attributes of each conservation objective are the ecological characteristics of the marine feature, and are 'Extent and Distribution', its 'Structure and Function' or its 'Supporting Processes', which together describe the desired condition or state of the feature. Table 4 below sets out the high-level Conservation Objective attributes and sub-attributes identified by JNCC.

For designated sites, more detailed conservation sub-attributes will be defined that take into account the site-specific characteristics and features for which the site is classified. JNCC is currently undertaking further work to develop site guidance and identify key and influential species for habitat types. At the high-level considered within this project it is not possible to assess how the activities and pressures may alter conservation objective attributes and sub-attributes as this will depend on site characteristics, detailed conservation objectives, the proposed scale and duration of each activity, and its spatial and temporal overlaps with site features. However, it has been possible to indicate which pressures might impact upon conservation objective attributes and sub-attributes.

Table 4. Conservation objective attributes and associated sub-attributes identified by JNCC.

Conservation objective attribute	Sub-attribute
Extent and distribution	Sediment composition
Extent and distribution	Bio-assemblages
Structure	Physical structure: finer scale topography
Structure	Physical structure: sediment composition
Structure	Biological structure: Key and Influential species
Structure	Biological Structure: Characteristic communities
Function	Ecological processes
Supporting processes	Hydrodynamic regime
Supporting processes	Water quality
Supporting processes	Sediment quality

2.5 Ecosystem Service Framework (Objective 3)

The ecosystem service frameworks used in this study were based on Potts *et al.* (2014) and the Common International Classification of Ecosystem Services (CICES v5.1; Haines-Young & Potschin 2018). The key difference between these two frameworks is that Potts *et al.* (2014) includes both intermediate ecosystem services and final ecosystem services and goods and benefits while CICES only considers final ecosystem services.

CICES was developed from the work on environmental accounting undertaken by the European Environment Agency. The CICES final ecosystem services were used rather than those identified in Potts *et al.* (2014), as the CICES framework for marine relevant final ecosystem services is comprehensive and captures current understanding of the wide variety of services that can be delivered by ecosystems.

The CICES classification aims to support natural capital accounting and valuation and is designed to reduce double counting of ecosystem services by focussing **only** on final ecosystem services and excluding intermediate services (the ecosystem processes and functions that support delivery of the final services).

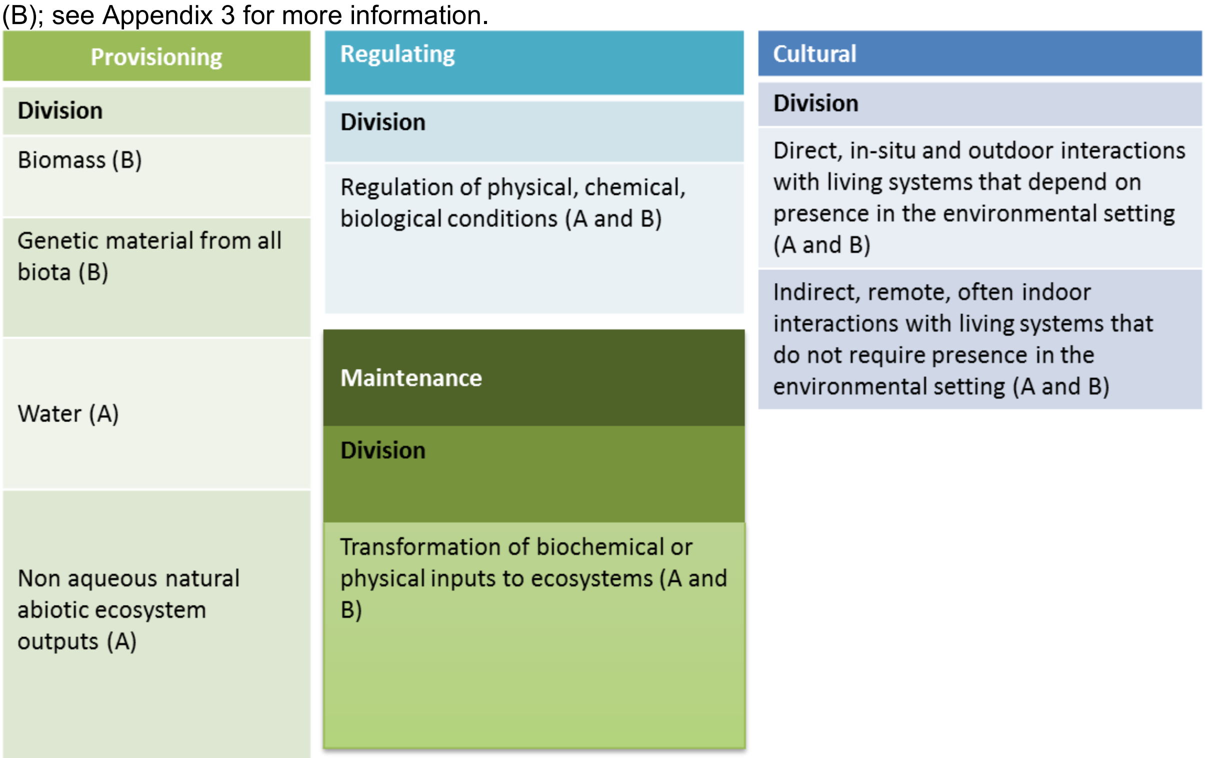
In the CICES classification ecosystem services are defined as the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them. The definition of each service identifies both the purposes or uses that people have for the different kinds of ecosystem service and the particular ecosystem attributes or behaviours that support them (Haines-Young & Potschin 2018). It is important to note that an ecological component may be considered to provide an intermediate or final service depending on context (Haines-Young & Potschin 2018). For example, crabs deliver an intermediate regulating service when they predate on nuisance species but represent a final ecosystem service when they are captured as food.

Within the Potts *et al.* (2014) and CICES frameworks, the intermediate and final ecosystem services are split into three major groups following international precedents in the Millennium Ecosystem Assessment (MEA 2005) and The Economics of Ecosystems and Biodiversity (TEEB 2010):

- Provisioning,
- Regulation and Maintenance, and,
- Cultural

The marine-relevant divisions within the CICES classification are given in Figure 1 (below). The CICES hierarchy proceeds through Division, Group and Class, with the distinctions between individual services becoming more specific at each layer. Assessments can be made at any level within the nested structure depending on the context and data available (i.e. at the scale of Group or Division if more specific information for individual Classes is not available). This is intended to allow flexibility and take account of challenges presented for particular applications and different spatial scales. Within this project some services were assessed at the group level and others at the class level.

Figure 1. Groupings of ecosystem services and main divisions for Abiotic factors (A); Biotic factors (B); see Appendix 3 for more information.



2.6 Ecosystem service selection

The selection of ecosystem services to scope into this work was based around those that are relevant to benthic marine systems. Not all ecosystem services can be related to marine ecosystems, as the concept was developed for terrestrial systems and thus some ecosystem services cannot be readily transposed from the terrestrial to the marine context (Hooper *et al.* 2019). Examples of ecosystem service types that cannot be readily transposed are covered in more detail below.

The literature review prioritised ecosystem services that have clear evidence and linkages to the ecological components identified in the CEM and that could feasibly be incorporated into the MESO BBN models. To incorporate the ecosystem services in the MESO model, evidence was required to link the ecological components in the CEM to the service(s) and to parameterise the model edges, priors and posteriors (see section 4.2.1). Only ecosystem services with clear ecological component links and an associated evidence base were considered likely candidates for inclusion in the MESO BBN models and were prioritised in the literature review (see Appendix 3 and Section 2.5). Where the first and second sifts identified information on other ecosystem services unlikely to be incorporated in the BBNs the information was still added to the review spreadsheets. Ecosystem services proformas for some of these services were created where at least some relevant information was found for the assessed habitats.

All the subtidal habitats were considered likely to provide the selected ecosystem services, but the magnitude of contribution, and the components providing the service, may vary. For example, each of the assessed habitats provides different commercially harvested species. The rates of ecosystem processes and services, and the components that support these, also vary between habitat types. For example, in reef habitats macroalgae are the key primary producers, while in mobile sediment habitats sediment diatoms support this service.

2.6.1 Candidate sublittoral habitat relevant ecosystem services included in the MESO BBN models

Ecosystem services with a clearly defined evidence base

Ecosystem services that met the criteria (linked to ecological components, candidate BBN model nodes and considered likely to be supported by a well-developed evidence base) were:

- Intermediate Services: Potts *et al.* (2014): Primary production;
- Provisioning Service: CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition, materials or energy;
- Provisioning Service: CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy; and
- Provisioning Service (abiotic) CICES 4.3.1 Mineral substances used for nutrition, materials or energy.

For these ecosystem services the linkage between ecological components and the ecosystem service is direct, as the ecological component directly contributes to the ecosystem service. An example of this type of relationship is CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition and materials that are clearly provided by the bio-assemblage ‘Macroalgae’ in the rock CEM and for which information on species targeted is available in the grey and peer-reviewed literature.

Ecosystem services that are supported by ecosystem processes

A number of ecosystem services are supported by ecological process and ecosystem functioning associated with the biota. In these examples the ecosystem service supply may be less quantifiable and be surrounded by higher levels of uncertainty, but nevertheless links can be made between ecological components identified in the CEM and ecosystem services incorporated in the MESO BBN models. These ecosystem services were also prioritised in the ecosystem services literature review.

Ecosystem services that met the criteria (linked to ecological components, candidate BBN model nodes and supported by evidence base) were:

- Intermediate Services: Potts *et al.* (2014): Nutrient cycling;

- Intermediate Services: Potts *et al.* (2014): Formation of physical barriers and Natural hazard regulation;
- Intermediate Services: Potts *et al.* (2014); Formation of species barriers
- Intermediate Services: Potts *et al.* (2014); Carbon sequestration;
- Regulating Service: CICES 2.1.1 Mediation of wastes or toxic substances of anthropogenic origin by living processes;
- Regulating Service: CICES 2.2.1 Regulation of baseline flows and extreme events;
- Regulating Service: CICES 2.2.6.1 Regulation of chemical composition of atmosphere and oceans (carbon sequestration) and
- Regulating Service: CICES 2.2.2.3. Maintaining nursery populations and habitats (Including gene pool protection).

2.6.2 Ecosystem services excluded from MESO BBN

For some ecosystem services the evidence base in the wider literature to identify and quantify linkages between ecological components and the delivery of the service is very limited. This may be because the link between the ecological components and ecosystem services is highly uncertain and the service is only present and/or provided under variable conditions. For example, larval supply is a highly stochastic process in marine systems (Siegel *et al.* 2008) and for this reason larval supply was not included in the models.

Alternatively, the service may only be utilised under some circumstances so that the service supply fluctuates and is not readily associated with ecological components in the CEM. Examples of these services are the supply of genetic materials from organisms.

In other cases, there may be a link between ecological components within the CEM and the service, but the evidence base does not support consistent assessment, either because the service is difficult to quantify, under studied or the evidence is not collected. In contrast to managed human activities such as fisheries, for example, recreational activities are not licensed, and no systematic evidence is collected on them or the evidence base is extremely patchy. The link to ecological components may be tenuous, for example there may be high levels of recreational activity in the area, but the service is facilitated by infrastructure such as access roads and car parks and the link to ecological components is of less relevance in delivering the service. Similarly, the set-up, of aquaculture service is facilitated by site suitability, local demand and other factors (Saunders 2010) and the CEM does not relate to the supply of the service.

- Intermediate Services: Potts *et al.* (2014): Larval/gamete supply;
- Provisioning Service: CICES 1.2.1 Genetic material from plants, algae or fungi;
- Provisioning Service: CICES 1.2.2 Genetic material from animals;
- Provisioning Service: CICES 1.2.3 Genetic material from organisms;
- Provisioning service CICES 1.1.2: Cultivated aquatic plants for nutrition, materials or energy;
- Provisioning service: CICES 1.1.4: Reared aquatic animals for nutrition, materials or energy; and
- Regulating Service: CICES 2.2.2.1 Pollination (or 'gamete' dispersal in a marine context.

Where readily available the literature review captured information related to these services, but they were not prioritised.

2.6.3 Cultural services

The role that the ecosystem plays in supporting cultural ecosystem services is different from provisioning and regulating ecosystem services. This is for two reasons:

1) The distinction between cultural ecosystem services and benefits is not clear; many of the services categories used are best understood as benefits produced not only through cultural services, but also through provisioning and regulating services (Chan *et al.* 2012).
2) The cultural ecosystem services are considered relational (i.e. the result of non-linear, multidirectional interactions between humans and ecosystems), comprising of environmental settings and cultural practices. Environmental settings both enable and are shaped by cultural practices (Fish *et al.* 2016). The important difference is that for the most part, cultural ecosystem services are place based and the ecosystem provides that space.

These key differences mean it is harder to relate changes in cultural ecosystem services to changes in ecological components as they may be more closely linked to landscape properties and thus vary widely in space and time. As such the majority of cultural ecosystem services have not been included in this work, primarily because subtidal habitats are not directly accessible to most of society.

Exceptions are where there are clear interactions:

- CICES 3.1.1 Physical and experiential interactions with natural environment and the parallel abiotic service
- CICES 6.1.1.1 Physical and experiential interactions with natural abiotic components of the environment.

In both cases these categories relate to divers (and anglers) and their experiential interactions with seabed components, as these societal groups experience the seabed or its assemblages first-hand. Where readily available the literature review captured information related to cultural services, but they were not prioritised.

2.6.4 Services excluded as not marine or marine but not linked to sublittoral habitat

Ecosystem services that are not relevant to marine subtidal systems were not included in this project or that are not provided by sublittoral marine ecosystems in the UK. Examples include CICES 2.1.2.1 Smell reduction and CICES 2.1.2.3 Visual screening. Other examples include CICES 5.2.1.3 Gaseous flows which relate to the mediation of flows by natural abiotic structures but are not relevant to seabed habitats.

2.6.5 Abiotic ecosystem services

This project follows the convention in Tempera *et al.* (2016) in generally excluding the CICES final ecosystem services that are delivered by abiotic components, although it is acknowledged that for some services the abiotic and biotic cannot be reasonably separated e.g. waste remediation. Abiotic raw materials and renewable abiotic energy whose availability, quantity or quality is not enhanced by living organisms or ecological processes (e.g. sand and gravel, salt, wind and wave energy) are natural resources but not ecosystem services (Liquete *et al.* 2013a). The exceptions were ecosystem services where biota and the abiotic habitat influence the capacity to provide that service:

- Intermediate service: Carbon sequestration (Potts *et al.* 2014); and
- Regulating service: CICES 5.2.1 Regulation of baseline flows and extreme events
- Regulating service: CICES 5.1.1 Mediation of waste, toxics and other nuisances by non-living processes.

These services were included in the literature review searches and prioritisation (see below).

2.6.6 Uncertainties in ecosystem service definition and interpretation

Some ecosystem services categories have been interpreted differently by different researchers: an example is that of genetic resources. CICES 5.1 defines it rather differently to the UKNEA ecosystem classification approach that Potts *et al.* (2014) follows. Division 1.2 in CICES 5.1 defines ‘Genetic material from all biota (including seed, spore or gamete production)’ and this encompasses classes for plants and animals supplying the genetic material and classes to categorise what the genetic material is collected for e.g. establishing new populations or the design and construction of new biological entities. This is very much referring to genetic resources that are collected from the wild such as broodstock for aquaculture in the marine context. By contrast Potts *et al.* (2014) have an intermediate service of ‘Larval and gamete supply’ that is defined in Atkins *et al.* (2015), as ‘Quantity of larvae/gametes supplied to a particular location (number per m^3); Quality of larvae/gametes supplied to a particular location (% affected by disease; mortality rates).

It is important to note that reviews to date that link ecological features to components of ecosystems have worked at different scales to the current research:

1) Potts *et al.* (2014) scored the importance of ecosystem services from broadscale habitats (EUNIS level 3) and some habitats of conservation importance (HOCI) which were generally EUNIS level 4 or 5 biotopes plus listed species;
2) Tempera *et al.* (2016) mapped the spatial distribution of marine ecosystem service capacity for biotopes from EUNIS level 1 to 5;
3) Salomidi *et al.* (2012) mapped the potential provision of ecosystem services from EUNIS level 4 biotopes based on expert judgement;
4) Galparsoro *et al.* 2014 also mapped ecosystem services from benthic habitats (EUNIS level 2-4) for the European North Atlantic Ocean.

To our knowledge this is the first attempt to link ecosystem components in terms of the grouping of functionally similar species into bio-assemblages, with their capacity to provide ecosystem services. This takes the association between the ecological component down to a much more detailed level in terms of the functions being undertaken by the ecological assemblage that support the intermediate and final ecosystem services. The strength of the linkages is supported by information relating to the life history and biological traits of the species and thus a much more robust approach than expert opinion at the scale of biotopes comprised of many different bio-assemblages.

2.7 Ecosystem services assessed in the MESO BBN

Table 5 below identifies the reviewed services that were incorporated in the MESO BBN models. A summary of the ecosystem services and their inclusion or rationale for exclusion is presented in Appendix 3. For marine relevant ecosystem services, evidence was gathered where available even if these could not be incorporated in the models (see Appendix 10 for proformas).

Table 5. The final list of ecosystem services assessed within this project and incorporated in the MESO BBN models. Evidence for other services was collated where readily available. (See Appendix 3 for other services).

CICES Code or Potts *et al.* (2014)	**Final List of Ecosystem Services**		**Ecosystem Service Proforma No.**
	Ecosystem service	**Relevant CEM nodes**	
Intermediate service	Primary production	Primary production	1
Intermediate service	Nutrient cycling	Nutrient cycling,	2
Intermediate service	Formation of species habitat	Habitat provision	4
Intermediate service	Formation of physical barriers	Sediment type	5
Intermediate service	Carbon sequestration	Carbon sequestration	7
CICES 1.1.5	Wild plants (terrestrial and aquatic) for nutrition and materials	Bio-assemblage: Macroalgae	10
CICES 1.1.6	Wild animals (terrestrial and aquatic) for nutrition and materials	Bio-assemblage	11
CICES 2.1.1	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Nutrient cycling/carbon sequestration	13
CICES 2.2.1	Regulation of baseline flows and extreme events	Bioengineering/habitat provision/sediment stability	5
CICES 5.2.1	Regulation of baseline flows and extreme events (**ABIOTIC)**	Sediment type	5

2.8 Ecosystem service realisation and demand

In this study the ecosystem services potential from ecological assemblages is evaluated. This is different to the amount of ecosystem service actually realised because of the additional factor of societal or sectoral demand for that specific ecosystem service. Current understanding of demand is subject to different approaches (e.g. demand = actual consumption; demand = desires and preferences; demand = a mixture of actual consumption and desired and preferences). Each approach leads to different insights and to our knowledge there is no standardised way of assessing ecosystem service demand. Demand is in based on understanding potential flows of ecosystem services but also includes demand metrics and proxies which are often values, preferences and benefits. Finally, ecosystem service-providing and benefitting areas may be spatially and temporally disconnected, making the understanding of flows of ecosystem services essential to understanding actual service delivery and the fulfilment of demand (Wolff *et al.* 2015; Wei *et al.* 2017).

2.9 Ecosystem services summary tables, confidence and level of contribution

The outputs of the ecosystem service review are presented in the accompanying Excel literature review summary spreadsheet. The reviewed evidence for the links between each ecological component and ecosystem service is summarised in the Ecosystem Service proformas (Appendix 10) and the summary tables for each habitat (separate Excel workbook deliverable). The type of link between each ecological component and ecosystem service, the confidence in the link and the relative magnitude and confidence in contribution or influence is assessed where possible. If there was uncertainty, magnitude and confidence were not assessed. The link categories and confidence assessment criteria are outlined below in Table 6 and Table 7 respectively. The models are generic between habitats, although sub-models are more variable. The final list of nodes assessed and presented in the summary tables consists of the generic list (the nodes that all the CEMs share). This set of nodes formed the basis of the MESO BBN models. The ecosystem service proformas vary slightly and incorporate some of the sub-model nodes.

The relative contribution assessments were used in the MESO BBN models as input parameters and the contribution categories are described in Section 4.3. Further reviews on feeding types and bioturbation modes were required to parameterise the MESO BBN models nodes (secondary production node that contributes to food resources, nutrient cycling and biodeposition and bioturbation to support nutrient cycling and mediation of wastes). As these nodes do not directly represent services, the results are not shown in the ecosystem service summary table.

Table 6. Categories used to identify the interaction between ecological components and ecosystem service.

Link Categories	Description
Provision	Direct link between the component and the provision of a service. Component directly provides the services, e.g. *Mytilus edulis* can be harvested and directly provide the service 'Wild animals (terrestrial and aquatic) used for nutritional purposes.'
Mediates	The component influences the flow (or rate) of the service, for example: climate mediates primary production; sediment mud content within a habitat mediates carbon sequestration.
Supports	The component supports a service but does not directly provide or mediate that service, for example, sand eels harvested for use as an aquaculture feedstock support the provision of fish from aquaculture.
Not assessed	The link was not assessed or there was no evidence found to support assessment.
Not relevant	There is no link between the ecological component and the ecosystem service.

Table 7. Confidence scores for ecosystem service links. The asterisk notation is used in the summary tables to present the confidence assessment in the relevant ecological component x ecosystem service cell combinations.

Category	Description
High (***)	There is a good understanding of the component-ecosystem service relationship and/or the assessment is well supported by evidence. There is consensus amongst the experts.
Medium (**)	Whilst there is an understanding of the component-ecosystem service relationship, this may be based on limited evidence and/or proxy information. There is a majority agreement between experts; but conflicting evidence/opposing views exist.
Low (*)	There is limited or no understanding of the component-ecosystem service relationship and/or the assessment is not well supported by evidence. There is no clear agreement amongst experts.
Variable	The component-ecosystem service relationship is highly variable in space and/or time, for example, geology influences the amenity value of a dive site, but few places have an iconic status.

2.10 Literature Review: Generic Method

The evidence review adopted a strategic approach to maximise efficiency and provide the best returns within the project resource allocation. The literature review methodology was rather generic for Objectives 1-3 with the outlined process followed for each of these objectives. The evidence review adopted a Rapid Evidence Assessment (REA) approach as described in Civil Service Guidance and described in Collins *et al.* (2014). This approach uses a structured, stepwise methodology, following an *a priori* defined protocol to comprehensively collate, critically appraise and synthesise existing research evidence (traditional academic and grey literature) (Dicks *et al.* 2017). Within the project time and resource constraints, the outline BBN model evidence requirements indicated where effort should be focused in order to model ecosystem service delivery. Evidence for ecosystem services that were not in the model, most notably the cultural services, was collected where this was readily available (identified in the first literature sift) but extensive searches were not conducted. The review encompassed a wide range of literature, including government reports and peer-reviewed scientific literature.

2.11 First and second sift of literature

A first, rapid sift was undertaken of the available literature. The search used defined terms which were entered into Google and Google Scholar, the specialist indexing and abstracting service Aquatic Sciences and Fisheries Abstracts; Web of Science, the journal collections of Science Direct, Wiley On-line and the National Marine Biological Library catalogue. Relevant evidence was based on the title. All search terms, the date of search and the sources used were recorded. All relevant references based on title were downloaded and added to reference libraries.

A second sift of the literature sorted references in the Endnote libraries into relevance for the pressure, conservation objective attribute and ecosystem service based on the title and abstract. Prioritisation categories are given in Table 8.

Table 8. Second sift prioritisation categories.

Priority	Description
Priority 1	Peer reviewed papers on pressures on the marine environment from the UK
Priority 2	Papers based outside the UK (geographical extent)
Priority 3	Date restrictions, preference for most recent
Priority 4	Technical (by date)
NR	Not Relevant

The second sift for sand habitats captured relevant information for the study's habitat types and general search terms e.g. marine offshore ecosystem services were not repeated for other broad habitats.

Additional literature was obtained by the following methods:

- Author's personal collections of papers and reports were searched;
- Further specific searches were undertaken on Google Scholar to address knowledge gaps;
- The first 1,000 references on the Plymsea archiving database (www.plymsea.ac.uk) were checked;
- Citations from papers and reports were sourced where relevant and reference lists were checked to identify new references;
- Statutory Nature Conservation Body on-line publications were searched;
- Where key reports were not available, authors or appropriate organisations were contacted; and
- JNCC Pressures X Activity Database[1] references were reviewed where relevant.

[1] http://jncc.defra.gov.uk/page-7650

The search terms and databases searched are documented in Appendix 4.

2.12 Ecosystem services review

A wide range of literature on the environmental and ecological impacts on intermediate and final ecosystem services was reviewed and the evidence collated in Excel spreadsheets as follows:

- the ecological component and final and/or intermediate ecosystem services links;
- the description, magnitude and nature of the interaction between the ecological component and the final and/or intermediate ecosystem services, qualified based on the strength and quality of the evidence.

Ecosystem service information was assigned, where feasible, to the Potts *et al.* 2014 intermediate services and/or the CICES final ecosystem service classification.

While ecological components within the conceptual ecosystem models may not directly provide an ecosystem service, they may modify delivery, for example the model components of depth, suspended sediments, water chemistry and temperature, and light attenuation all influence the level of the intermediate ecosystem service, primary production. For each ecological component x ecosystem service interaction, a short summary of the key evidence and information is provided in the attached proformas (Appendix 10) and the summary Excel tables (provided separately), which also include an estimate of the confidence or reliability of the evidence using the confidence estimation guidelines provided in Appendix C from Defra Report ME5218[2] (see Section 2.9).

A short knowledge gap analysis was also undertaken (Section 5).

All literature search terms were recorded (Appendix 4) and search terms included both ecosystem service as key words as well as relevant bio-assemblage, species and component terms. Relevant literature was identified in the first literature sift. The prioritisation of literature was guided using the criteria outlined in the ecosystem service framework sections (Section 2.5 and 2.6). Ultimately, within time and budget constraints the MESO BBN model requirements identified where effort should be focused. Further reviews on feeding types and bioturbation modes were required to parameterise the MESO BBN model nodes (e.g. secondary production node that contributes to food resources, nutrient cycling and biodeposition and bioturbation to parameterise contribution to nutrient cycling and mediation of wastes).

2.13 Pressure Review

The pressures literature was reviewed in order of priority and key information extracted to an Excel spreadsheet. The literature was linked to activities from the Standard List of Human Activities in the Marine Environment (JNCC 2018), and to pressures from the OSPAR framework. Activities that are not typically undertaken in sublittoral habitats or that do not produce pressures that may have direct, far-field effects on subtidal habitats (e.g. inshore recreational activities) were discounted from the review (see Appendix 2). The pressure review information was later collated in pressure proformas (Appendix 8) and associated confidence in the pressure x activity link identified (Table 9).

[2] [2] Defra ME5218, URL: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19471

Where possible, information regarding the EUNIS broad habitat associated with the activity was assigned, and links to ecosystem components from the JNCC Conceptual Ecosystem Models were made. Additional information detailing the nature of interaction between the activity and the habitat, and the magnitude and duration of impact were also recorded, using standardised terms where possible.

A wide range of literature on the environmental and ecological impacts of anthropogenic pressures was reviewed and the evidence collated in Excel spreadsheets as follows:

- the ecological component on which the pressure acts;
- the magnitude and nature of the interaction between the anthropogenic pressure and the ecological component (qualified based on the strength and quality of the evidence);
- the relative duration of the pressure impact (the duration of the pressure); and
- evidence for recovery of ecological components, recovery time and information on ecological thresholds.

Consideration in the review was given to activity and pressure pathway combinations to inform pressure scenarios to support the modelling objectives. Outline pressure scenarios for each activity were constructed using the JNCC Pressure – Activities Database (which provides direct links between pressure and activities within the marine environment) and the literature review, providing supporting evidence and breakdowns of the activities where applicable. Further aspects of each activity that were not captured in the PAD were also added to the pressure scenarios. These pressure scenarios are provided in the accompanying user manual and provide guidance to users of the MESO models as they indicate which pressures may be associated with each activity phase.

Each pressure x activity link within the scenarios was identified as Temporary or Permanent using evidence from the literature review.

- A temporary pressure refers to an impact on the marine environment that ceases after the activity stops, such as noise from drilling. Temporary pressures also leave reversible impacts on the environment, such as the removal of substrate from dredging, where the residual layer of seabed is the same as the pre-dredge site, enabling biological communities to recolonise the area.

- A permanent pressure indicates damage to the sublittoral environment that remains after the pressure has ceased, where the environment cannot recover to the pre-pressure state. An example of this would be substratum change from soft sediments to hard rock, after rock dumping for cable protection.

Table 9. Confidence scores for pressure x activity links based on evidence type, amount, quality and consistency and level of agreement / consensus.

Category	Description
High	There is a good understanding of the activity x pressure relationship and the link is well supported by evidence. There is consensus amongst the experts.
Medium.	Whilst there is an understanding of the activity x pressure relationship, this may be based on limited evidence and/or proxy information. There is a majority agreement between experts, however, conflicting evidence/opposing views exist.
Low.	There is limited or no understanding of the activity x pressure relationship and/or the assessment is not well supported by evidence. There is no clear agreement amongst experts.

2.14 Sensitivity Assessment

The sensitivity assessment identified the impacts of anthropogenic pressures on the biological community following the established framework MarLIN Marine Evidence based Sensitivity Assessment (MarESA)[3] and associated reports such as Tillin and Tyler-Walters (2014).

2.14.1 Definition of Sensitivity, Resistance and Resilience

The concepts of resistance and resilience introduced by Holling (1973) are widely used to assess sensitivity (Table 10). Resistance is an estimate of an individual, a species population and/or habitat's ability to resist damage or change as a result of an external pressure. It is assessed in either quantitative or qualitative terms, against a clearly defined scale. While the principle is consistent between approaches, the terms and scales vary. Resistance and tolerance are often used for the same concept, although other approaches assess 'intolerance' which is clearly the reverse of resistance.

A species is defined as very sensitive when it is easily adversely affected by human activity (low resistance) and/or it has low resilience (recovery is only achieved after a prolonged period, if at all). Highly sensitive species are those with both low resistance and resilience.

Table 10. Definition of sensitivity and associated terms.

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

Resilience is an estimate of an individual, a species population and/or habitat's ability to return to its prior condition, or recover, after the pressure has passed, been mitigated or removed. The term resilience and recovery are often used for the same concept and are effectively synonymous[4].

Sensitivity can, therefore, be understood as a measure of the likelihood of change when a pressure is applied to a feature (receptor) and is a function of the ability of the feature to tolerate or resist change (resistance) and its ability to recover from impact (resilience).

2.14.2 Sensitivity Assessment methodology

Tillin *et al.* (2010) developed a method to assess the sensitivity of certain marine features, considered to be of conservation interest, against physical, chemical and biological

[3] MarESA, URL: https://www.marlin.ac.uk/sensitivity/sensitivity_rationale

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

pressures resulting from human activities. The sensitivity assessment methodology (Tillin *et al.* 2010) bases the assessment on a theoretical population of the species in the middle of its environmental range. As Holt *et al.* (1995) have pointed out, organisms near the limits of their range are more sensitive to change, so that sensitivity assessments should concentrate on sensitivities of populations in 'mid-range' or typical habitats.

The sensitivity assessment method used (after Tillin *et al.* 2010) involves the following stages, which are explained in Appendix 5:

A. Defining the key elements of the feature (addressed in this project by the CEM models that define the bio-assemblage groups.
B. Assessing feature resistance (tolerance) to a defined intensity of pressure (the benchmark).
C. Assessing the resilience (recovery) of the feature to a defined intensity of pressure (the benchmark).
D. Combining resistance and resilience to derive an overall sensitivity score.
E. Assessing the level of confidence in the sensitivity assessment.
F. Providing a written audit trail.

The above steps ensure that the basis of the sensitivity assessment is transparent and repeatable and that the evidence base and justification for the sensitivity assessments is recorded.

2.15 Assessing sensitivity of the bio-assemblages

Assessing the sensitivity of species or biotopes to human pressures via evidence review is a time-consuming process and within the resources of the project, it was not possible to create new sensitivity assessments for each bio-assemblage within the CEMs. Evidence for species sensitivity to pressures was extracted instead from existing sensitivity assessments. Sensitivity assessment sources for each pressure for each species (where available) are shown in Appendix 7. The sensitivity assessment sources used were:

- MarLIN Marine Evidence based Sensitivity Assessment (MarESA[5]);
- Tillin and Tyler-Walters (2014); and
- Tillin and Hull 2013 (a-h).

The key resource for these were the Marine Evidence based Sensitivity Assessments (MarESA) developed by MarLIN (www.marlin.ac.uk). An advantage with using the MarESA assessments are that these are based on pressures within the ICG framework (see Table 11) and therefore align with the human pressures considered in this project as the same framework was adopted. A key drawback, however, is that MarESA methodology has been used largely to assess the sensitivity of **biotopes** based on selected key functional and structuring species and/or habitat characteristics, with the sensitivity assessment presented for the biotope rather than selected species. For use within this project, species sensitivities had to be disaggregated from the biotope assessment. The ease of this varied, in some cases the assessment was based on species and this was made clear; in other instances, the sensitivity assessment was based on a range of species or other biotope features such as substratum.

The CEM model reports all identify the biotopes that were the basis of the study and were used to identify characterising species. All biotopes used to develop the CEM were checked and species-specific evidence extracted. The audit trail for these is contained in the Excel

[5] www.marlin.ac.uk

spreadsheets which identify the biotopes used, and in Appendix 7 which identifies the biotopes in the CEM and the species information that was extracted from these from MarLIN. Where these biotopes contained little species-specific evidence, or the species was not assessed as part of the biotope assessment, further searches were undertaken of the MarLIN website to identify further evidence. Where no species information was found the World Register of Marine Species (WoRMS) was checked in case the species name had been changed (see Table 2 for taxonomic changes).

The sensitivity of the sand eel has not been assessed within any of the consulted sources and the sensitivity of this information was taken from the Feature Activity Sensitivity Tool[6] developed by Scottish Natural Heritage.

Table 11. Comparative table showing sensitivity assessments used in this project.

Sensitivity Assessments	**Species Basis of sensitivity assessment?**	**ICG pressures framework**
MarESA	No	Yes
Tillin & Tyler-Walters (2014)	Yes	Yes
Marine Institute reports (Tillin & Hull (2013a-g)	Yes	No

2.15.1 Creating sensitivity scores for bio-assemblages

Existing sensitivity scores and supporting evidence were collated into Excel spreadsheets for each habitat. For each species x pressure combination, the existing information and scores were considered, and an overall summary assessment created. These summary scores were then aggregated to create a bio-assemblage sensitivity assessment, following a set of simple rules

1) If appropriate, the most frequently represented sensitivity score was used.
2) If no score was the most frequently represented, for example, two scores were represented or there was a spread of scores, then the most precautionary score was used instead.
3) If distribution of scores was strongly bimodal e.g. the group contained species with high and low sensitivity assigning a score between both groups was considered to represent the range of sensitivities.

Confidence assessments were provided for each bio-assemblage x pressure combination. These considered the level of evidence, the amount of species for which there was no evidence and expert judgement was required and the level of disparity between scores in the group. Given the level of variability within functional groups (in terms of number of sensitivity assessments, evidence base and evenness of coverage) assigning scores was relatively subjective. Table 12 below outlines the confidence scoring and general considerations.

Table 12. Confidence scores based on evidence type, amount, quality and consistency and level of agreement/consensus.

Category	Description
High	There is a good understanding of the sensitivity and/or the assessment is well supported by evidence. There is consensus amongst experts and where more than one species represents the bio-assemblage, the assessment scores are the same, e.g. sensitivity is consistent within the bio-assemblage.
Medium	Whilst there is an understanding of the sensitivity, this may be based on limited evidence and/or proxy information for resistance and/or recovery. There is a majority agreement amongst experts, however, conflicting

[6] https://www.marine.scotland.gov.uk/feast/

	evidence/opposing views exist. When there is more than one species represented in the bio-assemblage the assessment scores are very similar, e.g. sensitivity is relatively consistent within the bio-assemblage.
Low	There is limited or no understanding of the sensitivity and/or the assessment is based on expert judgement. Where more than one species represents the bio-assemblage, the assessment scores are dissimilar and encompass a range of sensitivities so that there is a high degree of uncertainty in the score.

2.16 Conservation objective attribute review

JNCC provided a list of conservation objective attributes for sites (see Table 13). A wide range of literature on the environmental and ecological impacts of anthropogenic pressures on these conservation objective attributes (extent, distribution, structure, function) was reviewed in tandem with the pressure review. The evidence was collated as follows:

- the anthropogenic pressure x attribute interactions;
- the magnitude and nature of the interaction between the anthropogenic pressure and the conservation objective attribute, (qualified based on the strength and quality of the evidence); and
- the relative duration of the pressure impact (the duration of the pressure) and the recovery time.

There is considerable overlap between the parameter of the pressure and conservation objective attribute review. The ecological components reviewed relate to the conservation objective attributes, so the results of the review were not collated separately. A separate category was added to the ecological components ‘sediment topography’ to refer to the conservation objective attribute ‘structure’ and the sub-attribute ‘physical structure: finer scale topography’.

For all reviewed evidence, the impact of the activity/pressure on each conservation objective attribute and sub-attribute was recorded as shown in Table 13.

Table 13. Field records for conservation objective attributes and sub-attributes reviewed (these are presented in the separate Excel output).

Category	Description
Potential impact	It was considered likely that the activity/ pressure would lead to an impact on the conservation objective attribute and sub-attribute. The link was specified where possible, e.g. physical structure or biological structure for the structure sub-attribute.
Potential linked impact	The evidence reviewed refers directly to another conservation objective attribute/sub-attribute, for example, changes in structure may link to changes in extent and distribution.
No impact	The reference indicates that there is no impact on conservation objective attributes or sub-attributes.
No evidence	
Not relevant	The reviewed evidence is not relevant to pressure x conservation objective attribute impacts. For example, the reference discusses operation details or gear types (for fishing) or recovery rates.
Not relevant to habitat conservation objective attributes	

It should be noted that these assessments treated the pressure as if it was acting on a designated feature and did not take into account whether the study had actually been carried out in a designated site, or overlapped with designated features, the link is therefore theoretical.

The conservation objective attributes take into account only those attributes and sub-attributes that are reviewed in the reference and does not extrapolate likely impacts on other attributes and sub-attributes not specifically described. For example, an impact on physical structure is likely to result in an associated indirect impact on the biological community. However, if biological impacts were not described in the evidence this will have been recorded as ‘no evidence’ in the table.

Some conservation objective sub-attributes overlap, for example, ‘extent and distribution’ and ‘structure’ both refer to physical sediment composition and the bio-assemblage. Therefore, any changes in structure were also considered to potentially impact extent and distribution. Similarly, changes in biological structure were considered to have a potential impact on function.

For each pressure x conservation objective attribute interaction, a short summary of the key evidence and information in the final report is provided in the proformas (Appendix 8), with an estimate of the confidence or reliability of the evidence using the confidence categories outlined in Table 12 above.

All literature search terms were recorded; search terms included both pressure and activities as key words as well as relevant habitat and ecological attributes (Appendix 4).

Table 14. Conservation objective attribute, sub-attribute and most relevant pressures for sublittoral habitat.

Conservation Objective Attribute	Sub-attribute	Relevant pressures
Extent and distribution	Sediment composition	Physical change (to another seabed/sediment type) and other pressures that impact the sediment.
Extent and distribution	Bio-assemblages	All pressures that impact bio-assemblage
Structure	Physical structure: finer scale topography	Physical change (to another seabed/sediment type) and other pressures that impact the sediment.
Structure	Physical structure: sediment composition	Physical change (to another seabed/sediment type) and other pressures that impact the sediment.
Structure	Biological structure: Key and Influential species	All pressures that impact bio-assemblage
Structure	Biological Structure: Characteristic communities	All pressures that impact bio-assemblage
Function	Ecological processes	All pressures that impact bio-assemblage
Supporting processes	Hydrodynamic regime	Hydrological changes (inshore/local)
Supporting processes	Water quality	Hydrological changes (inshore/local) Pollution and other chemical changes
Supporting processes	Sediment quality	Pollution and other chemical changes

3 Ecological objectives: summary of key findings and outputs

3.1 Pressure Review (Objectives 1 and 2)

3.1.1 Pressure evidence for impacts

Physical damage (abrasion, subsurface penetration and disturbance) can be more clearly spatially and temporally defined than some other pressure types. The impact occurs within the footprint of the activities leading to the pressure and the species traits that determine tolerance have been well studied and can be relatively easily defined.

3.2 Activity information

More information was available for fishing activities and associated pressures than for other activity types. For all activities the evidence base varied for different parts of the operation or activity phases e.g. construction, operation, decommissioning.

3.3 Pressure evidence

As fishing is the best-studied human activity in the marine environment, the pressures associated with it were more understood than others, although aggregate extraction pressures have been extensively funded through an industrial levy which funded research.

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

The effects of surface abrasion on subtidal habitats are poorly studied compared to penetration and disturbance of the sub-surface of the seabed. This is considered due to the lack of impacting activities which lead to surface abrasion alone and the difficulties inherent in studying this impact for subtidal habitats. The sensitivity assessments for the abrasion pressure consider the likely direct, physical impact on individuals that are exposed to this pressure; for example, abrasion of the seabed may result in resuspension of fine sediments in muddy habitats and this indirect effect is reviewed under the changes in suspended solids (Pressure proforma 5) and the siltation pressures' (Pressure proforma 4). This pressure was associated with fishing activities, anchoring and mooring, offshore wind-farm operations, aggregate dredging, cable and pipeline laying among others (see pressure scenario spreadsheets).

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

The evidence base for substratum disturbance is most developed for fishing activities using towed gears in contact with the sediment. This is the most widespread human activity leading to this pressure. This pressure was also associated with anchoring and mooring, offshore wind-farm operations, aggregate dredging, cable and pipeline laying among others (see pressure scenario spreadsheets).

Siltation and suspended solids

Siltation and sediment deposition result from activities that disturb the seabed and have been studied in relation to dredging for aggregates and capital and maintenance dredging to remove sediment in shipping channels as well as the disposal of wastes at sea such as levels of sediment deposition in terms of deposit thickness. Siltation and water clarity changes (included as physical damage pressures) may occur over wider areas than the footprint of the activity as water currents and wave action may transport finer sediment that remains in suspension. For the activities studied the pressure is usually temporary, with sediment plumes created by aggregate, fishing and cable pipeline laying activities (among others) rapidly subsiding when the activity ceases. Sediment plumes relating to sediment disturbance have been characterised for aggregates and fishing (see Pressure proforma 5). Unlike abrasion, penetration and extraction changes in suspended sediments from these activities (when considered as single events), do not match the pressure benchmark used in sensitivity assessments which relate to a change in turbidity for one year.

3.3.1 Evidence proformas

The evidence proformas that summarise key information on the pressure impacts on ecological components are provided in Appendix 8. As there was little evidence for ecological impacts from removal of target and non-target species (beyond physical damage caused by their removal) these pressures do not have an associated evidence proforma. The proformas indicate whether the assessed evidence is above, at or below the pressure benchmark used in the sensitivity assessments; the confidence in the activity x pressure link is also assessed.

3.3.2 Sensitivity Review

The sensitivity assessment process provided a systematic approach for the collation of existing evidence to assess resistance, recovery and hence sensitivity to a range of pressures. When creating the final sensitivity assessment scores for the bio-assemblages, expert judgement was often required because the evidence base itself is incomplete both in relation to the biology of the features and understanding of the effects of human pressures. Notwithstanding the limitations of the evidence base, the collated sensitivity assessments provide a large volume of general evidence on which to make judgements on the most likely effects of pressures on species and habitats based on past experience, especially with respect to fishing. However, a key gap is the lack of specific studies that consider impacts of a given activity (or pressure) on a large number of species and habitats.

The results of the sensitivity assessments show:

- the majority of species (and hence ecological groups) in sedimentary habitats are sensitive to physical change, especially loss of habitat, change in sediment type and the deposition of thick layers of sediment;
- most species are sensitive to physical damage, e.g. abrasion and penetration of the seabed and sediment extraction;
- sedentary species and ecological groups that dominate the top layer of the sediment (shallow burrowing) or are epifauna, remain the most sensitive to physical damage;
- mobile species and species associated with coarse sediments in particular, (e.g. interstitial and burrowing amphipods, and perhaps cumaceans), are the least sensitive to physical change, damage and hydrological change, as they are already adapted to unstable, mobile substrata and recover rapidly.

3.4 Conservation objective attribute review

For each conservation objective attribute and sub-attribute, the relevant pressures that may impact on these were identified. There is a great deal of overlap between the conservation objective attribute and pressure proformas as these are based on the reviewed evidence. The evidence proformas that summarise key information on activities and pressures that impact conservation objective attributes are provided in Appendix 9. These proformas indicate whether the assessed evidence is above, at or below the pressure benchmark used in the sensitivity assessments; the confidence in the activity x pressure link is also assessed.

3.5 Ecosystem Services Review (Objective 3)

3.5.1 Ecological components that mediate services

A large number of ecological components at CEM levels 1, 2 and 3 (regional and global drivers, water column processes and local processes/inputs at the seabed were identified as mediating the supply of ecosystem services produced by the bio-assemblages. This is unsurprising as the original CEM models on which this work is based, were diagrams of the influences and functioning of the ecosystem; the nodes were selected for inclusion in the CEM (see Table 1 for references) on the basis that they influenced bio-assemblages. Therefore, all ecosystem services that are delivered by the biota are likely to be mediated by these components of the ecosystem.

The magnitude of influence of each of these interactions was defined in the original CEM reports and these form the basis of the assigned values for the level of mediation (influence) and the confidence. These interactions were also assessed in the literature review, where information was available, and the original information supplemented. Confidence in the links between ecological components and mediation of ecosystem service delivery by bio-assemblages are typically high.

3.5.2 Ecological components that support services

At the output levels, (5, 6 and 7) ecological components were frequently identified as likely to support rather than mediate services. This is to be expected as at these model levels, the components represent outputs of the bio-assemblage, rather than drivers and influencers. A number of these nodes are identified as ecological processes and functions that are intermediate (supporting) services (based on Potts *et al.* 2014) and support final ecosystem services. Examples of supporting ecological function and process nodes include the node ‘sediment stability’ which is likely to support primary production. Fewer ecological components at levels 1, 2, 3 and 4 were identified as supporting the delivery of intermediate or final (CICES) ecosystem services.

3.5.3 Summary Table Interpretation

The summary tables (one for each broad habitat) outline the contribution of each ecological component to each of the assessed marine ecosystem services. The table is intended to be read across rows, with the cell information identifying the relationship of the ecological component to the ecosystem service within an idealised conceptual habitat represented by the CEM. For example, primary production in rock habitat leads to the export of organic matter, thus primary production supports that ecological component. However, the export of organic matter is not considered to directly influence primary production within a habitat, so the cell entry is ‘not relevant’.

The strength of the relationship and associated confidence is based on the review and is generic rather than to being specific to individual biotopes. The applicability of these assessments is discussed further in the section on limitations (Section 5). The ecosystem services review proformas (Appendix 9) provide further information to support the assessments.

4 Bayesian Belief Network Models

4.1 Introduction to BBN

Bayesian Belief Networks (developed by Judea Pearl in the early 1980s) are a compact visual representation of a situation and the associated probabilities. Created from nodes (which represent entities within a habitat) and edges (showing the influence one node has on another), conditional probabilities can be used to express the relationships between the nodes via belief propagation algorithms (Laurtizen & Spiegelhalter 1999).

Overall, a Bayesian Belief Network can be considered as the interface between a causal diagram and the available data (Pearl 2018), which allows for both predictive and diagnostic reasoning to be investigated through the use of Bayes Theorem. Figure 1 shows a simplified Bayesian Belief Network (BBN).

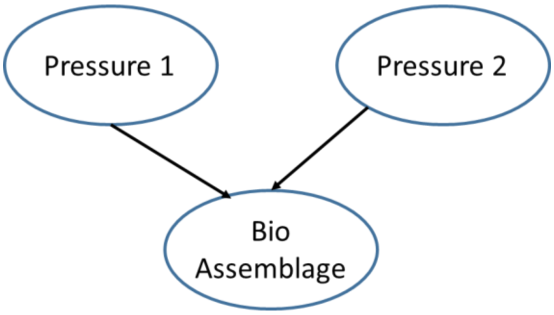


Figure 2. Simplified Bayesian Belief Network.

In Figure 2, two pressures can be seen to impact upon a bio-assemblage. The pressures are defined as parent nodes (that is there are no arrows leading into them), whilst the bio-assemblage is a child node. The value of this child node is conditional on the values of Pressure 1 and Pressure 2.

Within discrete Bayesian Belief Networks, states can be applied to the variables; for example, the pressure could be considered as being low, medium or high, whilst the bio-assemblage could decrease, remain the same or increase.

However, assigning such values is, in itself, non-trivial; what genuinely constitutes a “high” pressure in terms of a probability? Often, answers such as “higher than 90%” are provided, often with little or no scientific rigour behind them. Following this example through, the child node will need a series of conditional probabilities defining in terms of the “states” for the pressures. For example, the probability of the bio-assemblage decreasing, remaining the same or increasing when both Pressure 1 and Pressure 2 are low. In total nine sets of conditional probabilities would be required for this example, either through derivation from available data sets or elicitation from expert judgement.

Defining the required conditional probabilities, even for a simple network, rapidly becomes time consuming if indeed it is at all possible. In many real-world situations to which BBNs are applied, there is insufficient data to develop the conditional probability distributions from data. In these situations, the required conditional values must be derived from standard distributions or elicited from expert judgement.

Within this project, the minimal data sets available were not suitable for the development of conditional distributions based on experimental or research-based information. Furthermore, the number of variables and scenarios being considered meant that the use of expert judgement for the elicitation of the required values was impractical.

Hence, a more flexible approach which allows for multiple nodes to have influence on other nodes was required, whilst providing for rapid translation of sensitivity scores in the Bayesian Belief Network. At the design stage, the team concluded that a Gaussian Bayesian Belief Network was the most suitable approach.

4.1.1 Adoption of Gaussian Bayesian Belief Network

Within a Gaussian distribution, each variable is defined by a normal distribution. Each node follows a normal distribution with parent nodes being defined by their respective marginal distributions and child nodes (i.e. nodes with arrows leading into them) being defined by conditional probabilities.

Within a Gaussian BBN, information flows between variables through the use of Bayes Theorem, with the distributions being defined in terms of a linear relationship (with the underlying assumption that residual error follows a normal distribution for the variance).

In this project, the distributions incorporated into the network explicitly include uncertainty in both the lack of empirical data and the naturally occurring variance in the variable of interest. This natural variance can incorporate a wide range of random factors, such as a variation in occurrence of a bio-assemblage in a habitat or the random element of impact of a pressure (e.g. a contamination event occurring simultaneously with a powerful sea swell).

At the completion of this project the standard deviation of the distribution is entered as a habitat specific value. For the future, it is considered more appropriate for these variations of pressure application and bio-assemblage to be scenario specific. It is important to remember that whilst complex marine scenarios are being considered, there are, in many cases, only sparse data sets available. In such situations, simple models often perform better than more sophisticated ones.

Again, consider the simple BBN presented within Figure 1. The variables being included within the network could be defined as a standard normal distribution with values below zero representing a negative impact from an equilibrium state and values above zero equating to a positive impact (Figure 3).

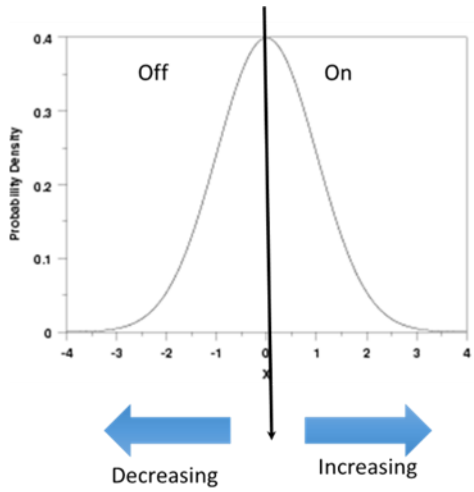


Figure 3. Nodes are defined in terms of a steady state equilibrium with a variance defined as a standard normal distribution.

The local distribution of the variation of each child node is expressed as a Gaussian linear model which includes an intercept (which equates to steady state condition) and the node's parents as explanatory variables, without any interaction term.

The use of linear dependencies provides tractability and the availability of closed-form results for many inference procedures. Overall, this approach develops a regression model for the response variable (child node) to describe how the response distribution depends upon the parent nodes. This approach assumes that:

1. The variables represented by the nodes are normally distributed:

$$X \sim N(\mu, \sigma)$$

2. Where *X* is a variable, *N* represents a normal distribution defined in terms of a mean, μ and a standard deviation σ.

3. The standard deviation of the response variable is the same for all values of the parent node:

$$\sigma_C = \sigma$$

4. The mean of the response variable is linearly related to the parent node or nodes:

$$\mu_C = \beta_0 + \beta_P$$

5. Where the subscripts $_P$ and $_C$ refer to parent and child respectively with β being a coefficient.

It is important to remember that a normal linear model does not explain the distribution of the parent, rather it describes the conditional distribution of the child at each value of the parent. Of key importance to this project is how to interpret and define the regression coefficients. Again, referring to the simple BBN in Figure 1, let P_1 be Pressure 1 and P_2 be Pressure 2. This leads to the definition for bio-assemblages as:

$$R_{Bio-assemblage} = \beta_0 + \beta_1 P_1 + \beta_2 P_2 + e$$

where β_0 is the intercept; the regression coefficients and predictor variables are also shown. The residual error term is defined by the factor *e*.

Working over the whole BBN, the joint distribution is a multivariate normal which is the product of all the local distributions[7].

The intercept term is the value that is predicted if both pressures equal zero. This is only meaningful interpretation if it is reasonable that both the predictor variables (pressures 1 and 2) can be zero. If this is not the case, then the intercept has no real meaningful interpretation and serves merely to anchor the regression to a suitable point.

The regression coefficients for the predictor variables represent the difference in the prediction of the bio-assemblage for “one-unit change in the pressures”. This approach supports the flow of information through the BBN whilst enabling the required values to be developed from the available data based upon the scope of expert knowledge.

In order to compute all the required calculations for the scenarios and research questions of interest, a Gaussian linear model must be defined for each node (and the variable it

[7] A multivariate normal distribution in its simplest form describes the joint distribution of a random vector of mutually independent univariate normal random variables with a mean of zero and variance of one. Generally, a multivariate normal distribution describes the joint distribution of a random vector represented as a linear transformation of a standard multivariate normal vector.

represents) within the BBN. Subsequently, the BBN will use statistical theory to calculate the probability distribution over the whole network.

The changes in the distributions of variables represented within the nodes are calculated through Bayesian inference:

$$Posterior\ distribution = \frac{likelihood\ x\ prior\ distribution}{normalising\ constant}$$

Which for the continuous network in Figure 1, is expressed as:

$$p(BA|P_1, P_2) = \frac{p(P_1|BA, P_2)p(BA|P_2)}{p(P_1|P_2)}$$

where the normalising constant $p(P_1|P_2)$ can be further defined as:

$$p(P_1|P_2) = \int p(P_1|BA, P_2)p(BA|P_2)d\theta$$

A review of the available information resulted in the following approach being utilised:

All pressures nodes (the influences), are defined to be either on or off (1 or 0) with a normal distribution catering for variation in presence.

Child node regression coefficients were based upon the response variables resistance to the parent node.

Currently, all parent nodes are defined in terms of a standard normal distribution (mean of zero and a standard deviation of 1) though it is accepted that over time this could change based on the analysis of available evidence/data sources. Within a Gaussian Bayesian Network, the conditioning effect of the parent nodes is given by an additive linear term in the mean and does not affect the variance. In other words, each node has a variance that is specific to that node and does not depend on the values of the parents (Figure 4).

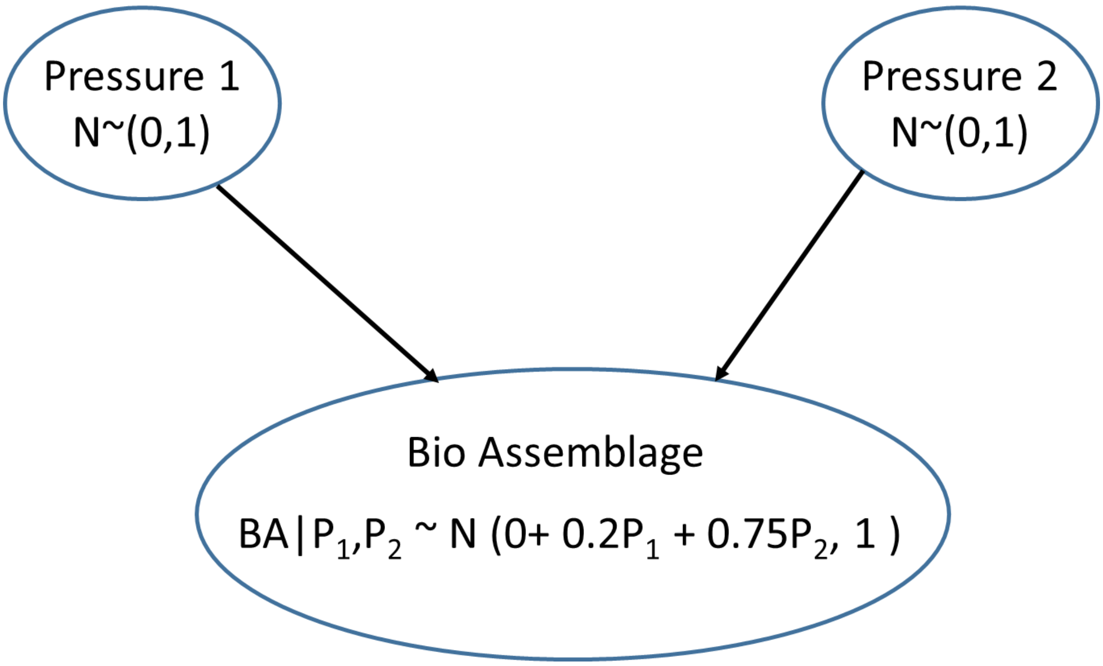


Figure 4. Development of linear representation.

Moving from the simple BBN in Figure 2, the impact of nodes flowing through the network was defined in terms of whether the node increased, decreased or had no effect upon the nodes to which it was linked.

Overall, the approach provides a tractable, robust approach to the development of a wide range of BBNs within a short timeframe. The approach can be expanded as additional information becomes available to refine the regression coefficients used and to support sensitivity analysis within the final output of the BBNs.

4.1.2 Implementation of the BBN within R scripts

In order to establish a scalable approach to importing resistance and resilience scores into a modelling environment, a set of R scripts were written to handle the import, storage, calculation and display of the habitat models within a web-based tool.

The scripts perform the following functions:

- Data import from spreadsheet structure
- Compilation of Bayesian Belief Network
- Calculating the impact of pressures upon the developed model

Each of these elements is described in further detail below.

Data import from spreadsheet structure

The data ingest process uses a pre-defined Excel spreadsheet comprising 4 sheets, as follows:

- The first sheet holds the pressures list as names in the first row. The second row holds the intercept and confidence values for these pressures.

- The second sheet defines the bio-assemblages and provides a mapping from the pressure nodes, to each bio-assemblage. The degree of impact (i.e. the inverse of resistance) is defined for each node bio-assemblage, which is influenced by the pressure. The growth rate at equilibrium and confidence level (i.e. the standard deviation of the variance for the Gaussian Model) is defined for each node.

- The third sheet defines the output processes and provides the mapping from pressures and bio-assemblages to the output processes.

- The fourth sheet defines the ecosystem services and provides the mapping from pressures, or bio-assemblages or output processes to the ecosystem services themselves.

These models have been built for the five main subtidal habitat types (coarse sediment, mixed sediment, mud, sand and rock).

The R script runs a validation check on each spreadsheet checking for the presence of each sheet, consistency of naming conventions and gathers data about the nodes and edges in order to build the network. This process defines a valid set of nodes and edges which can then be compiled into a Bayesian Belief Network.

Compilation of Bayesian Belief Network

Once a spreadsheet has been validated, the model is imported into the toolset. All the data necessary to describe the Bayesian Belief Network is held in the sheet.

The first stage of the compilation process defines the network itself using the *bnlearn* library within R to describe the network structure.

Following successful import of the network, the script builds the conditional probability distributions of each node within the network. This data is then stored and made available to the Graphical User Interface (GUI) when required.

Calculating the impact of pressures upon the developed model

From the GUI, a list of applied pressures can be passed to the selected habitat model as a binary indicator of presence. This process uses the *bnlearn* conditional probability method to stimulate the model with an evidence statement based upon the defined state of the input pressures. The method uses a Monte Carlo approach to estimate impact on variance. The method uses a cycle of 10,000 runs to define the distributions.

It can therefore be expected that there will be minor variation in outputs as a result of the effect of the number of runs. The number of runs is a trade-off between accuracy and speed of response. Tests to date indicate that variation between runs is minor.

The method returns a summary of the distribution of each node within the network in terms of a mean, minimum, maximum, one and two standard deviations from the mean. This is used to display the impact to the user through the GUI but can also be used programmatically to calculate hypothesis probabilities based upon priors and a suitable hypothesis as in discrete BBNs.

4.1.3 Graphical User Interface

A Graphical User Interface (GUI) has been added as a viewing facility onto the underlying R scripts. The GUI allows a user to select a habitat model, run simple pressure assessment tests, view the results and navigate around the network. The selectors on the left-hand side of the page allow for a model to be selected and also a transition viewer allows for a progression of information to be displayed, starting with mapping pressures to bio-assemblages, followed by the subsequent impact on output processes and finally the impact on ecosystem services.

The GUI has two primary components as follows:

- Pressure Test page for viewing impacts.
- Network viewer.
- Each GUI component is described in further detail below.

Test page for viewing impacts

The user interacts with the BBNs using this page. The primary method of interaction is the radio buttons towards the left-hand side of the page. Application of a pressure represents the pressure benchmark as defined in the sensitivity analysis. Multiple pressures can be applied simultaneously, and a cumulative impact of concurrent pressures can be assessed.

The data is presented as a series of box and whisker plots which represent the change in a node as a result of the application of a pressure(s). The values presented on the graph are the maximum, third quartile, median, first quartile and minimum value for each node. This provides a relatively straightforward method of visualising the relative impact upon a node coupled with the magnitude and direction of impact. The addition of the box and whisker plots allows a visual assessment of a likelihood of hypothesis, i.e. the probability that a node is in decline can be viewed by where the mean, quartiles and limits are versus the steady state (i.e. y=0).

The graphical display allows for zoom, selection, and de-selection of nodes to improve readability.

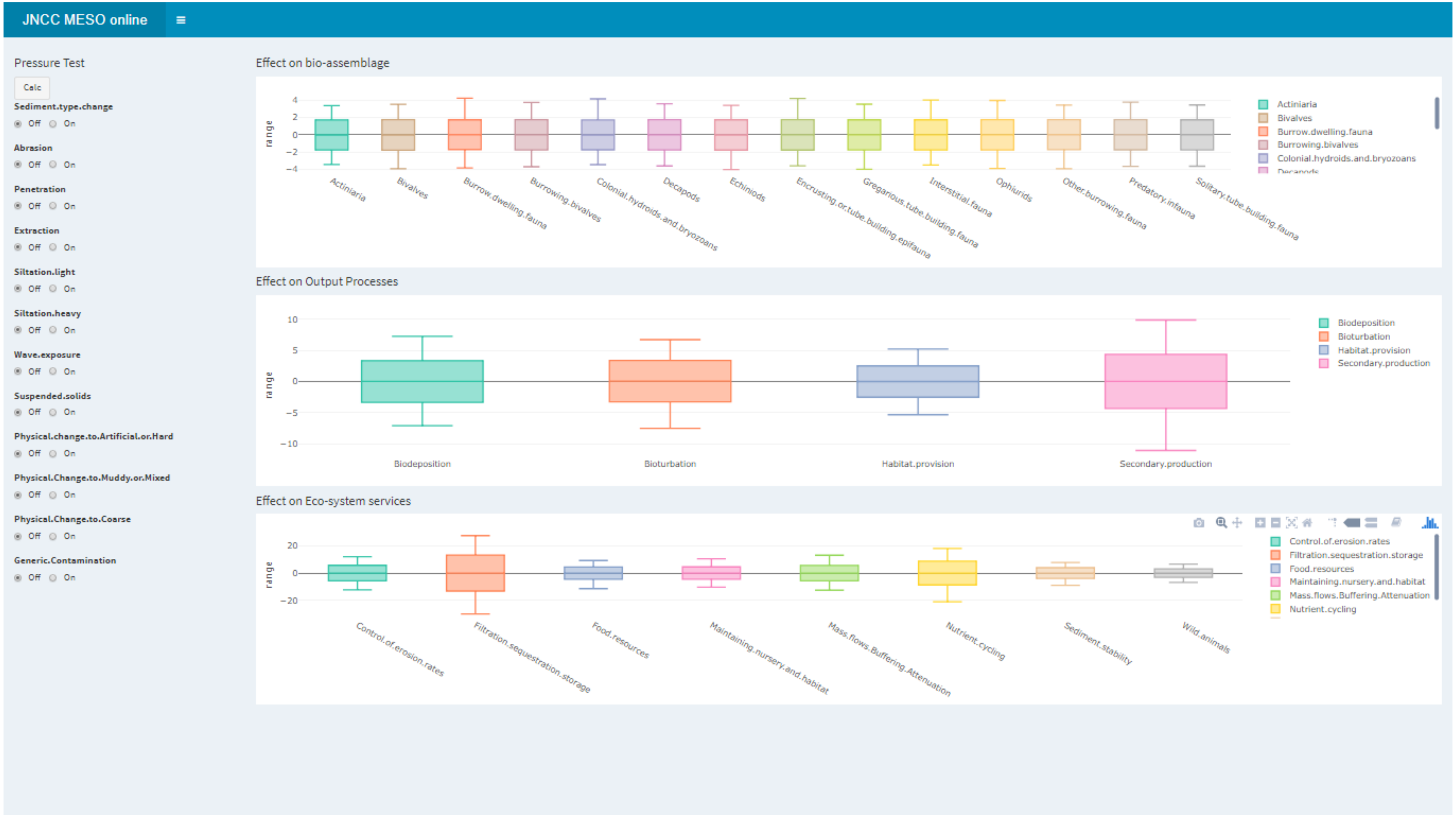


Figure 5. Pressure Test User Interface.

Network viewer

The network viewer page provides the user with the ability to investigate the network and understand the nodes, edges and values associated with each element of the network. The upper half of the display provides a visualisation of the network (with nodes coded by an identifier) and the influences (edges) displayed as arrows.

The lower half of the model allows for the user to search for node parameters in the left-hand side of the display and the influences on the right-hand side.

Search and sort facilities are provided to simplify the process of viewing the impact levels of one node on its child nodes.

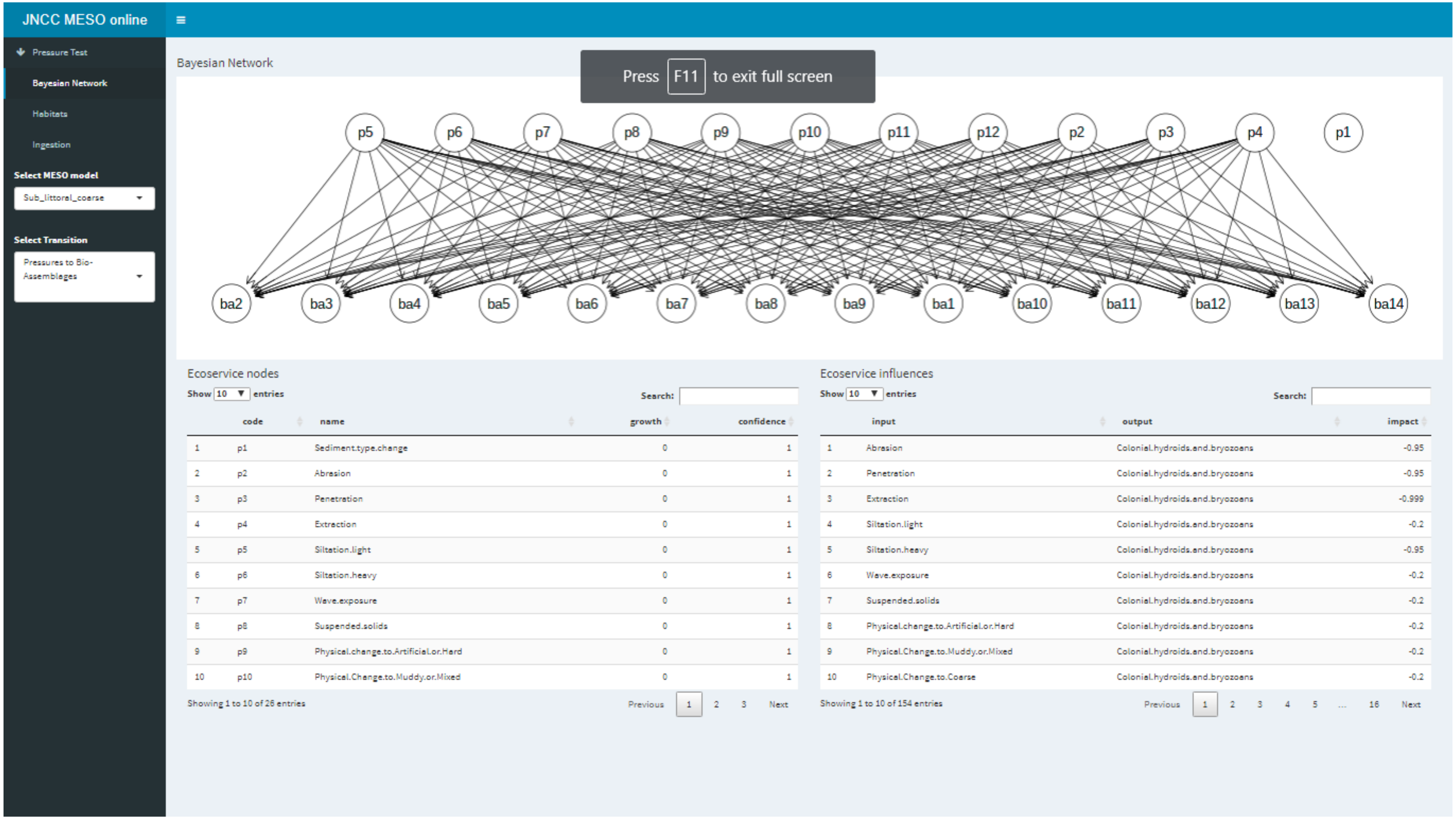


Figure 6. Network Viewer Page.

4.1.4 Summary of Features

As illustrated, the model can be set-up through the structured entry of information into an Excel spreadsheet. This is ingested into software written in R (a free and widely available open source language), leveraging the graphic interface capability of R-shiny, to model the distribution of posterior values under the effect of applying different combinations of pressures. The nodes being acted upon represent the components of each ecosystem, its biota, services and the forcing pressures, providing a visual summary of these interactions.

Discrete BBNs use discrete state variables and associated conditional probability tables (CPT) which grow exponentially with every new state we might wish model. Given the relative complexity of the original MESO conceptual models they could rapidly create BBNs for which it is impossible to develop the required CPTs. In turn, it would be more difficult, and less intuitive, to modify relationships between pressures, bio-assemblages and their output processes than map either directly or indirectly to ecosystem services. To overcome these limitations, we implemented a Gaussian Bayesian Belief Network (BBN) framework to facilitate the modelling of complex marine scenarios with a large number of nodes and edges, and with system responses most appropriately expressed along a continuum.

Continuum responses fit well with the way physical pressures act on biota and, in turn, their responses to them. While thresholds or step changes are not unknown in nature (and these can still be accommodated), continuous distributions provide the scope for finer control over responses to pressures that would otherwise be too complex to derive and present within CPTs. This latter point also has implications for the ease with which a system can be understood by a user and keeping track of relevant variables.

The design enables complete model flexibility for the addition (as required) of greater detail by routing outputs through alternative processes across scenarios. Incorporating simplicity through the combination of nodes wherever possible predisposes the models to scale in dimension, giving them the potential to be taken out of the conceptual and into the actual world domain.

In their present state, the models are dimensionless and the nodes representing bio-assemblages, output processes and ecosystem services are highly abstracted and notional. It is difficult to attribute metrics to them or, rather, it is for the user to interpret them in their own operational context. As previously noted, the user has access to the structure and parameterisation of the model through the primary spreadsheet input, however, it is important to bear in mind that there is no spatial or temporal scale associated with the models as they stand. Modelling the exertion of a pressure on the belief network is to observe a state change in child node responses. The model does not include recovery; it is simply concerned with the instantaneous effect of a pressure, or combination thereof, on down-graph nodes.

Input, or pressure, nodes are generally well defined, and the interpretation given to them is that when they are “on” the pressure node is delivering one dose of that pressure up to its benchmark. Pressure benchmarks were derived from previous work conducted by members of the project team (Tillin *et al.* 2010; Tillin & Tyler-Walters 2015).

4.2 Parameterising the model

4.2.1 Parameterising bio-assemblage sensitivity

Once existing published data on the biotopes containing the relevant organisms were disaggregated and reassessed, organism sensitivities were recombined for the functional biological groups specified in the conceptual models (see Section 2.15). The sensitivity assessments are based on combined resistance and recovery (see Appendix 7). Bio-assemblages that have the same sensitivity may respond differently to the initial impact. It was therefore decided that only the resistance component of the sensitivity assessment should be used in the models to identify the response to the pressure as the models do not currently have a temporal component over which recovery could be incorporated.

The resistance values used were assessed as High, Medium, Low and No Resistance to the applied pressure. Subsequently these were expressed numerically as -0.2 (High), -0.75 (Medium), -0.95 (Low) and -0.999 (No Resistance). A further category of -0.01 was used to denote insensitivity or no data, which are treated as the same thing. So far, these values have been developed through iterative subject matter and expert review and represent the relative proportions required to achieve an expected response across each node within the network. It should be noted that the values used are subject to review for each scenario considered and it is accepted that other values may be more robust in certain scenarios. This process cannot objectively be conducted until such time as we have datasets available from which each node response can be calibrated.

These is scope to continue to review and refine the value ranges that constrain child node responses to within realistic limits based on expert judgement. This could be achieved through a range of approaches. Currently, the normal distribution for each node defaults to the standard normal distribution (that is a mean of 0 and a standard deviation of 1). At each node this distribution can be edited. With suitable evidence, the standard deviation could be altered to reflect the relative certainty or uncertainty of the parameter under consideration and would improve the local quality of output from that part of the network. Alternatively, there may be advantage in grouping the functional groups into aggregations, as exemplified by the more general groups detailed in the original CEM, which would then pass a single score to an output process, therefore reducing the number of inputs into any one node. This would have the effect of reducing the variance of any child node, which can become sensitive to large numbers of inputs because of the way normal distribution variances combine. This can lead to the probability distribution flattening out causing imprecision in the assessment of the child node response and propagating that imprecision further down the network.

4.3 Model Input parameters for MESO BBN

Based on evidence from the ecosystem service review, BBN model input categories (Table 15) were selected to characterise the magnitude of contribution of each bio-assemblage to the ecosystem services that could be included in the model. This information is used to parameterise the edges that link nodes within the BBN model (see Figure 7 below for node linkages). The contribution to each output process or ecosystem service was scored between 0 and 1. Parameter selection was constrained to categories that could be applied consistently across the bio-assemblage groups and that were supported by evidence. The classes within each category, where possible, were chosen to encompass a wide range of habitat types, not just those represented by the CEMs. This was intended to allow the modelling approach to be applied across habitats in the future. Table 15 shows the nodes that were already in the CEM models or added to the BBN to represent ecosystem services. The categories define the magnitude of contribution from 0 to 1 and provide a definition of each category from “None-High” that was used in the summary table. Two input categories 0.75 and 1 were considered to represent high contribution to the service. The categories discriminate relative contribution between assessed features, it was considered that there was too little information to differentiate between these two categories in the summary table.

The evidence used to categorise relative contribution of ecological components (largely the biota but some habitat parameters) varied across services:

- Relative contribution to bioturbation (which supports a range of ecosystem services) was categorised according to existing functional classification schemes with relative contribution based on bioturbation potential. A key resource to assign species and therefore the bio-assemblage groups to bioturbation categories was the review by Queiros *et al.* (2013) that provided a functional classification for 1033 benthic invertebrate species based on information from the literature and expert opinion.

- No functional classification for biodeposition currently exists that is comparable to the bioturbation classification (Mermillod-Blondin & Rosenberg 2006).

- Input to secondary production output process was ranked based on feeding and food type using the secondary estimates from Cusson and Bourget (2005).

- Input to primary production was based on annual contribution values derived from the literature review

- Habitat provision was based on the volume and complexity of epifaunal structures; this information was also used to parameterise the biotic contribution to CICES 2.2.1.1 (Control of erosion rates) and CICES 2.2.1.3 (Hydrological cycle and water flow regulation (Including flood control, and coastal protection));

- CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy: based on the identity of targeted species and commercial importance;

- CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition, materials or energy: based on the identity of targeted species and commercial importance;

- CICES 5.2.1 Regulation of baseline flows and extreme events: based on sediment type as ranked by Liquete *et al.* (2013b);

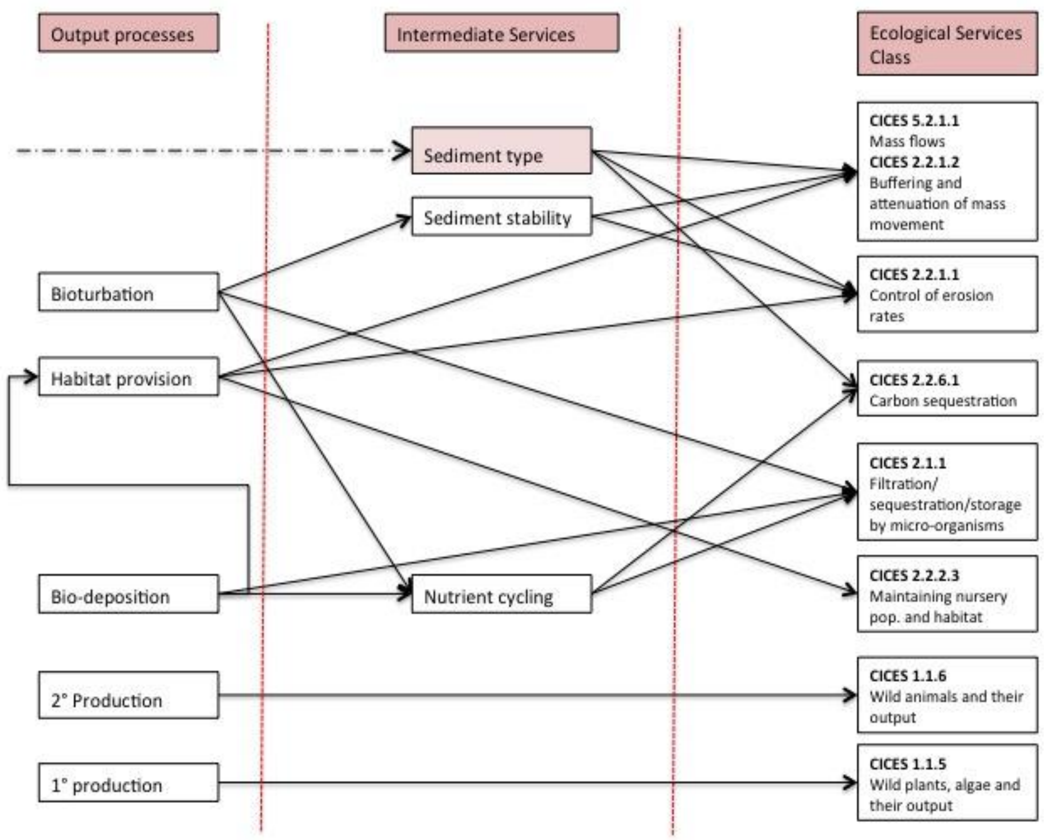
- Carbon sequestration: based on sediment type as a proxy.

Table 15. Input categories and classes within categories for the ecosystem service BBN model nodes. The input parameter row indicates the magnitude of contribution between 0 and 1. The magnitude of contribution categories show how the input parameters were translated to indicate contribution magnitude in the summary tables.

Input parameter categories (MESO BBN)	**0**	**0.25**	**0.5**	**0.75**	**1**
Magnitude of contribution (summary table categories) Categories	**None**	**Low**	**Medium**	**High**	**High**
BBN Model Nodes					
Bioturbation	Non-bioturbating species, e.g. epifauna	Surficial modifiers	Bio-diffusers	Upward and downward conveyors	Regenerators
Biodeposition	Not suspension feeder or switches between deposit / suspension feeder		Small suspension feeders	Passive suspension feeders	High density bivalve / active suspension feeder
Secondary production	Primary producers	Omnivores / predators	Deposit feeders	Grazers	Filter feeders
Primary production	Animals	0.25 $kg/m^2/yr^{-1}$ Low- e.g. Sparse *Sacharrina latissima* in sand habitats	0.5 -2 kg/m^2 year saltmarsh/ seagrass	5-10$kg/m^{2/yr-1}$	Dense macroalgal beds (15 $kg/m^2/yr^{-1}$)
Habitat provision	None, infauna, predatory epifauna, mobile epifauna	Low relief, mounds / pits	Tube building /low reef /mat forming	Solitary epifauna / sparse epiflora	Biogenic reef forming organisms /dense macroalgae
CICES 2.2.1.1. Control of erosion rates and CICES 2.2.1.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	None, infauna, predatory epifauna, mobile epifauna	Low relief, mounds / pits	Tube building /low reef /mat forming	Solitary epifauna / sparse epiflora	Biogenic reef forming organisms /dense macroalgae / all bio-assemblages within rock habitat
CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Plant or a not targeted animal		Sporadic targeting in some locations		Species actively targeted
CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Animal or plant not targeted		Sporadic targeting in some locations		Species actively targeted

CICES 5.2.1 Regulation of baseline flows and extreme events:		Mud	Sand	Coarse / mixed substrates	Reef habitat
Carbon sequestration (sediments)	Coarse / sand/ gravel /shingle/ cobble	Mud/ mixed	Dense macroalgae		Saltmarsh /biogenic reef

Figure 7. Node links between output processes, intermediate services and final ecological services. The dashed line represents an intermediate service provided by a node at a higher level in the CEM than output processes (sediment).



5 Limitations and Knowledge Gaps

Key limitations for this study were gaps within the available evidence to assess the impacts of pressures on ecological components and conservation objective attributes of designated sites, and the links between ecological components and ecosystem services. These knowledge gaps are discussed separately below, for pressures and activities (Section 5.1), species and habitat sensitivity (Section 5.2) and ecosystem services (Section 5.5).

5.1 Objective 1. Activity and Pressure information gaps

A key aim of this study was to identify how pressure from human activities impact the ecological components identified in the CEMs and potentially alter the flow of ecosystem services. Of all activities fishing was associated with the largest evidence base, with numerous examples of impacts from various gear types sources across a range of habitats. Aggregate extraction is also well-studied, resulting from stringent licensing, a producer's organisation and the previous existence of a fund specifically set-up to study the industry impacts. Other activities although widespread within the marine environment have been less studied. For example, a recent literature review on evidence for anchoring and mooring identified key evidence gaps regarding the level, scale and intensity of the pressures and impacts on sensitive seabed habitats and species (Griffiths *et al.* 2017). Most studies that evaluate impacts have considered recreational vessels on seagrass beds and corals and direct observations and empirical studies of the impacts of commercial vessel anchoring and mooring are rare (Griffiths *et al.* 2017).

Coverage of ecological components was also uneven; some components of the ecosystem are much better studied than others. For example, macrofauna are better studied than meiofauna and microorganisms.

Key evidence gaps or other limitations were identified for some of the reviewed pressures and it was not considered possible or desirable to produce pressure proformas for these.

5.2 Knowledge gap analysis - species and habitat sensitivity

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

In general, the following evidence gaps for pressure–sensitivity assessments developed for the bio-assemblages within this study were noted:

- Sand: In general, there were few evidence gaps for sand species, the most obvious gap was the lack of information (even basic life history data) for the polychaete *Aricidea cerrutii* which was the sole representative of a bio-assemblage. Other polychaetes for which there was little or no evidence, were *Ophelia borealis*, *Travisia forbesii*, *Sphaerosyllis bulbosa* and *Paraexegone hebes*. Predatory epifauna including starfish and decapods were a key evidence gap for this and other habitats.

- Coarse sediment: Species for which little information was available were: *Alcyonidium diaphanum*, the predatory decapods, *Pagurus bernhardus* and *Liocarcinus* spp. And the ophiurid, *Ophiura albida*. Information was relatively sparse for polychaetes with no evidence available for *Travisia forbesii*, and the interstitial polychaetes. The MarLIN assessments note that sandy and coarse offshore sediments are poorly studied compared to other biotopes, and the sensitivity of species such as venerid bivalves was largely based on expert judgement for most pressures.

- Mixed sediment: No sensitivity assessments were found for *Styela clava* an invasive tunicate, the sponge *Amphilectus fucorum*, the anemones *Sagartia elegans* and *Cereus pedunculatus*, the cumacean *Eudorella truncatula*, the amphipod *Maera grossimana* and the small mollusc *Calyptraea chinensis*.

- Mud: The tube builders *Phoronis muelleri*, *Photis longicaudata* and *Galathowenia oculata* had not been previously assessed and there was little information for burrowing polychaetes; *Malacoceros fuliginosus*, *Maxmuelleria lankesteri*, *Mediomastus fragilis*, *Scalibregma inflatum* and *Scoloplos armiger*. No previous sensitivity assessments were found for the burrowing holothurians *Labidoplax media* and *Leptosynapta bergensis*. As with other habitats the mobile predatory epifauna were a clear gap in sensitivity understanding.

- Rock: Species for which little information was available were the sponges *Cliona celata*, *Dysidea fragilis*, *Haliclona viscosa*, and *Myxilla incrustans* and the ascidians *Corella parallelogramma* and *Polyclinum aurantium*. The gastropod molluscs *Gibbula cineraria, Janolus cristatus* and *Margarites helicinus* have not been assessed by the previous projects. The crustaceans *Dexamine spinosa*, *Dyopedos porrectus* and *Pandalus montagui* were further representatives without associated sensitivity assessments.

Where only the genera were identified or where evidence was missing, information from other species, preferably those from the same genus where available, was used to fill evidence gaps:

- *Bathyporeia elegans* (sand CEM) assessment based on *Bathyporeia* spp. and *Bathyporeia pelagica* assessments (coarse sediment CEM);

- *Pagurus* spp. (Coarse sediment) assessment based on *Pagurus bernhardus* (sand CEM);

- *Spisula* spp (coarse sediment) assessment based on *Spisula subtruncata* assessments (sand CEM);

- *Ampelisca spinipes* (coarse sediment) assessment based on *Ampelisca* spp and *Ampelisca brevicornis* (sand);

- *Sertularia argentea* (rock, coarse sediment) assessment based on *Sertularia cupressina (sand)*;

- *Tubificoides pseudogaster* (mud) assessed based on *Tubificoides benedii* (MarLIN); and

- *Nemertesia ramosa* (mixed sediment) assessed based on *Nemertesia antennina* (rock).

Where no information was available, assessments made for similar taxonomic or functional groups were used:

- cumacean *Eudorella truncatula* (mixed sediment), assessments used the cumacean assessments in sand (largely based on *Diastylis rathkei*); and

- burrowing amphipod *Maera grossima* (mixed sediment) assessment based on *Bathyporeia elegans* (sand).

In summary, sensitivity assessment gaps exist across all the bio-assemblage groups studied. Mobile predators, such as seastars and crabs are not considered generally to characterise biotopes, which are largely defined based on sessile and sedentary species. They are not considered within the MarESA method, although Tillin and Tyler-Walters (2014) assessed the sensitivity of this ecological group. As these species are habitat generalists present in all the broad habitats, they represent a key evidence gap.

In general, non-native species are considered nuisances, rather than species of conservation interest and their sensitivity has not been extensively studied within the existing resources. There was therefore little information to assess invasive non-natives species within the bio-assemblages, such as *Crepidula fornicata* and *Sargassum muticum* (although these both have MarESA assessments) and *Styela clava*.

Within the CEMs the evidence base for sessile epifauna is greater than burrowing infauna. More information is available for larger species that are of specific interest, either for conservation or commercial purposes. The evidence base on which to assess sensitivity was much less for species that are small and of no commercial value such as many polychaetes, cumaceans, tanaids and others.

5.3 Confidence in pressure-sensitivity assessments

The confidence assessments made throughout the sensitivity assessment score aggregation process, were designed to demonstrate the source of the uncertainty in the evidence and the degree of expert judgement and interpretation required to make an assessment. For example, 'High' quality evidence may still not be directly applicable to the assessment and excellent evidence may disagree.

The only pressures where many of the sensitivity assessments were assessed with high confidence were the changes in physical substratum type. This pressure represents a significant impact on sediment habitats resulting from a change in substratum type from sediment to rock or artificial habitats. The high confidence reflects the relatively good understanding in the marine environment of the physical processes that structure sedimentary and rocky habitats. The lower confidence for coarse and mixed sediment habitats for this pressure, is a result of the presence of a number of species that are found attached to stones in these habitats and that are also present in reef habitats such as bryozoans.

The pressure 'extraction' was generally awarded a 'medium' confidence; for most species there was little specific evidence to support the sensitivity assessment but the extraction pathway to impact is clear; removing the sediment would remove either the majority, or all, species.

Confidence in abrasion and penetration pressures was evenly split between 'low' and 'medium' across the sedimentary habitats. Although there is a large evidence base for the effects of abrasion, particularly from fishing pressures, 'low' assessments were often the result of evidence gaps for species within a group where the applicability of the assessment could not be judged. Few bio-assemblages were assessed with high confidence for either pressure.

Confidence in siltation pressures varied markedly between the two pressure benchmarks. For low siltation (a deposit of 5cm) confidence was greater (medium confidence in more bio-assemblages) than for a thicker deposit of 30cm. For thinner deposits, many species that occur in depositional environments were considered likely to be able to burrow through a deposit. For thicker deposits this confidence reduces. Although there is some experimental evidence to support assessments of siltation these relate to very few species and the uncertainty in these pressures results from a lack of evidence.

Sensitivity to changes in suspended solids at the pressure benchmark is difficult to infer from habitat evidence and biological traits that are difficult to relate to the pressure benchmark of a change for a year. In general, species tolerances were assessed based on biological traits with permanently buried infauna considered to be resistant, while suspension feeding epifauna were considered likely to be more sensitive. Macroalgae were also considered likely to be sensitive to this pressure.

5.4 Sensitivity assessment limitations (Objective 1)

The MarLIN project has identified key limitations around the application of sensitivity assessments; these apply to both the collated species sensitivity assessment scores and the aggregated bio-assemblage scores. This should be considered when using the project outputs and any other future use:

- the sensitivity assessments are generic and NOT site specific. They are based on the likely effects of a pressure on a 'hypothetical' population in the middle of its 'environmental range'[8];
- sensitivity assessments are NOT absolute values but are relative to the magnitude, extent, duration and frequency of the pressure effecting the species or community and habitat in question; thus, the assessment scores are very dependent on the pressure benchmark levels used;
- the assessments are based on the magnitude and duration of pressures (where specified) but do not take account of spatial or temporal scale;
- the significance of impacts arising from pressures also needs to take account of the scale of the features;
- the sensitivity assessment methodology takes account of both resistance and resilience (recovery). Recovery pre-supposes that the pressure has been alleviated but this will generally only be the case where management measures are implemented; and
- there are limitations of the scientific evidence on the biology of features and their responses to environmental pressures on which the sensitivity assessments have been based.

5.4.1 Disaggregating ecological group and biotope scores

The MarESA assessments are based on biotope sensitivity and may consider characterising species or other factors such as substratum that characterise the biotope. In some instances, biotope sensitivities are very different to constituent species sensitivity. For example, when considering changes in sediment type, the biotope *character* would alter considerably if the sediment or substratum type changed but species themselves may not be as sensitive to a change. For example, the biotope, A5.141 *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles, is characterised by the presence of cobbles and pebbles and would be 'lost' if these were removed. However, the characterising species can be found on a range of substrata including hard rock and artificial substratum. The species, therefore, can be present even if the biotope would no longer be supported. In such instances, the biotope assessment or parts of the assessment text have been presented in the spreadsheet, but the sensitivity assessment has been adapted to the species.

In some instances, the biotope assessment and species assessments may not align where the species densities are considerably different. For example, *Sabellaria spinulosa* assessments are based on the *Sabellaria spinulosa* reef biotopes. However, these biotopes were not used in the construction of the CEMs and we understand that in the biotopes considered *Sabellaria spinulosa* may occur as individuals in low densities. The sensitivity of these is likely to be different from a reef but this has not been studied or quantified.

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

5.5 Objective 3. Ecosystem services

A key challenge in applying ecosystem service frameworks in management and decision-making is to have clear assessment frameworks that allow services to be measured. A systematic review of ecosystem services by Liquete *et al.* (2013a) found that some services are much better studied. There has been a focus on higher priority and obvious goods (e.g. fisheries) and the provisioning services that underpin them, than for other services. There are gaps in knowledge around some regulating and maintaining services, such as storm and erosion protection, habitat support for fisheries and pollution control (Barbier 2017).

Services with high economic value, and which are delivered by species that are larger and relatively tractable to study or experimentally manipulate, are associated with more evidence. For example, primary production by kelp has been estimated by several studies and is well supported (see Smale *et al.* 2013 for overview), while estimates of primary production by other components including microphytobenthos are less understood.

Challenges in interpreting ecosystem services, particularly in marine and freshwater, have been identified both generally (Liquete *et al.* 2013a; Maes *et al.* 2014) and for specific services, e.g. waste remediation (Watson *et al.* 2016) and nursery provision (Liquete *et al.* 2016). These services have proved more challenging to assess as the basis of the service itself had to be reviewed and considered in order to link to ecological components and parameterise for the MESO BBN development.

5.5.1 Provisioning Services

For all the ecosystem services considered, the abiotic and biotic components that directly provide the service were identified. In most cases the level of understanding of these services is greater than regulating and cultural services as they are more clearly linked to specific ecological components, e.g. species targeted by fisheries and harvesters or specific materials such as aggregates. A good level of literature information was sourced for most provisioning ecosystem services; gaps in the literature gathered on provisioning services are more likely to be a reflection of the time/resource constraints than an absence of available sources.

As this service primarily relates to the extraction of biological materials, most of the components which affect service delivery are those which directly influence the presence, growth and abundance of marine flora and fauna, and many influencing components are common to all services (Alexander *et al.* 2016).

5.5.2 Regulating services

Linking ecological components from the CEMS to the capacity to deliver regulating and maintenance service for the MESO BBN models to create a meaningful basis for assessment was challenging. In many instances the service can be considered to be ubiquitous; for example, all habitats with fauna can be considered to provide ecological services such as habitat provision and larval and gamete supply and to have the potential to support genetic resources.

5.5.3 Cultural services

Cultural ecosystem services are often omitted from cost–benefit analyses and impact assessments because data on benefits are unavailable, and there are considerable methodological challenges to measuring them (Jobstvogt *et al.* 2014). Although recent literature has been sourced that assesses these, studies have shown that valuation can be location specific. Nonetheless, the bio-assemblage and associated functions such as biodiversity habitat are clearly valued by site users. Although knowledge and interest of the general public may lag, the recent increase in public awareness of marine plastic driven by educational programs is countering the public perception that sublittoral ecosystems contain uncharismatic species (Jeffersen *et al.* 2014, 2015).

5.5.4 Ecosystem services, demand and realisation

Demand and realisation of ecosystem services will vary. In some instances, although there may be potential for a service to be provided, there is no requirement for it and the potential benefit is not realised. For example, *Mytilus edulis* reefs growing on an offshore wind farm have the potential to provide the services waste remediation and to be a harvestable good. However, if there are no wastes introduced into the marine environment the waste remediation service is not realised and similarly, their remoteness means they will not be targeted by a commercial fishery and the benefit is not realised.

Similarly, the value of ecosystem services can change according to demand. For example, the demand for cleaner wrasse from Scottish salmon farms has created a new fishery and increased the monetary value of the wrasse and therefore the supporting kelp bed services that produce these.

5.5.5 Ecosystem service provision varies temporally and spatially and according to condition

Spatial, temporal and condition variations compound uncertainties around the link between ecosystem services and ecosystem structure and function. The provision of a service may vary spatially across a habitat type; for example, a nursery function within a seagrass habitat may increase towards the centre of a dense bed rather than at the periphery. The nursery function may also vary seasonally and according to changes in other adjacent habitats. For example, the bed may become more significant as a nursery if adjacent habitats are impacted or lost. In the same way, the condition of the kelp bed will also influence the provision of services, for example a dense bed is more likely to provide greater wave attenuation than a sparse bed.

5.6 Ecosystem service knowledge gaps

The ecosystem service review found that the evidence base supporting linkages between the ecological components identified in the CEMs and ecosystem services is highly inconsistent; with some features offering the potential for relatively strong conclusions on the strength of links (mediating, supporting, provisioning) whereas for others there was little or no evidence. The review found that:

- substantially more evidence was available for provisioning services than for regulating and maintaining and cultural services. Commercial fisheries (food provisioning) are the most studied ecosystem service;
- previous reviews (e.g. Fletcher *et al.* 2012, Potts *et al.* 2014, Tempera *et al.* 2016 and Culhane *et al.* 2018) have focused on habitats and therefore more evidence is related to habitats than species. It is difficult to separate cultural services, particularly to individual species rather than habitats;
- the evidence base for individual species for processes and ecosystem services is limited with no evidence at all for most species;
- Intertidal and shallow subtidal habitats tend to be far better studied, particularly biogenic and vegetated habitats, reflecting both the accessibility of these habitats and the increased service realisation from these habitats;

- in order to support the MESO BBN modelling, proxy indicators of service level were required, e.g. levels of bioturbation as a proxy for waste remediation potential; and
- certain processes that support delivery of intermediate and/or final ecosystem services are better understood than others; primary and secondary production, food web dynamics and formation of species habitat are better understood and more predictable than waste remediation and carbon sequestration although many of the factors underlying the service delivery are understood.

5.7 Applicability of assessments

The CEMs represent a conceptual habitat and while they have been developed based on evidence of marine habitats, they cannot be considered to apply to every biotope on which they are based. Between biotopes there will be variation in the relationships between the ecological components and ecosystem services based on habitat and bio-assemblage differences. The ecosystem services assessments should be considered to represent a conceptual assessment of the likely links between ecological components and ecosystem services, scaled on evidence that may relate to the most (or conversely) the least productive biotopes for that service.

5.8 Model Limitations

5.8.1 Model parameterisation

While based on a synthesis of published and other evidence, the values available for input into the model are derived from expert opinion and require treating as such (Kuhnert *et al.* 2010; Marcot *et al.* 2006), this will have implications with the on-going validation and calibration of the models.

5.8.2 Model complexity- node and layer limitations

Throughout the design process we have endeavoured to meet best practice as defined through the literature on the topic, e.g. Landuyt *et al. (*2013) and Marcot *et al.* (2006). Recommendations were to limit the number of layers to five or less and keep the number of inputs to any node to a minimum (Marcot 2017). We reviewed the inclusion of every node in the conceptual models for relevance according to the overriding paradigm that the models must be expressed in terms of the ecosystem services that relate to them, avoiding spurious associations that would reduce model adequacy and robustness.

By conducting an analysis across all models, a reduced list of ecosystem services was derived, from the CICES lists (Table 5). The final list of ecosystem services were those which could be expressed in terms of preceding nodes, and for which a causal connection could be justified. Intermediate nodes between the biotic elements and the ecosystem services selected were permitted if they can be parameterised, (if not immediately then at least in theory), against a quantifiable metric. Bioturbation for instance can be reasonably estimated through the density of inhabited burrows of burrowing fauna; nutrient cycling can, in theory, be determined by measuring nutrient fluxes or their proxies, and sediment stability can be determined through assessment of its mobility or shear strength with appropriate instruments.

5.9 Limitations of Approach

Interpretation is straightforward for most pressures but becomes slightly problematic in two cases: Removal of Target species and Generic Contamination scenarios. Here the pressures map to multiple benchmarks depending on which species is considered the target species, or what specific contaminant is being introduced into the system. In either case the associated pressure benchmark will be determined by that choice and it would be difficult to justify modelling multiple contaminants, or species, on the same path. Our recommendation would be to set as many paths as contaminants to be modelled, or target species to be extracted, which then allows individual sensitivities to be set for each functional biological group. It is a simple task to add or subtract pathways through the graph according to the desired use. Similarly, it is simple to introduce additional nodes with their unique assessment of resistance through the mechanism of the input excel spreadsheet.

With the Gaussian distribution model there is also the possibility, though not currently implemented, to alter the level of an input pressure to represent a partial pressure situation. Discussions within the design team have considered this aspect, which is technically feasible though not universally applicable from an ecological point of view. A common argument advanced against providing this facility is that there is no underpinning evidence to support assessments of resistance, resilience and sensitivity along a dose/response gradient; in other words, we are unable to characterise a dose/response curve for any of these pressures. This holds for partial unit applications of pressure below, or indeed above, the benchmark on a population. However, the ability to alter the level of a pressure when in a spatial framework has a great deal more justification. In fact, it could almost be deemed necessary due to the patchiness of impact for many pressures in the spatial domain and the heterogeneous nature of species distributions within a habitat, not to mention habitat heterogeneity. For modelling purposes, the result would be interpreted as a mix of impacted and un-impacted parts of the population at the pressure benchmark. This is a future potential for these models and the format of the network allows for it without major structural changes. To extend the model application to a real-world situation involving a discrete area, we would strongly recommend implementing this feature.

5.10 BBN Summary

In summary, currently there is no spatial or temporal component to the developed BBNs. Rather, the models respond to a change in pressure state with a corresponding change in state across all nodes within the network as information flows through it. The model represents the un-quantified, abstracted properties of the biota leading to output processes that only have meaning in a relative sense by the time they link to ecosystem services (which themselves are notoriously hard to assign value to).

The models present changes in the conditional distributions for each child node in response to the application of a pressure (or combination of pressures). It is important to note that the models do not provide a mechanism for including events occurring after this such as recovery (or resilience to use its sensitivity assessment meaning). In the absence of any pressure the bio-assemblages reside at their default distribution values (mean = 0, SD = 1). Any differences apparent between functional groups at this stage are small and arise from the representativeness of the distribution which is gained from a Monte Carlo sampling of the underlying default normal distribution. Each distribution is sampled 10,000 times, providing a balance between processing time and consistency between comparable distributions. A higher sampling rate will further reduce differences between node distributions of functional groups and their underlying distribution.

6 Conclusions

The current project has examined how both the pressures resulting from human activities and their impacts on ecosystem services could be incorporated to improve BBN MESO models. To support the decision making we reviewed evidence for human activity-pressure links and their impacts on the marine environment. A further review of the relationship (if any) between each model component to relevant intermediate and final ecosystem services was also undertaken. The evidence reviews had two key aims, 1) identify the relationships between existing and proposed model nodes and links, and, 2) to seek to parameterise these and assess the confidence in the modelled relationship.

To our knowledge this is the first attempt to link ecosystem components in terms of the grouping of functionally similar species into functional groups (bio-assemblages), with their capacity to provide ecosystem services. This takes the association between the ecological component down to a much more detailed level in terms of the functions being undertaken by the bio-assemblage that support the intermediate and final ecosystem services. The strength of the linkages is supported by information relating to the life history and biological traits of the species and thus a much more robust approach than expert opinion at the scale of biotopes, comprised of many different functional groups.

6.1 Pressure review

The review has identified how key pressures impact the marine ecosystem through impacts on the ecological components identified in the CEMs. The evidence base was mostly developed for physical damage pressures resulting from fishing activities and aggregate dredging. Within the CEMs, the ecological component habitats and sessile benthos are best studied, with more information available for larger species, that are of particular interest either for conservation or commercial purposes. The evidence base on which to assess sensitivity was much less for species that are small and of no commercial value.

There was little evidence for impacts on local hydrological conditions and it is likely that there is little impact on these from the studied activities.

6.2 Ecosystem Service review

The review identified how ecosystem services delivery is provided, mediated and supported by ecosystem components and processes identified in the CEMs. The level of contribution and the confidence in these linkages was described. A lack of specific data on ecological thresholds for individual ecosystem components that contribute to ecosystem services delivery and the response of these to pressures was identified.

The literature review has shown that there is a large variability in the understanding of ecosystem services depending on the type (e.g. cultural) or level of exploitation (e.g. there is less information relating to newly developed uses of the marine environment, such as the use of genetic resources) being considered.

6.3 Models

The application of BBNs to the modelling of ecosystem services is not uncommon and there are many good examples that provided guidance and inspiration during the design phase of this project (e.g. Gonzalez-Redin *et al.* 2016; Haines-Young 2011; Landuyt *et al.* 2013; Pérez-Miñana 2016). This project established a Bayesian Belief network (BBN) framework capable of evaluating parameters, causal connections and relationships between independent, functional components of an ecosystem. It then set them in the context of the provision of ecosystem services that are, by definition, anthropocentric. This framework model will provide a context for further research and indicate where effort would best be focused to advance both the model and our understanding of relationships between the ecosystem components and their contingent services.

With current parameterisation the models can consistently indicate the direction of the state change (increase, decrease or no change) in response to a pressure(s) combination with reasonable fidelity. This limitation is based upon the inclusion of parameterisation from single source expert judgement. The appropriate way to proceed from this point is to conduct a formal peer review process of the structure and parameterisation choices made and to then formulate a synthesis of these opinions that will inform the final values to drive the response of each pathway through the model.

The models are generic and are based on generic links between ecosystem structure and function and the potential to provide ecosystem services. They cannot account for spatial and temporal variation in ecosystem services.

Another limitation for this study is that the aspect of ecosystem services modelled is potential delivery of a service, based on likely changes in ecosystem processes and functions in response to impacts from pressures resulting from human activities. The study does not consider the demand for an ecosystem service or its realisation, or the value of ecosystem service benefits and goods that result from services.

Other limitations include no specific weighting for the relative importance of a functional group or bio-assemblage within a habitat. For example, subtidal sand includes macroalgae, but these are extremely sparse and in terms of biomass would comprise a small component, whereas all bio-assemblages are equally weighted in the model, and not weighted according to their relative abundance, density or biomass.

6.4 Model validation and sensitivity testing

In order to be able to provide a traceable, proportionate, response the models require calibration against multiple exemplary data sets. This is out of scope of the current project, which has instead sought to specify the attributes of such a data set for future application. The best option for the continuing development of these models is to submit them to real world case studies comprising sufficiently detailed data to fully parameterise the network as they stand or as they might reasonably be modified to fit.

Working within the limitations of the project, it has been possible to begin to assess the sensitivity of the model in order to fully understand its adequacy to describe the scenarios under review and to ensure that uncertainty is dealt with appropriately. This will be achieved by determining if there are any systemic differences that could indicate failings in the model structures. This will give us an understanding of the propagation of uncertainty maintaining the least complicated, fit for purpose model possible based on the information we have been given.

To aid this process we have begun to develop versions of the model that differ structurally from each other and include different pathways for pressures and responses to propagate through the models. These are based on groupings that exist within the CEM provided to us at the beginning of the project (for instance Alexander *et al.* 2016) and represent justifiable complications of our original model design, which had been pared down to a minimal functional structure to keep the weight of evidence for edges and nodes as high as possible. By relaxing these constraints, a little we can formulate different structures that allow their inter- and intra- model measures of effectiveness and efficiency to be assessed using measure of divergence and information loss.

This means that currently the models represent a completed Alpha-level model (Marcot *et al.* 2006) that is still in need of peer review to validate the current parameterisation. When appropriate data sets are available, the models will require calibration. Our aims for the remainder of this project are to refine further the parameterisation of nodes and provide a description of what attributes an appropriate calibration data set must have as an aid to either designing the field data collection exercise necessary, or to compare against any existing data sets to assess for suitability.

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Appendix 1 Objective 1: List of assessed pressures

Table 16. Final List of Pressures assessed and rationale for exclusion of other pressures within the framework.

Pressure theme	Included in Model	Proforma Number
Physical change (reversible)	Habitat structure changes - removal of substratum (extraction)	1
	Abrasion/disturbance of the substratum on the surface of the seabed	2
	Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	3
	Smothering and siltation changes (depth of vertical sediment overburden) (light and heavy)	4
	Changes in suspended solids (water clarity)	5
Physical loss (permanent change)	Physical loss (to land or freshwater habitat) (include in later spatial models)	N/A
	Physical change (to another seabed type)	6
	Physical change to another sediment type	7
Biological Pressures	Removal of non-target species	N/A
	Removal of target species	N/A
Hydrological changes (inshore/local)	Wave exposure changes - local	N/A
High-level review - Assessed through a generic reduction in environmental condition scenario		
Pollution and other chemical changes	Hydrocarbon & PAH contamination.	NR
	Synthetic compound contamination	NR
	Transition elements & organo-metal (e.g. TBT) contamination.	NR
	Introduction of other substances (solid, liquid or gas)	NR
	De-oxygenation	NR
	Nutrient enrichment	NR
	Organic enrichment	NR
Biological Pressures	Introduction or spread of non-indigenous species (INIS)	NR
Not relevant to offshore habitats		
	Emergence regime changes - local, including tidal level change considerations	
	Water flow (tidal current) changes - local, including sediment transport considerations	
	Salinity changes – local, increase	
	Salinity changes – local, decrease	
	Temperature changes – local, increase	
	Temperature changes- local, decrease	
Not relevant to ecological components within CEMs		
Physical pressure (other)	Barrier to species movement	
	Electromagnetic changes	
	Death or injury by collision	
	Introduction of light or shading	
	Litter	
	Noise changes	
	Visual disturbance	
	Vibration	
Not included - evidence base too limited		
Physical pressure (other)	Radionuclide contamination	
Biological Pressures	Genetic modification & translocation of indigenous species	
	Introduction of microbial pathogens	

Appendix 2 Objective 1: List of Reviewed Activities

Table 17. List of activities reviewed.

Activity	Description
Exploratory drilling	Exploratory drilling to evaluate commercial viability of geological features.
Gas storage operations (carbon capture and natural gas storage)	The deposition/ injection of natural gases or carbon into identified submarine storage sites.
Offshore wind: Construction (if relevant see also Cables)	Seabed preparation (possibly dredging), cuttings/dredging disposal, piling, drilling, anchoring, mooring, vessel movement, vessel discharges/emissions, installation of scour protection, introduction of artificial substrate. This also includes the presence of the turbine structures and foundations – large offshore windfarms will be constructed over many years and the pressures due to the presence of turbines will therefore be present during the construction phase. For cabling please see and include the separate activity.
Offshore wind: Decommissioning (if relevant see also Cables)	Vessel movement, vessel discharges, use of jack-up barges, removal of structures/scour protection and associated habitat, use of explosives, cutting, drilling, excavation of seabed close to foundations. This also includes the presence of the turbine structures and foundations – large offshore windfarms may be decommissioned over long time scales and the pressures due to the presence of turbines will therefore be present during the decommissioning phase. For cabling please see and include the separate activity.
Offshore wind: Operation and maintenance (if relevant see also Cables)	Regular vessel movement, vessel discharges, rotor sweep, lighting, presence of turbine and foundation structures. Also includes use of jack-up barges for maintenance and deposition of additional scour protection. For cabling please see and include the separate activity.
Oil and gas infrastructure: Construction (see also piling and pipelines)	This activity includes the construction of oil and gas infrastructure in the marine environment including, but not limited to, the installation of rock dump to stabilise jack-up rigs, cementing, introduction of other protection material such as concrete mattresses, matting and gravel, the temporary installation of infrastructure (such as pipelines, debris baskets *etc*.), drilling wells and plugging and abandonment, accidental effects, vessel movement, installation of subsea infrastructure *etc*.
Oil and gas infrastructure: Decommissioning	The plugging and abandonment of wells, removal of structures and associated habitat, use of explosives, cutting, drilling. Disturbance of drill risings and cuttings. Placement of rock to cover remaining structures or to provide base for jack-up legs. Includes operation by supporting vessels, vessel discharges, use of ROVs, lifting and jack-up rigs.
Oil and gas infrastructure: Operation and maintenance	Production/operation, with routine supply, return of wastes to shore, power generation, chemical use, produced water, and re-injection of reservoirs.
Aggregate dredging	The regular excavation of aggregates (a mixture of sand and/or gravel sediments) for use generally in construction and beach recharge. Seabed sediments are removed through trailing suction or static grab dredgers. Dredging is associated with numerous vessel movements, sediment alteration and resuspension. NOTE: This assessment does NOT include aggregate dredging in the intertidal. Please contact Natural England for advice on intertidal aggregate dredging.
Dredge and spoil disposal	The disposal of dredged materials originating from the seabed.
Demersal seine netting	Activity includes demersal anchor/Danish seines and Scottish seines, as well as beach seines that come into contact with the seabed.

Demersal trawling	Activity includes beam trawls, demersal otter trawls, demersal pair trawls (excludes electronic pulse fishing).
Diving (incl. removal of living resources)	Collection of target species by divers, snorkelers. Includes recreational diving.
Dredging (shellfish)	Activity includes dredging (non-hydraulic) for shellfish e.g. scallops, oysters, mussels (including seed), clams & cockles. Includes dredges towed by vessels and tractors.
Electrofishing	Activity that includes trawls that interact with the seabed and use electric fields to fish for shellfish e.g. razor shells, shrimp or fish e.g. plaice, sole.
Hydraulic dredging	Activity includes hydraulic/suction dredging e.g. clams, cockles, razor shells.
Traps	Activity includes pots, creels & traps, as well as fyke nets and other similar gear.
Pipelines	Installation, maintenance and removal of pipeline including operations by supporting vessels.
Power cable: Decommissioning	Cables sometimes need to be retrieved or accessed for repairs or maintenance and are then reburied or protected. Additional cable protection can also be added where cable becomes unburied. Other specific pressures can also arise from power cable operation such as local temperature changes and electromagnetic field emission. The activity includes possible localised changes in physical environment as well as hydrodynamic changes through exposed cable/structures on the seabed, as well as vessel movement and anchoring during the operation.
Power cable: Laying, burial and protection	Methods and ways of laying cables vary depending on the water depth and the diameter of the cable. Submarine power cables have a diameter between 70 and up to 450mm. Cables can be laid either directly on the seabed, covered with material for protection or buried. The method used will depend on the area, the economic/ operational risk or environmental impacts. Protection is afforded in hazardous areas to avoid cable damage, i.e. where interaction with other activities is possible or likely. The most common method of protection is cable burial. This is usually done by seabed trench excavation through ploughing and hydraulic jetting. However, cables might be laid on the surface of the seabed if the area is unsuitable for burial (e.g. exposed rock or rocky outcrops). Cable protection is added in some cases when protection is needed due to the risk of damage. This can be done through rock placement on the seabed over the cable, mattressing, the addition of split pipe, concrete shells, *etc*. The activity includes seabed preparation activities (e.g. preparatory dredging, pre-lay grapnel runs, boulder removal, *etc*.), vessel movements and anchoring within the footprint.
Power cable: Operation and maintenance	Cables sometimes need to be retrieved or accessed for repairs or maintenance and are then reburied or protected. Additional cable protection can also be added where cable becomes unburied. Other specific pressures can also arise from power cable operation such as local temperature changes and electromagnetic field emission. The activity includes possible localised changes in physical environment as well as hydrodynamic changes through exposed cable/structures on the seabed, as well as vessel movement and anchoring during the operation.
Telecommunication cable: Decommissioning	When a cable is no longer needed or in use the general rule is the complete removal. However, this is often not feasible or appropriate and alternative approaches exist. When removal is deemed appropriate, cables are retrieved through grabbing and raising. Cables are also frequently disconnected and left buried to minimise environmental effects when the safe use of the seabed for other users is possible. The decommissioning process includes vessel movements and anchoring along the cable route.
Telecommunication cable: Laying, burial and protection	Methods and ways of laying cables vary depending on the water depth and the use of seabed by other activities. Telecommunication cables have a diameter similar to that of a garden hose, 17-22mm or up to 50mm when protective wire armour is used. Cables can be laid either directly on

	the seabed, covered with material for protection or buried. The method used will depend on the area, the economic/ operational risk or environmental impacts. Protection is afforded in hazardous areas to avoid cable damage, i.e. where interaction with other activities is possible/likely. The most common method of protection is cable burial. Seabed trench excavation through ploughing and hydraulic jetting is frequently used for burial. However, cables might be laid on the surface of the seabed if the area is unsuitable for burial (e.g. exposed rock or rocky outcrops). Cable protection is occasionally added where there is a reasonable risk of damage. This is usually done by rock placement on the seabed over the cable. The activity includes vessel movements and anchoring within the footprint.
Telecommunication cable: Operation and maintenance	Cables sometimes need to be retrieved or accessed for repairs or maintenance and are then reburied or protected. Additional cable protection can also be added where cable becomes unburied. The activity also includes vessel movement and anchoring during the operation.
Exploratory drilling	Exploratory drilling to evaluate commercial viability of geological features.
Physical Sampling (see also fishing and Extraction of genetic resources e.g. bioprospecting)	Sampling of the seabed, foreshore (intertidal) and/or water column *in situ* using a variety of marine survey techniques.
Vessel anchorages	A place where a vessel is anchored. Covers activity of anchoring generically and use of allocated anchorage areas where ships are permitted to anchor inside and outside harbours/ports. Including consideration of vessels when anchoring, anchored or weighing anchor.
Vessel moorings	Use of vessel moorings and activity associated with mooring of vessel. Mooring is a temporary or permanent structure to which a vessel may be secured e.g. swing mooring, trot, fore and aft mooring, pile mooring. Includes consideration of vessels when mooring or moored.

Appendix 3 Objective 3: Ecosystem Service Framework

Table 18. Intermediate ecosystem service and definitions from Potts *et al.* (2014). Those in grey were not considered to be relevant to sublittoral habitats or were relevant but it was not possible to consistently parameterise these within the BBN model. Information was reviewed for all relevant services, but evidence was prioritised where it supports the modelling work. Unless otherwise stated the definitions are taken from Fletcher *et al.* 2011.

Ecosystem Service			Definition	Overlap with CICES v5.1	Proforma
Intermediate services	Supporting services	Primary production	Production of plant biomass	Supports CICES 1.1.5.1 and 1.1.5.2	1
		Larval/ Gamete supply	Transport of larvae and gametes.	Equivalent to 2.2.2.1	2
		Nutrient cycling	Cycle by which a chemical element or molecule moves through both biotic and abiotic compartments of ecosystems.	Supports all provisioning services through biomass.	3
		Water cycling	Regulation of the timing of water flow through an ecosystem.		Not relevant
		Formation of species habitats	Formation of the physical properties of the habitats necessary for the survival of species.	Overlaps with CICES 2.2.2	4
		Formation of physical barriers	Formation of structures that attenuate (or block) the energy of water flow.	Equivalent to CICES 2.1.1	5
		Formation of seascape	Formation of seascapes that are attractive to people.		Not relevant
	Regulating services	Biological control	Interactions resulting in reduced abundance of species that are pests, diseases or invasive species.	CICES 2.2.3.1 Pest and disease control	6
		Natural hazard regulation	Regulating the formation of physical barriers service	CICES 2.1.1.1 CICES 2.1.1.2	5
		Regulation of water & sediment quality	Regulation of the removal of contaminants from water flowing through an ecosystem.	CICES 2.2.1.1 CICES 2.2.1.2	13
		Carbon sequestration	Large, slowly changing store of carbon (Armstrong *et al.* 2012). For instance, marine organisms act as a reserve or sink for carbon in living tissue and by facilitating burial of carbon in seabed sediments (Armstrong *et al.* 2012).	CICES 2.2.6.1 Regulation of chemical composition of atmosphere and oceans	7

Table 19. Final ecosystem services from CICES (v5.1; Haines-Young & Potschin 2018). The finer class divisions are not shown for brevity. The pressure proformas are provided in Appendix 10.

Section	Division	CICES Code	Group	Proforma
Ecosystem services included in MESO BBN and prioritised in literature review				
Provisioning (Biotic)	Biomass	1.1.5.	Wild plants (terrestrial and aquatic) for nutrition, materials or energy.	10
	Biomass	1.1.6.2	Wild animals (terrestrial and aquatic) for nutrition, materials or energy.	11
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	2.1.1.	Mediation of wastes or toxic substances of anthropogenic origin by living processes.	13
	Regulation of physical, chemical, biological conditions	2.2.1.	Regulation of baseline flows and extreme events.	5
	Regulation of physical, chemical, biological conditions	2.2.2	Lifecycle maintenance, habitat and gene pool protection.	2 and 4
	Regulation of physical, chemical, biological conditions	2.2.6.1	Atmospheric composition and conditions.	7
	Non-aqueous natural abiotic ecosystem outputs	4.3.1.	Mineral substances used for nutrition, materials or energy.	14
	Transformation of biochemical or physical inputs to ecosystems	5.1.1 (5.1.1.3 only)	Mediation of waste, toxics and other nuisances by non-living processes.	13
	Regulation of physical, chemical, biological conditions	5.2.1.	Regulation of baseline flows and extreme events.	5
Ecosystem services not included in MESO BBN but supported and reviewed with well-developed evidence base				
Provisioning (Biotic)	Biomass	1.1.2.	Cultivated aquatic plants for nutrition, materials or energy.	8
	Biomass	1.1.4.1	Reared aquatic animals for nutrition, materials or energy	9

Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	3.1.1.1 (not 3.1.1.2)	Physical and experiential interactions with natural environment	15
Ecosystem services - with significant evidence gaps, reviewed but low priority				
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	1.2.1.	Genetic material from plants, algae or fungi	12
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	2.2.3.	Pest and disease control	7
	Regulation of physical, chemical, biological conditions	2.2.4.2	Regulation of soil quality- **Considered to be captured in waste remediation service.**	13
	Regulation of physical, chemical, biological conditions	2.2.5.2	Water conditions **Considered to be captured in waste remediation service.**	13
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	3.1.2.	Intellectual and representative interactions with natural environment	15 (3.1.2.1 not included)
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	3.2.2.	Spiritual, symbolic and other interactions with natural environment; Other biotic characteristics that have a non-use value.	NR
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	5.2.2.1	Maintenance of physical, chemical, abiotic conditions	7
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	6.2.2.1	Other abiotic characteristics that have a non-use value	17
	Direct, *in situ* and outdoor interactions with natural physical systems that depend on presence in the environmental setting	6.1.1.1	Physical and experiential interactions with natural abiotic components of the environment	15

Ecosystem services not subject to review and with no evidence proformas due to evidence gaps and difficulty differentiating components that deliver the service				
Cultural (Abiotic)	Direct, *in situ* and outdoor interactions with natural physical systems that depend on presence in the environmental setting	6.1.2.1	Intellectual and representative interactions with abiotic components of the natural environment	NR
	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	6.2.1.1	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	NR
Ecosystem services not relevant to marine sublittoral habitats within study and excluded from review				
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	2.1.2	Mediation of nuisances of anthropogenic origin	
Provisioning (Abiotic)	Water	4.2.1	Surface water used for nutrition, materials or energy	
	Water	4.2.2	Ground water for used for nutrition, materials or energy	
	Non-aqueous natural abiotic ecosystem outputs	4.3.2.1	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	5.1.2.1	Mediation of nuisances of anthropogenic origin	

Appendix 4 Literature Review

First sift for each habitat type

Table 20. Date, database and searches and number of hits for each broad habitat type.

Date	Keywords	Name of database	No. of hits
27/11/18	Marine sand	Web of science	8,351
28/11/18	Marine sand	ASFA	66,347
	Marine sand – 2000-2019	ASFA	49,056
04/12/18	Subtidal mud	Web of science	402
	Subtidal mud	Science Direct	6,226
	Subtidal mud	ASFA	2,566
05/12/18	Subtidal rock	Web of Science	638
	Subtidal rock	Science Direct	5,715
18/12/18	Subtidal rock	ASFA	3,475
	Marine coarse sediment	Web of Science	2,109
08/01/19	Subtidal coarse sediment	Science Direct	5,100
	Subtidal coarse sediment	ASFA	1,750
09/01/19	Marine mixed sediment	Web of Science	4,483

Additional ecosystem service literature review

Table 21. Ecosystem Service literature review of Google scholar for ecosystem services delivered by sedimentary habitats. Ecosystem service papers were also identified in the first and second literature sifts see above.

Date	Keywords	Name of database	No. of hits
28/11/2018	Circalittoral sand function	Google Scholar	1,070
28/11/2018	Circalittoral sand process	Google Scholar	1,550
28/11/2018	Circalittoral sand service	Google Scholar	760
28/11/2018	Dissolved oxygen AND offshore sand habitat	Google Scholar	25,200
29/11/2018	Infralittoral sand process	Google Scholar	3,550
29/11/2018	Infralittoral sand service	Google Scholar	1,640
30/11/2018	Sand benthic ecological process	Google Scholar	124,000
30/11/2018	Marine offshore ecosystem service	Google Scholar	111,000
30/11/2018	Sublittoral sand ecosystem service	Google Scholar	5,790
30/11/2018	Secondary production benthic habitat	Google Scholar	88,900
30/11/2018	Marine sublittoral function	Google Scholar	20,400
30/11/2018	Marine sublittoral process	Google Scholar	24,000
15/01/2019	Marine Secondary Production	Google Scholar	2, 490,000
15/01/2019	Secondary production benthic macrofauna	Google Scholar	18,400
15/01/2019	Secondary production functional groups marine	Google Scholar	1,030,000

15/01/2019	Marine bioturbation	Google Scholar	62,100
15/01/2019	Bioturbation functional groups	Google Scholar	26,800
15/01/2019	Waste remediation marine	Google Scholar	52
15/01/2019	Marine nursery habitat	Google Scholar	82,900
15/01/2019	Marine biodeposition	Google Scholar	5,770
15/01/2019	Macrofauna biodeposition groups	Google Scholar	1,680

Table 22. Ecosystem service review for reef habitats.

Date	Keywords	Name of database	No of hits
15/01/19	Subtidal rock function	Google Scholar	720
15/01/19	Subtidal rock process	Google Scholar	698
15/01/19	Subtidal rock service	Google Scholar	341
15/01/19	Sublittoral rock function	Google Scholar	195
15/01/19	Sublittoral rock process	Google Scholar	201
17/01/19	Sublittoral rock service	Google Scholar	135
	Marine rock ecosystem service		
25/01/19	*Alaria esculenta* uses	Google Scholar	2780
25/01/19	*Alaria esculenta* habitat	Google Scholar	1740
25/01/19	*Alaria esculenta* value	Google Scholar	2300
25/01/19	*Laminaria ochroleuca* value	Google Scholar	1050
25/01/19	*Laminaria ochroleuca* uses	Google Scholar	1250
25/01/19	*Laminaria ochroleuca* habitat	Google Scholar	816
28/01/19	*Cancer pagurus* habitat rock	Google Scholar	1070
29/01/19	*Echinus esculentus* collection UK	Google Scholar	1070
29/01/19	Wave attenuation kelp	Google Scholar	5640
29/01/19	Wave attenuation mussel	Google Scholar	5300
29/01/19	*Ophiothrix fragilis* value	Google Scholar	1540
08/02/19	*Mytilus* services subtidal	Google Scholar	6640
08/02/19	*Mytilus* ecosystem services	Google Scholar	21200
11/02/19	Primary production rate algae red brown green	Google Scholar	122,000
11/02/19	Primary production rate macroalgae red brown green review	Google Scholar	15,300
11/02/19	Primary production rate macroalgae red brown green review	Google Scholar	14,900
14/02/19	*Anemonia viridis* ecosystem service	Google Scholar	56
14/02/19	*Metridium senile* ecosystem service	Google Scholar	35
28/03/19	ecosystem service recreational diving	Google Scholar	27000
28/03/19	ecosystem service recreational diving UK	Google Scholar	19000
28/03/19	ecosystem service SCUBA	Google Scholar	16000
29/03/19	seagrass marine tourism UK	Google Scholar	9000
29/03/19	diving marine tourism UK	Google Scholar	24000
29/03/19	UK marine genetic resources	Google Scholar	465000(!)
29/03/19	UK “marine genetic resources”	Google Scholar	787

Additional Pressure and Conservation objective attribute Review

Table 23. Pressures and conservation objective attribute literature review- Search Terms.

Date	Keywords	Name of database	No. of hits
27-28/11/2018	Seabed, abrasion, impacts	Google Scholar	5,560
28/11/2018	Seabed, disturbance,	Google Scholar	34,700
28/11/2018	Sublittoral, disturbance,	Google Scholar	15,400
29/11/2018	Trawling, sublittoral,	Google Scholar	6,330
29/11/2018	Dredging, sublittoral,	Google Scholar	8,510
29/11/2018	Smothering, sublittoral	Google Scholar	1,330
29/11/2018	Seabed, substratum, abrasion	Google Scholar	1,430
29/11/2018	Disturbance/abrasion	Google Scholar	27
29/11/2018	Aggregate extraction, marine, (2010+)	Google Scholar	18,100
29/11/2018	Marine, infrastructure	Google Scholar	144,000
30/11/2018	Siltation, marine, (2016+)	Google Scholar	4,360
28/11/2018	Seabed, abrasion	Google Scholar	7,640
30/11/2018	Marine cables	Google Scholar	133,000
30/11/2018	Marine pipelines *	Google Scholar	97,600
30/11/2018	Anchoring, mooring (2016+)	Google Scholar	3,240
30/11/2018	Anchoring, mooring, sublittoral (2016+)	Google Scholar	64
2/12/2018	Seabed abrasion	Natural England	213
2/12/2018	Seabed disturbance	Natural England	305
2/12/2018	Sublittoral disturbance	Natural England	145
2/12/2018	Trawling sublittoral	Natural England	131
2/12/2018	Dredging sublittoral	Natural England	131
2/12/2018	Smothering sublittoral	Natural England	67
2/12/2018	Aggregate extraction, impacts	Natural England	382
2/12/2018	Pipelines, cables	Natural England	60
2/12/2018	No clear way to search publications on website, looked through list of marine publications and added to library based on title		
2/12/2018	Seabed abrasion	JNCC	387
2/12/2018	Seabed disturbance	JNCC	1067
2/12/2018	Sublittoral disturbance	JNCC	767
2/12/2018	Trawling sublittoral	JNCC	527
2/12/2018	Dredging sublittoral	JNCC	416
2/12/2018	Smothering sublittoral	JNCC	217
2/12/2018	Aggregate extraction, impacts	JNCC	698
2/12/2018	Pipelines, cables	JNCC	236
2/12/2018	Seabed abrasion	SNH	46
2/12/2018	Seabed disturbance	SNH	145
2/12/2018	Sublittoral disturbance	SNH	110
2/12/2018	Trawling sublittoral	SNH	11
2/12/2018	Dredging sublittoral	SNH	11
2/12/2018	Smothering sublittoral	SNH	11
2/12/2018	Aggregate extraction, impacts	SNH	323
2/12/2018	Pipelines, cables	SNH	2
2/12/2018	Seabed abrasion	DEFRA	8
2/12/2018	Seabed disturbance	DEFRA	19
2/12/2018	Sublittoral disturbance	DEFRA	13
2/12/2018	Trawling sublittoral	DEFRA	5
2/12/2018	Dredging sublittoral	DEFRA	7
2/12/2018	Smothering sublittoral	DEFRA	1
2/12/2018	Aggregate extraction, impacts	DEFRA	341
2/12/2018	Pipelines, cables	DEFRA	9

Appendix 5 Sensitivity assessment methodology

Sensitivity assessment

The sensitivity assessment methods used by the sources for this project (Tillin *et al.* 2014; Tillin & Hull 2012, 2013; and the MarESA methodology) involve the following stages:

A. Defining the key elements of the feature to be assessed (in terms of life history, and ecology of the key and characterising species).

B. Assessing feature resistance (tolerance) to a defined intensity of pressure (the benchmark).

C. Assessing the resilience (recovery) of the feature to a defined intensity of pressure (the benchmark).

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

E. Assess level of confidence in the sensitivity assessment.

F. Written audit trail.

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

B and C) Assessing feature resistance (tolerance) and resilience to a defined intensity of pressure (the benchmark)
To develop each sensitivity assessment, the resistance and resilience of the key elements are assessed against the pressure benchmark using the available evidence. The benchmarks are designed to provide a 'standard' level of pressure against which to assess sensitivity.

The assessment scales used for resistance (tolerance) and resilience (recovery) are given in Tables 22 and 23 and respectively.

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

Table 24. Assessment scale for resistance (tolerance) to a defined intensity of pressure. These scales were used for all three sensitivity assessment methods used within this project.

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

Table 25. Assessment scale for resilience (recovery) (MarESA and Ecological group work).

Recovery Category	Description
Low	Full recovery 6+ years
Medium	Full recovery within 3-5 years
High	Full recovery within ≤ 2 years
Very High	Full recovery within 6 months

Table 26. Assessment scale for resilience (recovery) used for the Marine Institute work (Tillin & Hull 2010).

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

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

The resistance and resilience scores can be combined, as follows, to give an overall sensitivity score as shown in Table 28.

Table 27. Combining resistance and resilience scores to categorise sensitivity.

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

Table 28. Overall sensitivity - Marine Institute (MarESA sensitivity assessment equivalent in brackets) where different.

		Resistance			
		None (severe decline)	**Low (25-75% decline)**	**Medium (≤25% decline)**	**High (no effects)**
Recovery	**Low (6+ years)**	Very High (Assess on recovery information)	High (Assess on recovery information)	Low (Medium)	Not Sensitive (Low)
	Medium (3-5 years)	High (medium)	Medium (Medium)	Low -(Medium)	Not Sensitive (Low)
	High (≤2 years)	Medium (medium)	Medium (Low)	Low (low)	Not Sensitive (=NS)
	Very High (6 months)	Low (medium)	Low (low)	Low (low)	Not Sensitive

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

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

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

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

Appendix 6 Pressure correspondence between sensitivity assessments used in the pressure review

Key to table:

Green	Assessment at same pressure benchmark and directly equivalent
Amber	Some differences in benchmark, apply with caution and consider differences and implication for sensitivity
Red	Benchmarks different or no benchmark. Evidence may be applicable, but sensitivity assessment will need to be re-thought.

	Pressure	MARESA Benchmark	JNCC Ecological Groups (Tillin & Tyler–Walters 2014)	Marine Institute
	Wave exposure changes - local	A change in nearshore significant wave height >3% but <5% for one year	Yes	No equivalent
Physical damage (Reversible Change)	Changes in suspended solids (water clarity)	A change in one rank on the WFD (Water Framework Directive) scale, e.g. from clear to intermediate for one year.	Yes	Changes in turbidity suspended sediments
	Habitat structure changes - removal of substratum (extraction)	Extraction of substratum to 30cm (where substratum includes sediments and soft rocks but excludes hard bedrock)	Yes	Extraction
	Abrasion/disturbance of the substrate on the surface of the seabed	Damage to seabed surface features (species and habitats)	Yes	Surface disturbance Trampling by foot Trampling by vehicle
	Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	Damage to sub-surface seabed.	Yes	Shallow disturbance Deep disturbance
	Smothering and siltation changes (depth of vertical sediment overburden)	'Light' deposition of up to 5cm of fine material added to the seabed in a single, discrete event	No equivalent	Siltation Smothering pressure refers to coarse sediments/other material
		'Heavy' deposition of up to 30cm of fine material added to the seabed in a single discrete event	Yes	See above

Physical loss (Permanent Change)	Physical change (to another seabed type)	Change in 1 Folk class (based on UK SeaMap simplified classification).	Yes	Changes to sediment-increased coarseness- not at benchmark Changes to sediment composition- increased fines-not at benchmark
		Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa.	No equivalent	No equivalent
	Physical loss (to land or freshwater habitat)	Permanent loss of existing saline habitat within site	Yes	No equivalent
	Removal of non-target species	Removal of features or incidental non-targeted catch (by-catch) through targeted fishery, shellfishery or harvesting at a commercial or recreational scale.	Yes- but rationale different	Yes- but rationale different
	Removal of target species	Benthic species and habitats: removal of species targeted by fishery, shellfishery or harvesting at a commercial or recreational scale.	Yes- but rationale different	Yes- but rationale different

Appendix 7 Sensitivity assessment sources used to assess sensitivity for bio-assemblages within each broad habitat type

Table 29. Sand biotopes identified in the CEM matrix and checked against MarESA sensitivities.

Biotope Sources	MarESA
A5.14 - Circalittoral coarse sediment	
A5.141 - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebble	*Pomatoceros triqueter*
A5.23 - Infralittoral fine sand	
A5.231 - Infralittoral mobile clean sand with sparse fauna	*Nephtys cirrosa, Eurydice pulchra, Bathyporeis elegans*
A5.232 - *Sertularia cupressina* and *Hydrallmania falcata* on tide-swept sublittoral sand with cobbles or pebbles	*Sertularia cupressina, Hydrallmania falcata*
A5.233 - *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand	*Nephtys cirrosa, Bathyporeia spp.*
A5.234 - Semi-permanent tube-building amphipods and polychaetes in sublittoral sand	*Polydora ciliata, Spiophanes bombyx, Corophium and Ampelisca spp*
A5.24 - Infralittoral muddy sand	
A5.241 - *Echinocardium cordatum* and *Ensis* spp. in lower shore and shallow sublittoral slightly muddy fine sand	*Echinocardium cordatum, Ensis ensis*
A5.242 - *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand	*Tellina fabula*
A5.243 - *Arenicola marina* in infralittoral fine sand or muddy sand	*Arenicola marina*
A5.244 - *Spisula subtruncata* and *Nephtys hombergii* in shallow muddy sand	*Spisula subtruncata- information gap*
A5.25 - Circalittoral fine sand	
A5.251 - *Echinocyamus pusillus*, *Ophelia borealis* and *Abra prismatica* in circalittoral fine sand	*Ecinocyamus pusillus*
A5.252 - Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand	*Abra spp, polychaetes.*
A5.26 - Circalittoral muddy sand	
A5.261 - *Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment	*Abra alba, Nucula nitidosa*
A5.262 - *Amphiura brachiata* with *Astropecten irregularis* and other echinoderms in muddy sand	*Acrocnida brachiata, Astropectedn irregularis, Owenia fusiformis*
Additional Biotopes checked	
A4.1343 *Flustra foliacea* and colonial ascidians on tide-swept exposed circalittoral mixed substrata	*Flustra foliacea*
A4.213 *Urticina felina* and sand-tolerant fauna on sand-scoured or covered circalittoral rock	*Urticina felina*
A5.136 Cumaceans and Chaetozone setosa in infralittoral gravelly sand	*Chaetozone setosa*
A5.231. Infralittoral mobile clean sand with sparse fauna.	*Bathyporeia spp.*
A5.441 *Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment	*Cerianthus lloydii*
A5.5213 *Laminaria saccharina* and filamentous red algae on infralittoral sand	*Sacharrina latissima*

Table 30. Coarse sediment biotopes identified in the CEM matrix and checked against MarESA sensitivities.

Biotope Sources	MarESA
A5.13: Infralittoral coarse sediment	
A5.131: Sparse fauna on highly mobile sublittoral shingle (cobbles and pebbles)	No species assessed
A5.132: *Halcampa chrysanthellum* and *Edwardsia timida* on sublittoral clean stone gravel	*Halcampa chrysanthellum*
A5.133: *Moerella spp.* with venerid bivalves in infralittoral gravelly sand	*Moerella (Tellina pygmaea), Dosinia lupinus, Timoclea ovata*
A5.134: *Hesionura elongata* and *Microphthalmus similis* with other interstitial polychaetes in infralittoral mobile coarse sand	No relevant species
A5.135: *Glycera lapidum* in impoverished infralittoral mobile gravel and sand	*Glycera lapidum*
A5.136: Cumaceans and *Chaetozone setosa* in infralittoral gravelly sand	*Chaetozone setosa*
A5.137: Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand	*Lanice conchilega*
A5.14: Circalittoral coarse sediment	
A5.141: *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles	*Pomatoceros triqueter, Balanus crenatus*
A5.142: *Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel	*Mediomastus fragilis, Lumbrineris*
A5.143: *Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand	*Protodorvillea kefersteini*
A5.144: *Neopentadactyla mixta* in circalittoral shell gravel or coarse sand	*Neopentadactyla mixta*
A5.145: *Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel	*Branchiostoma lanceolatum*
Additional Biotopes	
A5.611: *Sabellaria spinulosa* on stable circalittoral mixed sediment	*Sabellaria spinulosa*

Table 31. Mixed sediment biotopes identified in the CEM matrix and checked against MarESA sensitivities.

Biotope Sources	MarESA
A5.43 Infralittoral mixed sediments	
A5.431 - *Crepidula fornicata* with ascidians and anemones on infralittoral coarse mixed sediment	*Crepidula fornicata*
A5.432 - *Sabella pavonina* with sponges and anemones on infralittoral mixed sediment	*Sabella pavonina*
A5.433 - *Venerupis senegalensis*, *Amphipholis squamata* and *Apseudes latreilli* in infralittoral mixed sediment	*Venerupis senegalensis; Amphipholis squamata*
A5.434 - *Limaria hians* beds in tide-swept sublittoral muddy mixed sediment	*Limaria hians*
A5.435 - *Ostrea edulis* beds on shallow sublittoral muddy mixed sediment	*Ostrea edulis*
A5.44 Circalittoral mixed sediments	
A5.441 - *Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment	*Cerianthus lloydii*
A5.442 - Sparse *Modiolus modiolus*, dense *Cerianthus lloydii* and burrowing holothurians on sheltered circalittoral stones and mixed sediment	*Modiolus modiolus*
A5.443 - *Mysella bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment	*Thyasira flexuosa*
A5.444 - *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment	
A5.445 - *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment	*Ophiothrix fragilis*

Additional biotopes	
A4.252 *Halichondria bowerbanki, Eudendrium arbusculum* and *Eucratea loricata* on reduced salinity tide-swept circalittoral mixed substrata	*Halichondria bowerbanki*

Table 32. Mud sediment biotopes identified in the CEM matrix and checked against MarESA sensitivities.

Biotope Sources	**MarESA**
A5.33 - Infralittoral sandy mud	
A5.331 - *Nephtys hombergii* and *Macoma balthica* in infralittoral sandy mud	*Nephtys hombergii, Macoma balthica*
A5.332 - *Sagartiogeton undatus* and *Ascidiella aspersa* on infralittoral sandy mud	*Sagartiogeton undatus*
A5.333 - *Mysella bidentata* and *Abra spp*. in infralittoral sandy mud	*Kurtiella bidentata, Abra spp.*
A5.334 - *Melinna palmata* with *Magelona* spp. and *Thyasira* spp. in infralittoral sandy mud	*Melinna palmata, Abra nitida, Magelona spp.*
A5.335 - *Ampelisca* spp., *Photis longicaudata* and other tube-building amphipods and polychaetes in infralittoral sandy mud	
A5.336 - *Capitella capitata* in enriched sublittoral muddy sediments	*Capitella capitata*
A5.34 - Infralittoral fine mud	
A5.341 - *Cerastoderma edule* with *Abra nitida* in infralittoral mud	*Cerastoderma edule*
A5.342 - *Arenicola marina* in infralittoral mud	*See Sand Table*
A5.343 - *Philine aperta* and *Virgularia mirabilis* in soft stable infralittoral mud	*Virgularia mirabilis*
A5.344 - *Ocnus planci* aggregations on sheltered sublittoral muddy sediment	*Ocnus planci*
A5.35 - Circalittoral sandy mud	
A5.351 - *Amphiura filiformis*, *Mysella bidentata* and *Abra nitida* in circalittoral sandy mud	*Amphiura filiformis*
A5.352 - *Thyasira* spp. and *Nuculoma tenuis* in circalittoral sandy mud	*Nuculoma tenuis*
A5.353 - *Amphiura filiformis* and *Nuculoma tenuis* in circalittoral and offshore sandy mud	
A5.354 - Virgularia mirabilis and *Ophiura spp.* with *Pecten maximus* on circalittoral sandy or shelly mud	*Pecten maximus*
A5.355 - *Lagis koreni* and *Phaxas pellucidus* in circalittoral sandy mud	*Lagis koreni*
A5.36 - Circalittoral fine mud	
A5.361 - Seapens and burrowing megafauna in circalittoral fine mud	*Calocaris macandrae, Nephrops norvegicus, Callianassa subterranea*
A5.362 - Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud	*Maxmuelleria lankesteri; Calocaris macandrae, Nephrops norvegicus, Callianassa subterranea*
A5.363 - *Brissopsis lyrifera* and *Amphiura chiajei* in circalittoral mud	*Brissopsis lyrifera*
Additional biotopes	
A5.322 - *Aphelochaeta marioni* and *Tubificoides* spp. in variable salinity infralittoral mud	*Aphelochaeta marioni*
A2.322 - *Hediste diversicolor* in littoral mud.	*Hediste diversicolor*

Table 33. Rock biotopes identified in the CEM matrix and checked against MarESA sensitivities.

Biotope Sources	**MarESA**
A3.1: Atlantic and Mediterranean high energy infralittoral rock	
A3.11: Kelp with cushion fauna and/or foliose red seaweeds	
A3.111: *Alaria esculenta* on exposed sublittoral fringe bedrock	*Alaria esculenta*
A3.112: *Alaria esculenta* forest with dense anemones and crustose sponges on extremely exposed infralittoral bedrock	Not reviewed
A3.113: *Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed infralittoral rock	*Laminaria hyperborea*
A3.114: Sparse *Laminaria hyperborea* and dense *Paracentrotus lividus* on exposed infralittoral limestone	Not reviewed
A3.115: *Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock	Not reviewed
A3.116: Foliose red seaweeds on exposed lower infralittoral rock	*Delesseria sanguinea*
A3.117: *Laminaria hyperborea* and red seaweeds on exposed vertical rock	Not reviewed
A3.12: Sediment-affected or disturbed kelp and seaweed communities	
A3.121: *Saccorhiza polyschides* and other opportunistic kelps on disturbed upper infralittoral rock	
A3.122: *Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock	
A3.123: *Laminaria saccharina*, *Chorda filum* and dense red seaweeds on shallow unstable infralittoral boulders and cobbles	
A3.124: Dense *Desmarestia* spp. with filamentous red seaweeds on exposed infralittoral cobbles, pebbles and bedrock	*Desmarestia aculeata*
A3.125: Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	Not reviewed
A3.126: *Halidrys siliquosa* and mixed kelps on tide-swept infralittoral rock with coarse sediment	*Halidrys siliquosa*
A3.127: *Polyides rotundus*, *Ahnfeltia plicata* and *Chondrus crispus* on sand-covered infralittoral rock	*Polyides rotundus, Ahnfeltia plicata* and *Chondrus crispus*
A3.2: Atlantic and Mediterranean moderate energy infralittoral rock	
A3.21: Kelp and red seaweeds (moderate energy infralittoral rock)	
A3.211: *Laminaria digitata* on moderately exposed sublittoral fringe rock	
A3.212: *Laminaria hyperborea* on tide-swept, infralittoral rock	Not reviewed
A3.213: *Laminaria hyperborea* on tide-swept infralittoral mixed substrata	Not reviewed
A3.214: *Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock	Not reviewed
A3.215: Dense foliose red seaweeds on silty moderately exposed infralittoral rock	
A3.216: *Laminaria hyperborea* on moderately exposed vertical rock	Not reviewed
A3.217: *Hiatella arctica* and seaweeds on vertical limestone / chalk	
A3.22: Kelp and seaweed communities in tide-swept sheltered conditions	
A3.221: *Laminaria digitata*, ascidians and bryozoans on tide-swept sublittoral fringe rock	*Halichondria panicea*
A3.222: Mixed kelp with foliose red seaweeds, sponges and ascidians on sheltered tide-swept infralittoral rock	*Chondrus crispus*
A3.223: Mixed kelp and red seaweeds on infralittoral boulders, cobbles and gravel in tidal rapids	Not reviewed

A3.224: *Laminaria saccharina* with foliose red seaweeds and ascidians on sheltered tide-swept infralittoral rock	
A3.225: Filamentous red seaweeds, sponges and *Balanus crenatus* on tide-swept variable-salinity infralittoral rock	*Balanus crenatus*
A3.3: Atlantic and Mediterranean low energy infralittoral rock	
A3.31: Silted kelp on low energy infralittoral rock with full salinity	
A3.311: Mixed *Laminaria hyperborea and Laminaria ochroleuca* forest on moderately exposed or sheltered infralittoral rock	*Laminaria ochroleuca*
A3.312: Mixed *Laminaria hyperborea* and *Laminaria saccharina* on sheltered infralittoral rock	Not reviewed
A3.313: *Laminaria saccharina* on very sheltered infralittoral rock	
A3.314: Silted cape-form *Laminaria hyperborea* on very sheltered infralittoral rock	
A3.315: *Sargassum muticum* on shallow slightly tide-swept infralittoral mixed substrata	*Sargassum muticum*
A4.1: Atlantic and Mediterranean high energy circalittoral rock	
A4.11: Very tide-swept faunal communities on circalittoral rock	
A4.111: *Balanus crenatus* and *Tubularia indivisa* on extremely tide-swept circalittoral rock	Not reviewed
A4.112: *Tubularia indivisa* on tide-swept circalittoral rock	
A4.12: Sponge communities on deep circalittoral rock	
A4.121: *Phakellia ventilabrum* and axinellid sponges on deep, wave-exposed circalittoral rock	*Axinella dissimilis*
A4.13: Mixed faunal turf communities on circalittoral rock	
A4.131: Bryozoan turf and erect sponges on tide-swept circalittoral rock	*Bugula plumosa*
A4.132: *Corynactis viridis* and a mixed turf of crisiids, *Bugula spp.*, *Scrupocellaria spp.* and *Cellaria spp.* on moderately tide-swept exposed circalittoral rock	
A4.133: Mixed turf of hydroids and large ascidians with *Swiftia pallida* and *Caryophyllia smithii* on weakly tide-swept circalittoral rock	Not reviewed
A4.134: *Flustra foliacea* and colonial ascidians on tide-swept moderately wave-exposed circalittoral rock	*Flustra foliacea*
A4.135: Sparse sponges, *Nemertesia* spp., and *Alcyonidium diaphanum* on circalittoral mixed substrata	*Nemertesia spp.* and *Alcyonidium diaphanum*
A4.136: *Suberites spp.* with a mixed turf of crisiids and *Bugula spp*. on heavily silted moderately wave-exposed shallow circalittoral rock	*Suberites spp.*
A4.137: *Flustra foliacea* and *Haliclona oculata* with a rich faunal turf on tide-swept circalittoral mixed substrata	
A4.138: *Molgula manhattensis* with a hydroid and bryozoan turf on tide-swept moderately wave-exposed circalittoral rock	
A4.139: Sponges and anemones on vertical circalittoral bedrock	*Clavelina lepadiformis, Metridium senile* and *Holothuria forskali*
A4.2: Atlantic and Mediterranean moderate energy circalittoral rock	
A4.21: Echinoderms and crustose communities on circalittoral rock	
A4.211: *Caryophyllia smithii* and *Swiftia pallida* on circalittoral rock	*Swiftia pallida*
A4.212: *Caryophyllia smithii*, sponges and crustose communities on wave-exposed circalittoral rock	*Caryophyllia smithii*
A4.213: *Urticina felina* and sand-tolerant fauna on sand-scoured or covered circalittoral rock	*Urticina feline*
A4.214: Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock	

A4.215: *Alcyonium digitatum* and faunal crust communities on vertical circalittoral bedrock	*Alcyonium digitatum*
A4.23: Communities on soft circalittoral rock	
A4.231: Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay	*Pholas dactylus*
A4.232: *Polydora* sp. tubes on moderately exposed sublittoral soft rock	*Polydora*
A4.233*: Hiatella*-bored vertical sublittoral limestone rock	Not relevant
A4.241: *Mytilus edulis* beds with hydroids and ascidians on tide-swept exposed to moderately wave-exposed circalittoral rock	*Mytilus edulis*
A4.242: *Musculus discors* beds on moderately exposed circalittoral rock	
A4.3: Atlantic and Mediterranean low energy circalittoral rock	
A4.31: Brachiopod and ascidian communities on circalittoral rock	
A4.311: Solitary ascidians, including *Ascidia mentula* and *Ciona intestinalis*, on wave-sheltered circalittoral rock	*Ascidia mentula* and *Ciona intestinalis*
A4.312: Large solitary ascidians and erect sponges on wave-sheltered circalittoral rock	
A4.313: A*ntedon spp.,* solitary ascidians and fine hydroids on sheltered circalittoral rock	*Antedon bifida, Antedon petasus*
A4.314; *Neocrania anomala* and *Protanthea simplex* on sheltered circalittoral rock	*Novocrania anomala*
Additional biotopes	
A3.3134 Grazed *Laminaria saccharina* with *Echinus*, brittlestars and coralline crusts on sheltered infralittoral rock	*Echinus esculentus*
A1.444 *Audouinella purpurea* and *Cladophora rupestris* on upper to mid-shore cave walls.	*Cladophora rupestris*
A1.122 *Corallina officinalis* on exposed to moderately exposed lower eulittoral rock.	*Corallina officinalis*
A4.111 *Balanus crenatus* and *Tubularia indivisa* on extremely tide-swept circalittoral rock.	*Balanus crenatus*

Table 34. Species information obtained from Marine Institute reports (Tillin & Hull 2013a-e) used to assess sensitivity of bio-assemblages to pressures within this project.

Polychaetes	**Algae**	**Molluscs**
Lumbrineris latreilli	*Halydris siliquosa*	*Abra alba*
Magelona filiformis	*Laminaria digitata*	*Abra nitida*
Protodorvillea kefersteini	*Laminaria hyperborean*	*Cerastoderma edule*
Pholoe inornata	*Laminaria sacchaarina*	*Fabulina fabula*
Glycera alba	**Porifera**	*Macoma balthica*
Glycera lapidum	*Halichondria panicea*	*Mysella bidentata*
Hediste diversicolor	**Oligochaetes**	*Nucula turgida*
Nephtys cirrosa	*Tubificoides benedii*	*Nucula nitidosa*
Nephtys hombergii	*Tubificoides pseudogaster*	*Phaxas pellucidus*
Arenicola marina	**Amphipods**	*Thracia papyracea*
Capitella capitata	*Ampelisca brevicornis*	*Thyasira flexuosa*
Scoloplos armiger	*Ampelisca typica*	*Timoclea ovata*
Euclymene oerstedii	*Bathyporeia sp*	*Venerupis senegalensis*
Clymenura leiopygous	*Corophium volutator*	
Heteroclymene robusta	**Echinodermata**	
Owenia fusiformis	*Echinus esculentus*	
Pomatoceros lamarkii	**Cnidaria**	
Pomatoceros triquester	*Metridium senile*	

Prionospio	*Caryophyllia smithi*	
Prionospio fallax	*Alcyonium digitatum*	
Pygospio elegans		
Spio filicornis		
Spio martinensis		
Spiophanes bombyx		
Streblospio shrubsolii		
Melinna palmata		
Lanice conchilega		

Table 35. Ecological groups and representative species from previous JNCC work (Tillin & Tyler-Walters 2014) used to assess sensitivity of bio-assemblages to pressures within this project.

Ecological group	Key or characterising species assessed
1(a) Erect, longer-lived epifaunal species with some flexibility	*Virgularia mirabilis*
1(b) Erect, shorter lived epifaunal species.	*Obelia longissimi,* *Sertularia argentea*
	Nemertesia ramosa
1(c) Soft-bodied epifaunal species	*Alcyonium digitatum,* *Flustra foliacea,* *Ascidiella aspera,* *Styela gelatinosa,* *Urticina felina*
1(d) Small epifaunal species with hard or protected bodies.	*Balanus crenatus,* *Pomatoceros triqueter*
2 Temporary or permanently attached surface dwelling or shallowly buried larger bivalves.	*Pecten maximus,* *Modiolus modiolus*
3 Mobile predators and scavengers	*Asterias rubens,* *Astropecten irregularis, Pagurus bernhardus*
4 Infaunal very small to medium sized suspension and/or deposit feeding bivalves	*Abra alba (as Abra spp.),* *Abra prismatica (as Abra spp.),* *Phaxas pellucidus, Timoclea ovata,* *Thyasira flexuosa*
5. Small- medium suspension and/or deposit feeding polychaetes	*Ampharete falcata, Caulleriella zetlandica, Lanice conchilega, Polydora caulleryi, Scoloplos armiger*
6. Predatory polychaetes	*Glycera lapidum,* *Nephtys hombergii, Protodorvillea kefersteini*
7 Very small-small, short lived (<2 years) free-living species	*Bathyporeia elegans,* *Eudorellopsis Deformis, Iphinoe trispinosa*
8(a) Echinoderms – Subsurface dwelling echinoids	*Brissopsis lyrifera, Echinocyamus pusillus, Echinocardium cordatum*
8(b) Surface dwelling echinoids	*Echinus esculentus*
8(c) Free living interface suspension/deposit feeders: Ophiuroidea	*Ophiura albida,* *Amphiura filiformis, Ophicomina nigra,* *Ophiothrix fragilis*
8(d) Large burrowing Holothuroidea	*Neopentadactyla mixta*
9 Burrowing, hard bodied species	*Calocaris macandrae, Nephrops norvegicus*
10 Soft bodied species	*Branchiostoma lanceolatum,* *Cerianthus lloydii, Maxmuelleria lankesteri*

Appendix 8 Pressure proformas

Pressure proforma 1. Habitat structure changes - removal of substratum (extraction)

Proforma 1	**Habitat structure changes - removal of substratum (extraction)**					
ICG pressure description Unlike the "physical change" pressure type where there is a permanent change in sea bed type (e.g. sand to gravel, sediment to a hard artificial substrate) the "habitat structure change" pressure type relates to temporary and/or reversible change, e.g. from mineral extraction where a proportion of seabed sands or gravels are removed but a residual layer of seabed is similar to the pre-dredge structure and as such biological communities could re-colonise; navigation dredging to maintain channels where the silts or sands removed are replaced by non-anthropogenic mechanisms so the sediment typology is not changed.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs						
Extraction of substratum to 30cm (where substratum includes sediments and soft rocks but excludes hard bedrock).						
Links to other pressures						
This pressure may result in other pressures which are assessed separately; these include physical change to sediment type where the sediments uncovered are different to those removed or recovery results in a different sediment type through, for example, differences in flow regime or sediment supply (see Pressure proforma 7, physical change to another seabed type). Sediment disturbance may also lead to re-suspension of sediments (see Pressure proforma 5, change in suspended solids) with releases of contaminants to the water column (see Pressure proforma 10, Pollution) and subsequent sediment deposition (see siltation rate changes). Removal of fauna and changes to the structure of communities living on or close to the seabed in and around the extraction area can also occur (Removal of non-target species).						
Activities that contribute to this pressure						
	Pressure benchmark			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Category: Extraction (and disposal) of non-living resources						
Aggregate Dredging: In the UK, most aggregate dredging is carried out by trailer suction dredgers with a rear-facing pipe dragged along the seabed. Anchor or static dredging, where the vessel remains stationary over an area of spatially restricted or locally thick deposits, is less common as it is only possible where deposits allow (Hill *et al.* 2011). Most marine aggregate dredging in the UK is carried out by trailer suction dredging. This creates a series of longitudinal furrows, generally 2-3m wide and up to 50cm deep, as the drag head passes over the seabed. Direct impacts on the seabed are typically local, confined to dredge pits (static) (20m deep x 75m diameter), or tracks/furrows (trailer suction) (4-6m long x 0.1-5m wide x 0.3-0.5m deep) (Kenny & Rees 1994; Boyd *et al.* 2004; Rees 2006; LeBot *et al.* 2010; Hill *et al.* 2011). Dredging is usually undertaken for 1 to 14 hours annually (Frojan *et al.* 2001), with reports of a site being dredged for up to 25 years (Hill *et al.* 2011). Hill *et al.* (2011) report that 70% of total surface area sediment can be removed a depth of 0.3m, in furrows 1-2m wide. Recovery of furrows is apparent in areas of high natural disturbance (Bellew & Drabble 2004; Hill *et al.* 2011). Boyd *et al.* (2004), reported recovery of dredge tracks (0.3-0.5m deep) in 8 months, whereas Bellew and Drabble (2004) suggest a recovery time of 2-4 years. In		=		H		

less dynamic areas infilling may take longer in areas with more stable sediments tracks still visible 5 years after cessation of dredging (Cooper *et al.* 2005). Reported impacts on bio-assemblage vary according to habitat type and intensity and method of dredging (Hill *et al.* 2011; Emu 2004). Extraction of the sediment will remove epifauna and most infauna. Reduction in average number of species from 38 to 13. Substantial reduction in average number of individuals, from 591 per 0.25m-2 in 1992 to 34 immediately post dredging and biomass from 22.6g to 0.2g. Marked reduction in the abundance of the sea-squirt *Dendrodoa grossularia* and the barnacle *Balanus crenatus* immediately post dredging in dynamic environments, where opportunistic species are dominant even in undredged areas, effects may be less detectible and recovery rapid (EMU 2004). Recovery of physical sediment characteristics may take longer (see Pressure proforma 7). The topographic 'recovery' of furrows can occur through several processes. Furrows can become in-filled by sediments, by the deposition of small particles where dredging has altered local hydrodynamics or from screening products, particularly sand (Hill *et al.* 2011). Biological recovery is variable. Boyd *et al.* (2005) found that seven years after cessation of dredging, the macrofaunal assemblage found within a site of lower dredging intensity was not significantly different from the reference sites.						
Category: Transport						
Vessel anchorages and Vessel moorings. No evidence for this pressure.						
Category: Other man-made structures						
Cables and Pipelines: **Construction:** Construction of cables and pipelines includes trenching or ploughing the sediment for cable or pipeline installation and burial. Outflow pipes/outfalls are either buried or surface laid across coastal and seabed habitats. Where they are buried trench excavation into the sediment will be required (Ludwig 1988). **Operation and Maintenance:** Maintenance can include the exposure, reburial and repairing of cables and pipelines. **Decommissioning:** Varies depending on the scenario, can involve removal, cutting, or burial		=		H		
Category: Energy generation						
Offshore Windfarms: **Construction:** The construction stage of offshore windfarms depends on the scenario, but typically involves preparation of the seabed, drilling and pile driving, rock placement and cable laying, and scour protection placement, which can all impact the seafloor. **Operation and Maintenance:** Offshore windfarm can influence wave exposure changes. Krone *et al.* (2017) report that the seafloor around the tripods and the jackets can be significantly lowered down to more than 3m and 1m respectively, due to massive scouring processes. **Decommissioning:** This stage is dependent on the scenario but often involves rock placement, dredging, and the removal of structures.			>	H		
Oil and Gas **Construction:** Construction of an oil and gas platform involves a multitude of subsea operations including seabed trenching. There is limited literature detailing the length of the construction phase. **Operation and Maintenance:** Subsea operations involved in the operation and maintenance of an oil and gas platform include drilling and blasting.			>	H		

Decommissioning: Decommissioning of an oil and gas platform is scenario specific; subsea operations can include removal of cuttings, infrastructure, mattresses, and pipelines. The duration of pressure from decommissioning will be scenario specific; there is one study relating to a 15-year decommissioning programme for a 13-platform facility in the Norwegian North Sea (ConocoPhillips 1999; Ekins *et al.* 2006).							
Category: Extraction of living resources							
No evidence found from fishing or harvesting							
1. Regional to global drivers							
Evidence							
Climate	This pressure will not alter climate.						
Depth	**Aggregate Dredging**: In areas of high intensity trailer suction dredging, the seabed can be lowered by 2-3m, and up to 5m over a number of years (Desprez 2000; Tillin *et al.* 2011). **Fishing:** Watling *et al.* (2001) observed a loss of top few cm of the fine fraction of the upper sediment layers, shortly after scallop dredging. **Offshore Windfarms** **Operation and Maintenance:** Seafloor depth around tripods and jackets has been found to be lowered by over 3m and 1m respectively, as a result of scouring processes (Krone *et al.* 2017).				H		
Geology	**Aggregate Dredging:** Removal of sand from aggregate dredging (without screening) typically leads to a coarser sediment composition, when gravel deposits are exposed (LeBot *et al.* 2010; Hill *et al.* 2011). During gravel extraction sediments may become finer; a similar change in composition is also observed when screening is used, to return fine sediments back to the seabed (Hill *et al.* 2011). Infilling of the dredge furrows and pits by small particulate matter can also occur with reduced current velocity, leading to a decrease in sediment size (Hill *et al.* 2011).				H		
Propagule Supply	No direct impact but propagule supply from outside the impacted area could be affected by associated changes in water flow and wave exposure (see below).						L
Water Currents	**Aggregate Dredging:** Changes to topography as a result of substratum removal can lead to a change in bottom hydrography (Rees 2006; OSPAR 2009), with observations of a drop in current strength from creation of depressions in the seafloor (Desprez 2000).				H		
Wave Exposure	**Aggregate Dredging:** Evidence suggests that changes to wave exposure may be small and localised, with minimal changes in wave energy at the adjacent seabed or coastline (Brampton & Evans 1998; Houghton *et al.* 2011). Newell and Woodcock (2013) suggest that aggregate dredging on sand or gravel banks will result in lowered crest level, with potentially reduced wave dissipation across the feature.				H		
2. Water Column Processes							
Evidence							
Primary production	Not directly relevant but aggregate extraction, dredging and other types of sediment disturbance that result in habitat extraction can lead to increases in suspended sediment which can result in reduced light attenuation and reduced primary production (See changes in suspended sediment, Pressure Proforma 5). No evidence was found to assess changes in this ecological component.						L
Suspended Sediment	Aggregate extraction, dredging and other types of sediment disturbance can lead to increases in suspended sediment (See changes in suspended sediment, Pressure Proforma 5 for more details).				H		

Light Attenuation	Aggregate extraction, dredging and other types of sediment disturbance can lead to increases in suspended sediment which can result in reduced light attenuation. (See changes in suspended sediment, Pressure Proforma 5).	**H**		
Water Chemistry and temperature	**Dredging:** The potential impacts of re-suspension of sediments include the spreading of sediments and associated contaminants in the surroundings, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2009). See Changes in suspended sediments (Pressure Proforma 5).	**H**		
Dissolved oxygen	Not relevant to extraction but see changes in suspended sediment (Proforma 5).			
Sublittoral Sediment (topography)	**Aggregate Dredging:** Changes in topography from sediment extraction include the creation of furrows and dredge tracks in the sediment (Kenny & Rees 1994; Boyd *et al.* 2004; Cooper *et al.* 2005, 2007a, 2007b; Hill *et al.* 2011; Tillin *et al.* 2011), and deep pits when static suction dredging has been used (Newell & Woodcock 2013). Sediment instability associated with furrow infilling can also result from dredging and have negative impacts on biological communities (Hill *et al.* 2011). In areas of high intensity dredging with screening, creation of large sand waves can result; Hill *et al.* (2011) observed 10m high sand waves, 200x400m wide. However, when substratum extraction is undertaken without screening, the lowering of sandbanks can result, removing coastal protection (Tillin *et al.* 2011).	**H**		
	Cables and Pipelines **Construction:** Trenching for outflow pipes and cables can result in changes to seabed topography, with trenches 1.3m wide x 1.3m deep for offshore windfarm cables (Ludwig *et al.* 1998; Taormina *et al.* 2018).	**H**		
	Offshore Windfarms **Construction:** Loss of sublittoral habitat in the immediate area where turbines are placed (Sanders *et al.* 2017).	**H**		
	Oil and Gas **Construction:** During pipeline installation trenches are dug into the seabed, causing seabed disturbance up to 20m from the pipeline (Ivensen 2009). **Operation:** Upheaval bucking of pipelines, or the development of free spans below the pipeline can result in seabed disturbance (Ivensen 2009).		**M**	
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	No evidence but will be likely to be removed. Aggregate extraction will provide carrion as sediment plumes from aggregate extraction are rich in organic matter, most likely from fragments of dead or dying invertebrates (Newell *et al.* 1998).			**L**
Grazing and predation	Seabed mobility is a proxy for the extent to which the habitat is affected by natural physical disturbance. Abrasion may mobilise and move sediments (see sediment topography) but was not considered likely to directly alter natural seabed mobility. Although removal of organisms may alter seabed stability (see below).			**L**
Seabed Mobility	Seabed mobility is a proxy for the extent to which the habitat is affected by natural physical disturbance. Habitat extraction will remove organisms that may stabilise sediments. See seabed stability (below). Impacts on natural mobility by extraction are likely to depend on site specific geology and, more or less stable, underlying habitats may be exposed by extraction. Changes to topography and reductions in the depth of the seabed may have		M	

	an impact on the local hydrodynamic regime, disrupting local current strengths and altering patterns of sedimentation (Tillin *et al.* 2011). This may reduce or increase seabed mobility.			
Recruitment	May begin rapidly after removal. Recovery of many benthic invertebrate populations will depend on new juvenile recruits settling at the location in the form of larvae rather than the migration of adults. The settlement of many benthic species larvae has been demonstrated to be influenced by chemical cues from the same species or prey species or biofilms (Pawlik 1992; Rodriguez *et al.* 1993). By removing surficial deposits, the dredging process is likely to remove these cues inhibiting settlement rates within the dredging zone.			**L**
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets. The direct impact of sediment extraction on the benthic assemblage will be the removal of benthic organisms reducing the structure (abundance, biomass and diversity) of that habitat. Some individuals may survive entrainment and be returned to the sea in the outwash or during screening although heavily shelled species such as bivalves, snails and crabs are more likely to be retained within the hopper and therefore would be lost with the cargo. Newell *et al.* (1998) stated that removal of 0.5m depth of sediment is likely to eliminate benthos from the affected area. Some epifaunal and swimming species may be able to avoid this pressure. The extent of the impact is often closely related to the intensity of dredging both in space and in time. In areas of low intensity dredging, for example where 20% of the seabed is removed in shallow dredge tracks, abundance and biomass can be reduced by 70-80 % whilst species diversity may be reduced by 30%. When dredging intensity is higher, for example with repeated removal of sediment over a period of several days, reductions can be over 95% for abundance and biomass and almost 70% for diversity (Newell *et al.*1998).				
5. Output processes				
Evidence				
Biodeposition	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998). Reductions in particle size following aggregate removal will reduce attached, filter feeding epifauna which contribute to this process.		**M**	
Hydrodynamic flow	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Bioturbation	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Primary production	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Secondary production	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Sediment processing	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Habitat modification/ Bioengineering	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
Supply of propagules	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998).		**M**	
6. Local ecosystem functions				
Evidence				
Food resource	The sediment plumes resulting from aggregate extraction are rich in organic matter, most likely from fragments of dead or dying invertebrates (Newell *et al.* 1998) and attract mobile predators to feed in the dredge tracks. Other food sources in the longer term are likely to be depleted due to direct removal of biota and organic matter *etc*. in the extracted sediments.	H		
Nutrient cycling	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998). In extreme cases sediment infilling by fine sediments can lead to ‘anoxic’ or low oxygen conditions in the pits		**M**	

	and furrows (Newell *et al.* 1998). This will affect nutrient cycling pathways within sediments (see Ecosystem service proforma 3).			
Biogeochemical cycling	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998). In extreme cases sediment infilling by fine sediments can lead to 'anoxic' or low oxygen conditions in the pits and furrows (Newell *et al.* 1998). This will affect nutrient cycling within sediments and biogeochemistry (see Ecosystem service proforma 3).		**M**	
Sediment stability	There may be high levels of sediment instability associated with infilling processes, following aggregate dredging which prevent the establishment of mature faunal communities (Boyd *et al.* 2004; Cooper *et al.* 2005, cited from Hill *et al.* 2011). Alternatively, changes in water flow and infilling by fine sediments may result in more stable sediments.		**M**	
Habitat provision	Decline due to removal of all or most of the bio-assemblage (Newell *et al.* 1998). Aggregate extraction often shifts sediment composition from gravelly sand to sandy gravel reducing the availability of attachment sites for encrusting epifaunal species such as barnacles, ascidians, hydroids and bryozoans (Hill *et al.* 2011). Erect epifauna provide habitat.		**M**	
Microbial activity	Decline due to removal in surficial sediments.		**M**	
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	Decline. Few benthic invertebrates are able to escape entrainment from aggregate dredging and research shows that under the path of an aggregate extraction draghead there is a 30-70% reduction in species diversity, a 40-95% reduction in the number of individuals and a similar reduction in biomass of benthic communities (Newell *et al.* 1998).	**H**		
Biotope Stability	Unlikely to result from pressure (see sediment stability above).		**M**	
Export of Biodiversity	Decline due to removal of biota by habitat extraction.		**M**	
Export of Organic Matter	It is likely that high levels of fatal damage are suffered and sediment plumes from aggregate extraction are rich in organic matter, most likely from fragments of dead or dying invertebrates (Newell *et al.* 1998). Increased faunal diversity and abundance up to 2km from a dredged sand site has been observed, possibly as a result of release of organic matter by dredging activity and transportation of resources by the dredge plume (Newell *et al.* 2004).		**M**	
Knowledge Gaps				

Pressure proforma 2. Abrasion/disturbance of the substratum on the surface of the seabed

Pressure	**Abrasion/disturbance of the substratum on the surface of the seabed**					
ICG pressure description Physical disturbance or abrasion at the surface of the substratum in sedimentary or rocky habitats. The effects are relevant to epiflora and epifauna living on the surface of the substratum. In intertidal and sublittoral fringe habitats, surface abrasion is likely to result from recreational access and trampling (including climbing) by human or livestock, vehicular access, moorings (ropes, chains), activities that increase scour and grounding of vessels (deliberate or accidental). In the sublittoral, surface abrasion is likely to result from pots or creels, cables and chains associated with fixed gears and moorings, anchoring of recreational vessels, objects placed on the seabed such as the legs of jack-up barges, harvesting of seaweeds (e.g. kelps) or other intertidal species (trampling) or of epifaunal species (e.g. oysters). In sublittoral habitats, passing bottom gear (e.g. rock hopper gear) may also cause surface abrasion to epifaunal and epifloral communities, including epifaunal biogenic reef communities. Activities associated with surface abrasion can cover relatively large spatial areas (e.g. bottom trawls or bioprospecting) or be relatively localized activities (e.g. seaweed harvesting, recreation, potting, and aquaculture).						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs						
Damage to surface features (e.g. species and physical structures within the habitat)						
Activities that contribute to this pressure						
Category: Extraction (and disposal) of non-living resources	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Aggregate Dredging: Aggregate dredging is associated with the more severe physical damage sediment pressures of extraction of sediment (see Pressure proforma 1).						
Category: Transport						
Recreational and Commercial Anchoring: Movement of an anchor chain across the surface of the substratum leads to abrasion. The footprint of abrasion from anchoring is dependent on the length, size and weight of the chain deployed, and environmental conditions (Griffiths *et al.* 2017). The pressure duration is dependent on the scenario but is generally short term (<1 week) (Griffiths *et al.* 2017), there is little information on the duration of impact or recovery of the sites.		=		H		
Recreational and Commercial Mooring: Movement of a mooring chain across the surface of the substratum leads to abrasion. The pressure persists for the operational duration of the mooring. Chronic abrasion leads to discernible impacts within the abraded area with changes in sediment and infauna observed (Griffiths *et al.* 2017 and references therein). Observed mooring scars range from 3m^2 to 300m^2 with scar size influences depending on the size and structure of the mooring, and prevailing environmental conditions (Walker *et al.* 1989; Griffiths *et al.* 2017). Disturbance is localised, within and immediately around the anchor chain footprint (Keenan *et al.* 2012). Duration of mooring impacts generally last over 1 year (Latham *et al.*, in prep; Herbert *et al.* 2009), with impacts still apparent after 15 months (Herbert *et al.* 2009). There is limited literature detailing recovery of sites after mooring.			>	H		
Category: Extraction of living resources						
Fishing: A range of fishing gear types are used to capture fish and invertebrates. Abrasion may result from static traps and mobile gears; the area and severity of abrasion will be affected by the set-up and the magnitude of operations. Typically, footropes, tickler chains and bobbins from mobile gear will cause abrasion as will the placement		=		H		

and movement of static gear lines and anchors (see Polet *et al.* 2010, for a review of different gear types and operation).						
Category: Other man-made structures						
Cables and Pipelines **Construction:** Construction of cables and pipelines generally involves pre-operational 'sweeping' of the seafloor, that could lead to abrasion. Overall, the disturbance strip produced by the ploughshare and skids in direct contact with the seabed ranges from c.2m to c.8m wide depending on plough size. Pipelines are installed onto or into the seabed. This requires the movement of heavy machinery and vehicles across the surface of the surface of the seabed or coastal habitat (Ludwig 1988). **Operation and Maintenance:** Wave action may shift exposed cable (rock habitats), and can result in surface scraping and incisions in rock outcrops (Kogan *et al.* 2006) **Decommissioning:** Varies depending on the scenario, can involve removal, cutting, or burial. As a cable is pulled from the seabed it disturbs the sediments and associated benthic fauna (Carter *et al.* 2009).		=	>		M	
Category: Energy generation						
Offshore Windfarms **Construction:** The construction stage of offshore windfarms depends on the scenario, but typically involves more severe physical damage pressures than abrasion. **Operation and Maintenance:** Offshore windfarm operation does not tend to cause abrasion. **Decommissioning:** This stage is dependent on the scenario, but often involves more severe physical damage pressures than abrasion.						L
Oil and Gas Impacts on the seabed from oil and gas platforms are most evident during the construction and decommissioning phases. The impact footprint will depend on the size of the platform, but indirect impacts have been detected 1-2km from platforms (Cordes *et al.* 2016). **Construction:** Construction of oil and gas platforms involves a multitude of subsea operations, including seabed levelling, and structure placement. There is limited literature detailing the length of the construction phase. **Operation and Maintenance:** Subsea operations involved in the operation and maintenance of an oil and gas platform include drilling, blasting and flaring. The duration of pressure will be scenario specific, however offshore structures are designed for lifetimes of 25 years (Sadeghi, 2007). **Decommissioning:** Decommissioning of an oil and gas platform is scenario specific; subsea operations can include removal of cuttings, infrastructure, mattresses, and pipelines. The duration of pressure from decommissioning will be scenario specific; there is one study relating to a 15-year decommissioning programme for a 13-platform facility in the Norwegian North Sea (ConocoPhillips 1999; Ekins *et al.* 2006).		=	>		M	
Category: Research						
Physical Sampling: Physical sampling can refer to a multitude of activities, including dredging, grabs, coring and sediment profile imaging, some phases of these may involve abrasion. The pressure durations are typically short term, and the magnitude of impact dependant on the sampling technique. There is limited literature on the recovery from these pressures.		=		H		

1. Regional to global drivers				
Evidence				
Climate	This pressure will not alter climate.			
Depth	Abrasion of the surface is unlikely to alter depth beyond negligible amounts.	H		
Geology	Abrasion may lead to changes in sediment composition (see Pressure proforma 7)		**M**	
Propagule Supply	*Ex situ* propagule supply will not be altered by this pressure, but recruitment may be indirectly influenced by changes to sediment (see below). Abrasion can re-suspend organisms, Drillet *et al.* (2004) showed that copepod eggs are re-suspended in the water column following passage of an otter trawl providing them with the opportunity to hatch and recruit nauplii to the water column. However, egg viability was reduced by the passage of the gear components. Abrasion may therefore alter propagule supply to adjacent habitats.			**L**
Water Currents	This pressure will not alter water currents			**L**
Wave Exposure	This pressure will not alter wave exposure			**L**
2. Water Column Processes				
Evidence				
Primary production	Abrasion may alter suspended sediment and impact primary production. Abrasion and penetration of the seabed results in dissolved and particulate nutrient releases so that bottom trawling (and other activities) may trigger considerable productivity pulses, in addition to pulses from the natural seasonal cycle (Dounas *et al.* 2007). (see Pressure proforma 5 suspended sediment)		**M**	
Suspended Sediment	Abrasion may resuspend sediment (see proformas 5)	**H**		
Light Attenuation	Re-suspended sediment resulting from abrasion may reduce light penetration See Proforma 5 (suspended sediment).	**H**		
Water Chemistry and temperature	**Oil and Gas Decommissioning:** During decommissioning, if cutting piles are left *in situ* and covered, the area can become exposed to abrasion and penetration pressures from trawling, which can re-suspend contaminants within the cutting piles (Ekins *et al.* 2006). **Dredging:** The potential impacts of re-suspension of sediments include the spreading of sediments and associated contaminants in the surroundings, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients, resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2009). See Changes in suspended sediments (Pressure Proforma 5).	**H**		
Dissolved oxygen	No evidence.			
Sublittoral Sediment (topography)	**Recreational and Commercial Mooring:** Herbert *et al.* (2009) and Latham *et al.* (in prep) report no obvious changes in topography in areas impacted by mooring buoys for over a year.	**H**		
	Recreational and Commercial Anchoring: Abrasion can occur on the seafloor when the anchor drags across the substratum in response to tidal changes or wind, the anchor may also move sideways 'crabbing' the sediment, abrasion can also occur during the retrieval of the anchor (Abdullah, 2008; Griffiths *et al.* 2017).	**H**		
	Operation and maintenance: Cable strumming from nearshore wave action can cause incisions in rocky outcrops (Kogan *et al.* 2006; Taormina *et al.* 2018). On rare occasions cables need reburial or repair, such activities can cause abrasion on the seabed (Berr 2008).	**H**		

	Oil and Gas **Decommissioning:** The process of decommissioning an offshore windfarm can vary and is dependent on the scenario. Activities undertaken during this stage that cause abrasion on the seafloor include: - Covering contaminated drill cuttings - Leaving structures in place, and monitoring of site (impacts are minimal) - Removal of cuttings with a suction dredge - Removal of footings with cuttings left in place - Covering pipelines with rocks (Ekins *et al.* 2006).		**M**	
	Physical Sampling: Techniques that cause abrasion on the seabed include: - Subtidal Biotope ID (using divers), deployment of a weighted shot-line, with small anchor - Towed camera sledge (transects typically 100-250m)		**M**	
	Fishing Demersal mobile gears will impact a larger area through abrasion than static gears such as pots and creels where there is limited interaction with the substratum. Fishing with mobile demersal gears on sediment results in the replacement of a landscape with widespread, small-scale, low-relief topographic features (ripples and mounds) with a rather smoother landscape, interspersed with higher relief, but less frequent features caused by the ploughing of trawl doors (Kaiser *et al.* 2002). Dredging on rocky reefs damages epifauna including bryozoans, hydroids, soft corals and sponges, but that the damage was incremental, increasing with the number of dredge tows performed (Boulcott & Howell 2011). Observations of lobster and crab pots being hauled from rocky substrates in southern England, revealed that the habitats and their communities appeared relatively unaffected by potting. The results suggest that four weeks of reasonably intense fishing did not have immediate detrimental effects on the abundance of the species selected for study, although some individual ross coral colonies (*Pentapora foliacea*) were damaged. Very few signs of impact on epifaunal species were observed at any of the sites. There was evidence of some detachment of ascidians and sponges and damage to large individuals of the ross coral, *Pentapora foliacea*. However, as it was not clear if this was as a direct result of the hauling of pots carried out in the experiments it was not quantified. The pink sea fan *Eunicella verrucosa* colonies on East Tennants reef were frequently seen to bend under the weight of pots then spring back once the pots had passed.	**H**		
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	Otter trawling: Watling *et al.* (2001) recorded, lowered food quality of the sediment (as measured by microbial populations, enzyme hydrolysable amino acids, and chlorophyll-*a*), microbial assemblage structure returned to expected ranges within a few months of the experiment. Abrasion may change the level of particulate organic matter in the water column by resuspending organic matter from the substratum (Pusceddu *et al.* 2005). This change will be temporary.		**M**	
Grazing and predation	Abrasion may affect this process by removing grazers and predators and their food. The vulnerability of epifauna to this pressure is likely to be greater than infauna. Grazing is most relevant to rock habitats characterised by algae. Mobile scavengers and predators will benefit from the opportunity to feed on exposed, damaged and dead individuals following this pressure (Caddy 1973), variable responses have been observed with		**M**	

	increases in mobile scavengers in some habitats and not others (Ramsay *et al.* 1998).			
Seabed Mobility	Seabed mobility is a proxy for the extent to which the habitat is affected by natural physical disturbance. Abrasion may mobilise and move sediments (see sediment topography) but was not considered likely to directly alter natural seabed mobility. Removal of organisms may alter seabed stability (see below).			**L**
Recruitment	Removal of epifauna and complex habitats has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels (Howarth *et al.* 2014). Studies at three sites in the Gulf of Maine (off Swans Island, Jeffreys Bank, and Stellwagen Bank) showed that mobile fishing gear altered the physical structure. Reductions in habitat complexity may lead to increased predation on juveniles of harvested species and ultimately recruitment to the harvestable stock (Auster *et al.* 1996). Physical abrasion from mobile fishing gears can damage the quality of spawning and nursery grounds through physical damage to the sedimentary habitat. Changes in the condition of spawning and nursery grounds in response to abrasion are not clear and it is unlikely that consistent relationships apply to different habitat types (eftec 2014 and references therein).		**M**	
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets.				
5. Output processes				
Evidence				
Biodeposition	This process is supported by suspension feeding epifauna and epifaunal bivalves that capture suspended particles and produce faeces and pseudofaeces. The loss or reduction of these functional groups will reduce the level of this process.		**M**	
Bioengineering	Abrasion can damage and remove structures that protrude above the sediment such as tubes and mounds and can damage and remove epifauna that also provide habitat complexity. Organisms may be able to repair damage, but this process will decline where the biota that support it are removed, e.g. algal canopies and biogenic reefs (Auster *et al.* 1996; Auster *et al.* 1999).	**H**		
Hydrodynamic flow	Abrasion is likely to detach attached macroalgae and epifauna that alter hydrodynamic flow No direct evidence was found to assess this change.		**M**	
Bioturbation	Bioturbators that irrigate tubes and burrows and that are close to the surface may be damaged or killed. However, deeper burrowing organisms are likely to remain and support this service.		**M**	
Primary production	Abrasion is likely to detach attached macroalgae and re-suspend or bury microphytobenthos that produce this service. No direct evidence was found to assess this change.		**M**	
Secondary production	Abrasion will alter secondary production; the level will depend on bio-assemblage impacts. As a general rule, filter feeders have higher secondary production rates (Cusson & Bourget 2005). Epifaunal filter feeders are likely to be impacted by abrasion with larger filter feeders more vulnerable than smaller, chronic abrasion can result in habitats becoming dominated by scavengers, predators and deposit feeders (Tillin *et al.* 2006), which typically have lower secondary production rates (Cusson & Bourget 2005)		**M**	
Sediment processing	Abrasion may enhance sediment processing as burrowing, deposit-feeding infauna are more likely to survive abrasion (Tillin *et al.* 2006).		**M**	
Habitat Provision	Fishing activity (e.g., trawls, dredges) reduces habitat complexity by smoothing bedforms (e.g., sand waves and ripples), removing emergent epifauna (e.g., sponges, worm tubes, amphipod tubes,	**H**		

	mussels, hydroids, and anthozoans) and species that produce structures such as pits and burrows (e.g. crabs and fishes) (Auster *et al.* 1999).			
Supply of propagules	The damage inflicted upon nursery habitats by fishing gears (removal of epifauna and complex habitats) has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels (Howarth *et al.* 2014). Abrasion can re-suspend organisms; Drillet *et al.* (2004) showed that copepod eggs are re-suspended in the water column following passage of an otter trawl providing them with the opportunity to hatch and recruit nauplii to the water column. However, egg viability was reduced by the passage of the gear components. Quantifying impacts on this process and impacts on recruitment in the habitat and adjacent habitats is difficult to quantify.		**M**	
6. Local ecosystem functions				
Evidence				
Food Resources	Removal and damage to biota by abrasion result in increased availability of carrion to scavengers, while removal of macroalgae will reduce provision of food to grazers. Following otter trawling, Watling *et al.* (2001) recorded lowered food quality of the sediment (as measured by microbial populations, enzyme hydrolysable amino acids, and chlorophyll-*a*), microbial assemblage structure returned to expected ranges within a few months of the experiment. Abrasion at medium intensities may increase the availability of small polychaetes that support plaice, thus enhancing yields. Biomass of prey decreases at higher trawling intensities (Hiddink *et al.* 2008).	**H**		
Habitat Provision	Fishing with demersal gears results in the replacement of a landscape with widespread, small-scale, low-relief topographic features (ripples and mounds) with a rather smoother landscape, interspersed with higher relief, but less frequent features caused by the ploughing of trawl doors (Kaiser *et al.* 2002). Reduction in habitat complexity resulting from abrasion will alter habitat provision to species. Removal of surficial features is likely to favour flatfish such as Dover sole that are chemosensory over visual predators, such as dabs and plaice that feed on mobile fauna associated with a low level of habitat complexity (Kaiser *et al.* 1999). Removal of epifauna and complex habitats has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels (Howarth *et al.* 2014).	**H**		
Microbial Activity Enhancement	Otter trawling: Watling *et al.* (2001) recorded, lowered food quality of the sediment (as measured by microbial populations, enzyme hydrolysable amino acids, and chlorophyll-*a*), microbial assemblage structure returned to expected ranges within a few months of the experiment.		**M**	
Nutrient Cycling	Epifaunal filter feeders are particularly vulnerable to abrasion altering nutrient cycling. Filter feeding organisms capture organic matter from the water column and re-deposit this either as faeces or pseudofaeces on or within sediments. This organic matter can then be remineralised (broken down to inorganic components) by microbes.		**M**	
Biogeochemical cycling	Alterations to bio-assemblage and functional diversity (feeding and bioturbation groups) will change the pathways and rates of biogeochemical cycling. Changes in macrobenthos due to intensive trawling disturbance could cause large fluctuations in		**M**	

	benthic chemical fluxes and storage by the removal of bioturbators (Duplisea *et al.* 2001).			
Population Control	The damage inflicted upon nursery habitats by fishing gears (removal of epifauna and complex habitats) has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels. It is likely that recruitment across a range of species is affected.		**M**	
Sediment Stability	Sediment stability is likely to decline where abrasion enhances the predominance of deposit feeders that increase erodability of sediments. The removal of biogenic habitat and the loss of biodepositors that enhance sediment stability will result in changes to sediment stability that may be mitigated or increased by changes in sediment composition e.g. winnowing of fine sediments or exposure of more stable substratum.		**M**	
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	Unlikely to result from pressure, loss of macroalgae, epifauna and biogenic habitat complexity resulting from abrasion reduces species richness and removes the habitat provision for associated species that enhances biodiversity.		**M**	
Biotope Stability	Abrasion, particularly repeated abrasion that alters community structure will impact biotope stability by altering the community composition. Examples include the loss of erect epifauna and replacement by smaller- abrasion tolerant species and infauna (Tillin *et al.* 2006).		**M**	
Export of Biodiversity	Abrasion, particularly repeated abrasion that alters community structure will impact the export of organic matter through changes in bio-assemblage		**M**	
Export of Organic Matter	Abrasion, particularly repeated abrasion that alters community structure will impact the export of organic matter through changes in primary and secondary production and nutrient cycling (see above).		**M**	
Carbon sequestration	Abrasion will reduce carbon storage in organisms through reductions in secondary production and nutrient cycling (see above). Sediment disturbance and re-suspension will release stored carbon with sediments.		**M**	
Knowledge Gaps				

Pressure proforma 3. Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion

Proforma 3	**Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion**					
ICG pressure description The disturbance of sediments where there is limited or no loss of substrate from the system. This pressure is associated with activities such as anchoring, taking of sediment/geological cores, cone penetration tests, cable burial (ploughing or jetting), propeller wash from vessels, certain fishing activities, e.g. scallop dredging, beam trawling. Agitation dredging, where sediments are deliberately disturbed by and by gravity & hydraulic dredging where sediments are deliberately disturbed and moved by currents could also be associated with this pressure type. Compression of sediments, e.g. from the legs of a jack-up barge could also fit into this pressure type. Abrasion relates to the damage of the seabed surface layers (typically up to 50cm depth). Activities associated with abrasion can cover relatively large spatial areas and include: fishing with towed demersal trawls (fish & shellfish); bioprospecting such as harvesting of biogenic features such as maerl beds where, after extraction, conditions for recolonisation remain suitable or relatively localised activities including seaweed harvesting, recreation, potting, aquaculture. A change from gravel to silt substrate would adversely affect herring spawning grounds.						
Links to other pressures.						
Sediment disturbance may also lead to the re-suspension of solids (see changes in suspended solids) and subsequent deposition which can result in changes to the substratum type.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs.						
Damage to sub-surface features (e.g. species and physical structures within the habitat).						
Activities that contribute to this pressure						
Category: Transport	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**>**	**=**	**<**	**H**	**M**	**L**
Category: Extraction (and disposal) of non-living resources						
Aggregate Dredging: No evidence for this pressure (see Pressure proforma 1)						
Category: Transport						
Recreational and Commercial Anchoring: Recreational and Commercial Anchoring: during anchor setting, penetration into the substratum can occur, disturbing sediments within its footprint. A poorly set anchor may drag though the sediment with vessel movement; penetration may also occur during anchor retrieval (Tillin *et al.* 2017). Commercial anchors can penetrate to depths up to 9.2m in mud and silt, and 2.9m in sand (Griffiths *et al.* 2017). and create furrows with a maximum width of 5m, ridges and accumulations of disturbed sediment (Fader & Miller 1990; Keenan *et al.* 2012). A commercial 1t anchor accidentally dragged through a coral reef habitat created a scar 128m x 3m wide (Rogers & Garrison 2001). The pressure duration is dependent on the scenario but is generally short term (<1 week) (Griffiths *et al.* 2017), however there is little information on the duration of impact. Recovery of soft sediment topography after recreational anchoring has been observed after 6 months (Backhurst & Cole 2000), however no recovery of the coral reef was observed 10 years after anchor penetration (Rogers & Garrison 2001).		**=**		**H**		
Category: Other man-made structures						
Cables and Pipelines **Construction:** Pre-operational sweeping on the seafloor by a ship towed grapnel penetrates between 0.5 and 1m into soft sediment (Carter *et al.* 2009). **Construction:** Ploughing for cable laying abrades the seabed and can leave a ploughed strip c.0.3m wide, the skids that support the plough		=			M	

can also leave a footprint on the seabed in soft substrates (Carter *et al.* 2009). **Operation and Maintenance:** Sediment penetration occurs during cable reburial or uncovering for repair (Merck and Wasserthal, 2009). **Decommissioning:** Varies depending on the scenario, can involve removal, cutting, or burial.						
Category: Energy generation						
Oil and Gas Impacts on the seabed from oil and gas platforms are most evident during the construction and decommissioning phases. The impact footprint will depend on the size of the platform, but indirect impacts have been detected 1-2km from platforms (Cordes *et al.* 2016). **Construction:** Construction of an oil and gas platform involves a multitude of subsea operations, including seabed levelling, trenching, jetting, structure placement, and rock dumps. There is limited literature detailing the length of the construction phase. **Operation and Maintenance:** Subsea operations involved in the operation and maintenance of an oil and gas platform include drilling and blasting. The duration of pressure will be scenario specific, however offshore structures are designed for lifetimes of 25 years (Sadeghi 2007). **Decommissioning:** Decommissioning of an oil and gas platform is scenario specific; subsea operations can include removal of cuttings, infrastructure, mattresses, and pipelines. The duration of pressure from decommissioning will be scenario specific; there is one study relating to a 15-year decommissioning programme for a 13-platform facility in the Norwegian North Sea (ConocoPhillips 1999; Ekins *et al.* 2006).		**=**		**H**		
Category: Research						
Physical Sampling: Physical sampling can refer to a multitude of activities, including dredging, grabs, coring and sediment profile imaging. The pressure durations are typically short term, and the magnitude of impact dependant on the sampling technique. There is limited literature on the recovery from these pressures. **Physical Sampling:** Techniques that cause penetration to the seabed include: - Sediment profile imaging- camera penetrates the sediment 2/3 the height of the face plate.		**=**			**M**	
Category: Extraction of living resources						
A review of demersal gear fishing studies by Hiddink *et al.* (2017) found the following penetration depths and impacts: • Otter trawls had the smallest impact, removing on average 6% of organisms per trawl pass and penetrating on average 2.4cm into the sediment. • beam trawls remove on average 14% of organisms per trawl pass and penetrate on average 2.7cm into the sediment. • towed dredges remove on average 20% of organisms per trawl pass and penetrate on average 5.5cm into • hydraulic dredges had the largest impact, removing on average 41% of organisms per pass and penetrating 16.1cm into sediment.		**=**			**M**	
1. Regional to global drivers						
Evidence						
Climate	This pressure will not alter climate.					
Depth	**Beam trawling**: Depth changes resulting from fishing activities will be minor. Depth differences of the seabed bathymetry, between inside and outside the trawl path, after a single beam trawl passage is 8.8mm with a maximum depth difference of 28.5mm (Depestele *et al.* 2016).			H		

Geology	**Recreational and Commercial Mooring:** Contrasting evidence on the impacts of recreational moorings on sediments, with observations of no obvious changes to the sediment composition (Latham *et al.* in prep), and reports of sediments favouring greater prominence of larger particles, such as gravel and shell fragments after a year of mooring in the sites (Herbert *et al.* 2009).	H		
Propagule Supply	*Ex situ* propagule supply will not be altered by this pressure, but recruitment may be indirectly influenced by changes to sediment (see below). Abrasion can re-suspend organisms, Drillet *et al.* (2004) showed that copepod eggs are re-suspended in the water column following passage of an otter trawl providing them with the opportunity to hatch and recruit nauplii to the water column. However, egg viability was reduced by the passage of the gear components. Abrasion may therefore alter propagule supply to adjacent habitats.			**L**
Water Currents	Changes in topography may alter currents but changes at the pressure benchmark are likely to be small and extremely localised.			**L**
Wave Exposure	This pressure will not alter wave exposure.			**L**
2. Water Column Processes				
Evidence				
Primary production	Penetration of sediments can re-suspend sediment with and impact primary production (see Pressure proforma 5, suspended sediment). Abrasion and penetration of the seabed results in dissolved and particulate nutrient releases so that bottom trawling (and other activities) may trigger considerable productivity pulses, in addition to pulses from the natural seasonal cycle (Dounas *et al.* 2007).			**L**
Suspended Sediment	**Demersal mobile gears**: The quantity of sediment resuspended by trawling depends on sediment grain size and the degree of sediment compaction which is higher on mud and fine sand than on coarse sand (Kaiser *et al.* 2002). Once entrained, the sediment is dispersed in a cloud, with a vertical profile that depends on the turbulence and the particle settling velocities (O'Neill *et al.* 2011; Palanques *et al.* 2001). The sediment gradually settles as the turbulence decays, so that the concentration of remobilised sediment decays with distance from the seabed and from the gear component. Sediment particle models indicate that the silt suspended by a full day of scallop dredging has, after six tidal cycles, become diluted to levels that are less than 2% of the lowest natural background levels. **Cables and Pipelines** **Construction:** Trenching for cable laying leads to an increase in suspended sediment in the water column, up to 200m from the site (Seacon 2005). Using 'jetting' for the burial of cables and pipelines can lead to an increase in suspended sediment (Carter *et al.* 2009). **Decommissioning:** Removal of cables abrades the seabed and re-suspends sediment into the water column (Meißner *et al.* 2006; Carter *et al.* 2009).	**H**		
Light Attenuation	Re-suspended sediment resulting from penetration and abrasion may reduce light penetration See Proforma 5 (suspended sediment).	**H**		
Water Chemistry and temperature	**Oil and Gas** **Decommissioning:** During decommissioning, if cutting piles are left *in situ* and covered, the area can become exposed to abrasion and penetration pressures from trawling, which can resuspend contaminants within the cutting piles (Ekins *et al.* 2006).	**H**		
Dissolved oxygen	**No evidence found**			
		H		

Sublittoral Sediment (topography)	**Offshore Windfarms** **Operation and Maintenance:** Contrasting evidence has been found for site specific effects, with evidence of scouring around the foundations reported (Whitehouse *et al.* 2011; Christie *et al.* 2012), and evidence of minimal negative impact on the marine environment observed by Byrne and Firm (2000).		**M**	
	Cables and Pipelines **Construction:** Pre-operational sweeping on the seafloor by a ship towed grapnel penetrates between 0.5 and 1m into soft sediment (Carter *et al.* 2009). **Construction:** Ploughing for cable laying abrades the seabed and can leave a ploughed strip c.0.3m wide, the skids that support the plough can also leave a footprint on the seabed in soft substrates (Carter *et al.* 2009). **Operation and Maintenance:** Sediment penetration occurs during cable reburial or uncovering for repair (Merck & Wasserthal 2009).		**M**	
	Oil and Gas **Construction:** Direct impact on sediment at emplacement of export pipelines (Bakke *et al.* 2013). **Decommissioning:** Activities that lead to changes in sediment topography: - Shallow disposal of topside and jacket (localised disturbance) - Removal of footings with cuttings *in situ* - Recovery of pipelines (Ekins *et al.* 2006)	**H**		
	Physical Sampling: Techniques that cause penetration to the seabed include: - Sediment profile imaging camera penetrates the sediment 2/3 the height of the face plate - Sublittoral coring.		**M**	
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	Otter trawling: Watling *et al.* (2001) recorded lowered food quality of the sediment (as measured by microbial populations, enzyme hydrolysable amino acids, and chlorophyll-*a*), microbial assemblage structure returned to expected ranges within a few months of the experiment. Abrasion may change the level of particulate organic matter in the water column by resuspending organic matter from the substratum (Pusceddu *et al.* 2005). This change will be temporary.		**M**	
Grazing and predation	Penetration and abrasion may affect this process by removing grazers and predators and their food. The vulnerability of epifauna to this pressure is likely to be greater than infauna. Grazing is most relevant to rock habitats characterised by algae. Mobile scavengers and predators will benefit from the opportunity to feed on exposed, damaged and dead individuals following this pressure (Caddy 1973), variable responses have been observed with increases in mobile scavengers in some habitats and not others (Ramsay *et al.* 1998).		**M**	
Particulate organic matter	Abrasion and penetration may change the level of particulate organic matter in the water column by resuspending organic matter from the substratum (Pusceddu *et al.* 2005). This change will be temporary.		M	
Seabed Mobility	Seabed mobility is a proxy for the extent to which the habitat is affected by natural physical disturbance. Penetration and abrasion may mobilise and move sediments (see sediment topography) but was not considered likely to directly alter natural seabed mobility. Removal of organisms may alter seabed stability (see below).			**L**
Recruitment	Removal of epifauna and complex habitats has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw		M	

	et al. 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels (Howarth *et al.* 2014). Studies at three sites in the Gulf of Maine (off Swans Island, Jeffreys Bank, and Stellwagen Bank) showed that mobile fishing gear altered the physical structure. Reductions in habitat complexity may lead to increased predation on juveniles of harvested species and ultimately recruitment to the harvestable stock (Auster *et al.* 1996). Physical abrasion from mobile fishing gears can damage the quality of spawning and nursery grounds through physical damage to the sedimentary habitat. Changes in the condition of spawning and nursery grounds in response to abrasion are not clear and it is unlikely that consistent relationships apply to different habitat types (eftec 2014 and references therein).			
4. Habitat and Bio-assemblages				
See sensitivity assessments.				
5. Output processes				
Evidence				
Biodeposition	Biological traits analysis of species assemblages has identified that filter feeding epifauna were more abundant in areas with lower levels of trawling, whereas areas with higher trawling levels had a greater abundance of mobile animals, scavengers and infauna (Tillin *et al.* 2006). Removal of epifaunal filter feeders will reduce biodeposition. No quantitative information was found for the impacts of penetration on biodeposition.		**M**	
Bioengineering	Abrasion can damage and remove structures that protrude above the sediment such as tubes and mounds and can damage and remove epifauna that also provide habitat complexity. Organisms may be able to repair damage, but this process will decline where the biota that support it are removed, e.g. algal canopies and biogenic reefs (Auster *et al.* 1996; Auster *et al.* 1999). The 11-year closure of an area to scallop dredging enhanced scallop stocks but also enhanced habitat complexity and biodiversity (Bradshaw *et al.* 2003).	**H**		
Hydrodynamic flow	Penetration is likely to detach attached macroalgae and epifauna that alter hydrodynamic flow No direct evidence was found to assess this change.		**M**	
Bioturbation	Biological traits analysis of species assemblages has identified a number of species traits which are linked to resistance. Tillin *et al.* (2006) found that epifauna, filter-feeders, attached and larger animals were more abundant in areas with lower levels of trawling, whereas areas with higher trawling levels had a greater abundance of mobile animals, scavengers and infauna.		**M**	
Primary production	Modelled responses of the plankton community to simulated trawling responses revealed that bottom trawling may trigger considerable productivity pulses, in addition to pulses from the natural seasonal cycle (Dounas *et al.* 2007).		M	
Secondary production	Studies on secondary production and trawling show that production by larger bodied species may decrease but that this may be compensated for at lower disturbance levels by smaller species which grow rapidly (Jennings *et al.* 2002). Reduction in biomass of abundant species such as nematodes,	H		
Sediment processing	Penetration may enhance sediment processing as burrowing, deposit feeding infauna are more likely to survive abrasion (Tillin *et al.* 2006). However, as opportunistic smaller species are more likely to survive than larger burrowers (Jennings *et al.* 2001), some reduction in this process may occur.			**L**
Habitat modification	Fishing activity (e.g., trawls, dredges) reduces habitat complexity by smoothing bedforms (e.g. sand waves and ripples), removing emergent epifauna (e.g. sponges, worm tubes, amphipod tubes, mussels, hydroids, and anthozoans) and species that produce	H		

	structures such as pits and burrows (e.g. crabs and fishes) (Auster *et al.* 1999). The 11-year closure of an area to scallop dredging enhanced scallop stocks but also enhanced habitat complexity and biodiversity (Bradshaw *et al.* 2003).			
Supply of propagules	The damage inflicted upon nursery habitats by fishing gears (removal of epifauna and complex habitats) has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels.	H		
6. Local ecosystem functions				
Evidence				
Food resource	The passage of the dredge across the sediment floor will have killed or injured some organisms that will then be exposed to potential predators/scavengers. Changes in food source are likely to have species specific effects depending on diet. For example, Shephard *et al.* (2010) found that plaice on gravel showed significant declines in length-at-age with increasing trawling effort, while plaice on sand showed significant increases in length-at-age. The contrasting trawling effects may reflect dietary differences between substrates as plaice on sand substrates predominantly consume polychaetes, which may proliferate at moderate trawling intensity on these substrates (Hiddink *et al.* 2008). Conversely, plaice on gravel substrates consume more fragile organisms such as echinoderms and bivalves that show marked declines with bottom trawling.		M	
Nutrient cycling	Direct disturbance of the seafloor enhances the upward flux of nutrients by releasing pore-water nutrients as a pulse, rather than a steady release or controlled bioturbation (Pilskaln *et al.* 1998). Trawling resuspension will introduce both regenerated ammonium and its nitrified product, nitrate, into the well-oxygenated water column, where it is not subject to bacterial denitrification and hence will be more available to the aerobic ecosystem (Pilskaln *et al.* 1998). Trawling activity may be important in supplying significant inputs of silica (as dissolved silicate) to the overlying water column from the underlying sediments. Indirect effects are also possible. Trawling removes larger burrow dwelling polychaete worms (fewer and larger burrows) and favours the establishment of more opportunistic assemblages (more numerous, but smaller burrows potentially altering burrow spacing and geometry. The density and size of animal burrows in sediments can substantially affect both the direction and magnitude of nitrogen flux across the sediment-water interface Aller (1982, 1988).		M	
Biogeochemical cycling	Trawling can affect organic-matter remineralisation and nutrient cycling through sediment resuspension and burial of organic matter to depth (Sciberras *et al.* 2016). Removal of bioturbators and bioirrigators could alter benthic mineralisation processes and biogeochemistry (Braeckman *et al.* 2010).		M	
Sediment stability	Sediment stability is likely to decline where abrasion enhances the predominance of deposit feeders that increase erodability of sediments. The removal of biogenic habitat and the loss of biodepositors that enhance sediment stability will result in changes to sediment stability that may be mitigated or increased by changes in sediment composition e.g. winnowing of fine sediments or exposure of more stable substratum.		M	
Habitat Provision	Fishing with demersal gears results in the replacement of a landscape with widespread, small-scale, low-relief topographic features (ripples and mounds) with a rather smoother landscape, interspersed with higher relief, but less frequent features caused by the ploughing of trawl doors (Kaiser *et al.* 2002). Reduction in habitat complexity resulting from abrasion will alter habitat	**H**		

	provision to species. Removal of surficial features is likely to favour flatfish such as Dover sole that are chemosensory over visual predators such as dabs and plaice that feed on mobile fauna associated with a low level of habitat complexity (Kaiser *et al.* 1999). Removal of epifauna and complex habitats has been shown to negatively impact scallop recruitment (Collie *et al.* 1997; Bradshaw *et al.* 2002), whilst the protection of nursery habitats has been shown to dramatically enhance scallop settlement levels (Howarth *et al.* 2014).			
Microbial Activity Enhancement	Otter trawling: Watling *et al.* (2001) recorded lowered food quality of the sediment (as measured by microbial populations, enzyme hydrolysable amino acids, and chlorophyll-*a*), microbial assemblage structure returned to expected ranges within a few months of the experiment.		**M**	
Nutrient Cycling	Epifaunal filter feeders are particularly vulnerable to abrasion and penetration pressures. Filter feeding organisms capture organic matter from the water column and re-deposit this either as faeces or pseudofaeces on or within sediments. This organic matter can then be remineralised (broken down to inorganic components) by microbes.		**M**	
Biogeochemical cycling	Alterations to bio-assemblage and functional diversity (feeding and bioturbation groups) will change the pathways and rates of biogeochemical cycling. Changes in macrobenthos due to intensive trawling disturbance could cause large fluctuations in benthic chemical fluxes and storage by the removal of bioturbators (Duplisea *et al.* 2001).		**M**	
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	Unlikely to result from pressure.			
Biotope Stability	Unlikely to result from pressure			
Export of Biodiversity	Unlikely to result from pressure. Reductions in habitat complexity may lead to increased predation on juveniles of harvested species and ultimately recruitment to the harvestable stock (Auster *et al.* 1996).			
Export of Organic Matter	Repeated exposure to penetration pressures, that alter community structure will impact the export of organic matter through changes in primary and secondary production and nutrient cycling (see above).		**M**	
Knowledge Gaps				

Pressure proforma 4. Smothering and siltation changes (depth of vertical sediment overburden) (light and heavy)

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

ICG pressure description

When the natural rates of siltation are altered (increased or decreased). Siltation (or sedimentation) is the settling out of silt/sediments suspended in the water column. Activities associated with this pressure type include mariculture, land claim, navigation dredging, disposal at sea, marine mineral extraction, cable and pipeline laying and various construction activities. It can result in short lived sediment concentration gradients and the accumulation of sediments on the sea floor.

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

"Heavy" smothering also relates to the changes in siltation (e.g. by outfalls, increased run-off, dredging/disposal or dredge spoil) deposition of layers of sediment on the seabed but is associated with activities such as sea disposal of dredged materials where sediments are deliberately deposited on the seabed.

Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs.

'Light' deposition of up to 5cm of fine material added to the habitat in a single, discrete event.
'Heavy' deposition of up to 30cm of fine material added to the habitat in a single discrete event.

Siltation resulting from human activities occurs at the pressure benchmark when large amounts of material are placed on the seabed as in the disposal of capital and maintenance dredging. The disposal of sewage sludge may also result in thick deposits on the seabed. Aggregate dredging accompanied by screening (the process of discharging unwanted grades of sediment) may also lead to the deposition of sediment layers although this is unlikely to reach the benchmark level. Some siltation may also result from activities that lead to abrasion or disturbance of the seabed and consequent re-suspension of sediments that are transported and re-deposited. The activities will typically result in deposits much thinner than the pressure benchmark. Deposition of suspended sediments has two impacts on the seabed. Animals living in or on the seabed can be immediately smothered and buried, while the habitat change alters the character of the associated benthic assemblage (considered under the pressure 'Physical change').

Activities that contribute to this pressure

Category: Extraction (and disposal) of non-living resources	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**>**	**=**	**>**	**H**	**M**	**L**
Aggregate Dredging: Heavy siltation from screening can lead to the infilling of dredging furrows (Hill *et al.* 2011).				**H**		
Category: Transport						
Vessel anchorages and Vessel moorings. Recreational and Commercial Mooring: Mooring abrasion can lead to the resuspension of particles, which can smother associated flora and fauna, causing damage and mortality (Smith *et al.* 2017).						
Category: Other man-made structures						
Cables and Pipelines: **Construction:** Operations including cable laying, burial and protection, and the maintenance and construction of outfall pipes can all cause localised heavy sediment resuspension (Ludwig, 1998; BERR, 2008). Smothering of coral structures was observed along a 100m corridor (Ulfsnes *et al.* 2013). **Operation and Maintenance:** Cable reburial or uncovering for repair, and pipeline outflow discharge can all cause localised heavy sediment resuspension (Ludwig 1998; BERR 2008). Pipeline structures can also				**H**		

cause changes in hydrodynamics which can cause heavy siltation (Ludwig 1998). **Decommissioning:** During cable uncovering spoil from the trench excavation smothers the adjacent seabed, and significant sedimentation can occur from increased suspended sediment (generally cables are left in place) (BERR 2008).						
Category: Energy generation						
Oil and Gas: **Construction:** Pipeline installation into can mobilise sediments into suspension (Ivensen 2009). **Operation:** Suspended sediment can have an impact of 100-500m from the platform (Cordes *et al.* 2016). **Decommissioning:** Excavation of drill cuttings using jetting can resuspend sediments. Impacts on the seabed from oil and gas platforms are most evident during the construction and decommissioning phases. The impact footprint will depend on the size of the platform, but indirect impacts have been detected 1-2km from platforms (Cordes *et al.* 2016).					**M**	
Offshore Windfarms: **Demersal mobile gears:** Little direct evidence for siltation and smothering although suspended sediment has been assessed (see Pressure proforma 5). Jennings and Kaiser (1998) report that the impacts of towed demersal gears in soft sediment can include smothering of suspension feeding fauna through the resuspension of sediment by the fishing gears. The quantity of sediment resuspended by trawling depends on the sediment grain size and the degree of compaction, which is higher on mud and fine sand compared to coarse sand. **Demersal static gears-** No evidence, unlikely to lead to this pressure.						**L**

1. Regional to global drivers				
Evidence				
Climate	This pressure will not alter climate.			
Depth	This pressure will reduce depth according to the level of overburden added to the existing sediment surface.	H		
Geology	**Aggregate Dredging:** High intensity dredging with screening, can lead to heavily siltation, and a fining of sediments (Hill *et al.* 2011). A change in sediment composition to smaller grain sizes (clay/silt) also results from the disposal of dredged sediments into the water column (OSPAR 2008).	H		
Propagule Supply	Not relevant, siltation and smothering will not affect supply of propagules but could impact *in situ* recruitment (see below)			
Water Currents	Changes to topography and reductions in the depth of the seabed from dredge and spoil disposal may have an impact on the local hydrodynamic regime, disrupting local current strengths and altering patterns of sedimentation (Bolam 2012).		**M**	
Wave Exposure	This pressure will not alter wave exposure.			**L**
2. Water Column Processes				
Evidence				
Primary production	Associated suspension of sediments in the water column may reduce light penetration and primary production by phytoplankton.			**L**
Suspended Sediment	During disposal of dredged sediment at sea large amounts of sediment are brought into suspension (Essink 1999) (see proformas 5 for this pressure).	H		
Light Attenuation	Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub surface light attenuation (Kd) (Devlin *et al.* 2008) and photic zone (Cloern 1987)	**H**		
Water Chemistry and temperature	Smothering and siltation may result in remobilisation of contaminants during deposition or subsequent winnowing of the deposit by current and wave action. The potential impacts include		**M**	

	spreading of sediments and associated contaminants in the surroundings, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2009)			
Dissolved oxygen	Where deposits consist of fine material the concentration of oxygen in the pore-waters declines due to biological demand (respiration) and is not replenished because of limited water movement between very fine particles. A covering layer of 1m can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999).		**M**	
Sublittoral Sediment (topography)	Deposits will smother sediments resulting in physical changes to composition and the smothering of fine scale topography.		**M**	
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	No evidence. Siltation and smothering will result in the placement of a deposit that may be defaunated or low in organic matter and that will reduce food source availability.			L
Seabed Mobility	No evidence			
Recruitment	The first organisms to recolonise dredged material usually are not the same as those that originally occupied the site. They consist of opportunistic species whose environmental requirements are flexible enough to allow them to occupy the disturbed areas. Trends toward re-establishment of the original community are often noted within a year or two (Blanchard & Feder 2003). The general recolonisation pattern is often dependent upon the nature of the adjacent undisturbed community, which provides a pool of replacement organisms capable of recolonising the site by adult migration, passive advection or larval recruitment.		M	
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets.				
5. Output processes				
Evidence				
Biodeposition	An increase in suspended organic particulates and subsequent increased deposition of organic matter in sheltered environments where sediments have high mud content will increase food resources to deposit feeders. This may lead to a shift in community structure with increased abundance of deposit feeders and a lower proportion of suspension feeders, as feeding is inhibited where suspended particulates are high, and the sediment is destabilised by the activities of deposit feeders (Rhoads & Young 1970).			**L**
Bioengineering/ Habitat modification	No evidence for direct effects. Smothering of erect epifauna, biogenic habitat and sediment topography is likely to alter habitat complexity.		**M**	
Hydrodynamic flow	No evidence for direct effects.			
Bioturbation	No evidence for direct effects. Some burrowing organisms may be more resistant to this pressure with some species being able to reach the surface and re-establish burrows. There is likely to be some impact son species which will be mediated by the thickness and type of overburden (see species sensitivity assessments).		**M**	
Primary production	Decline: smothering will prevent photosynthesis by attached macroalgae and microphytobenthos present at the sediment/substratum (see species sensitivity assessments).		**M**	

Secondary production	Decline: By smothering and burying epifauna and infauna, secondary production within the habitat will decline (see species sensitivity assessments).		**M**	
Sediment processing	Decline: reduction in bioturbators and burrowing species sediment processing will be reduced.		**M**	
Supply of propagules	The quality of spawning and nursery grounds can be damaged through physical damage to the sedimentary habitat. Changes in the condition of spawning and nursery grounds in response to pressures are not clear and it is unlikely that consistent relationships apply to different habitat types and species (eftec 2014 and references therein).		**M**	
6. Local ecosystem functions				
Evidence				
Food resource	Smothering will reduce availability of benthic food resources.			L
Nutrient cycling	A covering layer of 1m can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999). Smothering will alter dissolved and particulate nutrient exchange between the sediment and water column.			L
Biogeochemical cycling	Smothering and anoxia will alter biogeochemical cycling and smother many bioturbators altering cycling rates.		**M**	
Sediment stability	No evidence.			
Habitat provision	In comparatively rare circumstances, the physical impacts can also interfere with the migration of fish (e.g. the impact of high levels of turbidity on salmonids in estuarine areas) or crustacea (e.g. if deposition occurs in the coastal migration path of crabs) (OSPAR 2009). Burial of biota, biogenic reefs and macroalgae and other features such as sediment topography will alter habitat provision.		**M**	
Microbial activity	A covering layer of 1m can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999). Changes in sediment chemistry can alter microbial activity.		**M**	
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	Decline. Few benthic invertebrates are able to escape entrainment from aggregate dredging and research shows that under the path of an aggregate extraction draghead there is a 30-70% reduction in species diversity, a 40-95% reduction in the number of individuals and a similar reduction in biomass of benthic communities (Newell *et al.* 1998).	**H**		
Biotope Stability	Decline due to removal of biota by smothering.		**M**	
Export of Biodiversity	Decline due to removal of biota by smothering.		**M**	
Export of Organic Matter	Smothering will result in loss of biota and subsequent changes in function including lower export of organic matter. Functional groups such as macroalgae which export large amounts of detritus, are particularly vulnerable to smothering at the pressure benchmark.		**M**	
Knowledge Gaps				
There are clear knowledge gaps associated with this pressure regarding the effects on ecosystem processes and functions. There have been some studies that have identified survival rates and ability to burrow through sediment but in general there is little further evidence.				

Pressure proforma 5. Changes in suspended solids (water clarity)

Pressure	**Changes in suspended solids (water clarity)**					
ICG pressure description Changes water clarity (or turbidity) due to changes in sediment & organic particulate matter and chemical concentrations. It is related to activities disturbing sediment and/or organic particulate matter and mobilizing it into the water column. It could be 'natural' land run-off and riverine discharges or from anthropogenic activities such as all forms of dredging, disposal at sea, cable and pipeline burial, secondary effects of construction works, e.g. breakwaters. Particle size, hydrological energy (current speed & direction) and tidal excursion are all influencing factors on the spatial extent and temporal duration. Salinity, turbulence, pH and temperature may result in flocculation of suspended organic matter. Anthropogenic sources are mostly short lived and over relatively small spatial extents. Changes in suspended sediment loads can also alter the scour experienced by species and habitats. Therefore, the effects of scour are also addressed here.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs						
A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to intermediate for one year						
Activities that contribute to this pressure						
Category	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Aggregate Dredging: There are three ways in which aggregate dredging produces sediment plumes – via the draghead, screening and overflow where fine particulate matter suspended in excess water overflows from vessel into water column via spillways (Hill *et al.* 2011). During dredging, turbid plumes are generated near the seabed by mechanical agitation and near the sea surface by overflow; the plume follows the prevailing tidal current during dredging or the direction of the residual current if it persists for a longer time (Le Bot *et al.* 2010). Coarser particles within the plume of sediment will settle by gravity within the primary impact zone (Newell *et al.* 1998), although the footprint of impact can be extended by sediment plumes dictated by strength and direction of currents and winds, and particle size of material released (Hill *et al.* 2011). Plumes containing lower suspended sediment concentrations (e.g. 5-10mg/l) were predicted to extend for 5-10km along the direction of the tidal flows but these were barely distinguishable from background levels (Desprez 2000).	**<**			**H**		
Dredge disposal: During disposal of dredged sediment at sea large amounts of sediment are brought into suspension (Essink 1999).	**<**			**H**		
Category: Transport						
Vessel anchorages and Vessel moorings. No evidence for this pressure.						
Category: Other man-made structures						
Cables and Pipelines: Construction: Cable laying, burial and protection can lead to an increase in suspended sediment (BERR 2008). Drilling can lead to an increase in suspended sediments, detected 1000m downstream (Ulfsnes *et al.* 2013). Trenching for cable laying leads to an increase in suspended sediment in the water column, up to 200m from the site (Seacon, 2005). Using 'jetting' for the burial of cables and pipelines can lead to an increase in suspended sediment (Carter *et al.* 2009). Decommissioning: Removal of cables abrades the seabed and re-suspends sediment into the water column (Meißner *et al.* 2006; Carter *et al.* 2009; Ekins *et al.* 2006; BERR 2008).	<			H		

Category: Energy Generation							
Offshore Windfarms: Large, turbid wakes are present downstream of individual turbines that may extend for over 1km (Hooper *et al.* 2014 and references therein). Suspended sediment changes can lead to mortality of algae, reduce photosynthetic capacity, recruit viability (Smith *et al.* 2017).			=			M	
Oil and Gas Decommissioning: Activities involved in the decommissioning of an oil and gas platform, can result in the resuspension of fine sediments (Ivensen 2009).							
Category: Extraction of living resources							
Demersal mobile gears: The quantity of sediment resuspended by trawling depends on sediment grain size and the degree of sediment compaction which is higher on mud and fine sand than on coarse sand (Kaiser *et al.* 2002). Once entrained, the sediment is dispersed in a cloud, with a vertical profile that depends on the turbulence and the particle settling velocities (O'Neill *et al.* 2011; Palanques *et al.* 2001). The sediment gradually settles as the turbulence decays, so that the concentration of remobilised sediment decays with distance from the seabed and from the gear component. Sediment particle models indicate that the silt suspended by a full day of scallop dredging has, after six tidal cycles, become diluted to levels that are less than 2% of the lowest natural background levels.		<			H		
1. Regional to global drivers							
Evidence							
Climate	This pressure will not alter climate.						**L**
Depth	This pressure will not alter depth.						L
Geology	Cooper *et al.* (2007) noted that a depositional 'footprint' associated with the dredging plume could be identified on the seabed for approximately 3-4km from the dredging area in a dynamic environment with strong currents re-mobilising sediments from the seabed and where screening was undertaken as part of the dredging process. Mobile sands recover faster due to infilling.					M	
Propagule Supply	This pressure will not alter propagule supply.						**L**
Water Currents	This pressure will not alter water currents.						**L**
Wave Exposure	This pressure will not alter wave exposure.						**L**
2. Water Column Processes							
Evidence							
Primary production	Phytoplankton production is directly dependent on light penetration into the water column. Increased water turbidity results in a decrease in light penetration which is likely to affect phytoplankton adversely (Essink 1999, cited from OSPAR 2008)				**H**		
Suspended Sediment	The potential impacts include spreading of sediments and associated contaminants in the surroundings, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2008)				**H**		
Light Attenuation	Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub surface light attenuation (Kd) (Devlin *et al.* 2008) and controls the photic zone (Cloern 1987)				**H**		
Water Chemistry and temperature	Potential impacts include, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk and release of nutrients from sediments resulting in increase in eutrophication (OSPAR 2008).					**M**	
Dissolved oxygen	**No evidence**						

Sublittoral Sediment (topography)	Infilling following deposition may alter sediment topography (Hill *et al.* 2011).			L
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	No evidence			
Seabed Mobility	Seabed mobility is a proxy for the extent to which the habitat is affected by natural physical disturbance. Changes in suspended solids will result in sediment transport but this was not considered likely to directly alter natural seabed mobility. Removal of organisms may also alter seabed stability (see below).			L
Recruitment	No evidence			
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets.				
5. Output processes				
Evidence				
Biodeposition	Increases in suspended sediment may result in increased particle capture by bivalves and subsequent deposition as pseudofaeces.			
Bioengineering	No evidence			
Hydrodynamic flow	Not relevant. Changes in suspended solids may result from changes in hydrodynamic flow but are not considered to influence this component.			
Bioturbation	No evidence			
Primary production	Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub surface light attenuation (Kd) (Devlin *et al.* 2008) and controls the photic zone (Cloern, 1987). Changes in suspended solids could result in changes to primary production.	H		
Secondary production	No evidence			
Sediment processing	No evidence			
Habitat modification	No evidence			
Supply of propagules	No evidence			
6. Local ecosystem functions				
Evidence				
Food resource	An increase in suspended particulates and subsequent increased deposition of organic matter in sheltered environments where sediments have high mud content will increase food resources to deposit feeders. This may lead to a shift in community structure with increased abundance of deposit feeders and a lower proportion of suspension feeders (as feeding is inhibited where suspended particulates are high and the sediment is destabilized by the activities of deposit feeders (Rhoads & Young 1970)).			
Nutrient cycling	No evidence.			
Biogeochemical cycling	No evidence.			
Sediment stability	No evidence.			
Habitat provision	No evidence.			
Microbial activity	No evidence.			
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	No evidence.			
Biotope Stability	No evidence.			
Export of Biodiversity	No evidence.			
Export of Organic Matter	No evidence			

Knowledge Gaps
There is little information on how changes in suspended solids may result in changes to output processes and functions.

Pressure proforma 6. Physical change (to another seabed type)

Pressure	**Physical change (to another seabed type)**
ICG pressure description The permanent change of one marine habitat type to another marine habitat type, through the change in the substratum, including to artificial (e.g. concrete). This, therefore, involves the permanent loss of one marine habitat type but has an equal creation of a different marine habitat type. Associated activities include the installation of infrastructure (e.g. surface of platforms or wind farm foundations, marinas, coastal defences, pipelines and cables), the placement of scour protection where soft sediment habitats are replaced by hard/coarse substratum habitats, removal of coarse substrata (marine mineral extraction) in those instances where surficial finer sediments are lost, capital dredging where the residual sedimentary habitat differs structurally from the pre-dredge state, creation of artificial reefs, mariculture i.e. mussel beds. Protection of pipes and cables using rock dumping and mattressing techniques. Placement of cuttings piles from oil & gas activities could fit this pressure type, however, there may be additional pressures, e.g. "pollution and other chemical changes" theme. This pressure excludes navigation dredging where the depth of sediment is changed locally but the sediment typology is not changed.	
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs	
Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa	
Activities that contribute to this pressure	

Category	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Aggregate dredging: Where deposits overlay hard substratum extraction of sediment may expose rock seabed. Relict deposits are unlikely to recover, but where sediment transport processes allow sediment habitats can return.		**=**		**H**		
Category: Transport						
Vessel anchorages No evidence for this pressure.						
Vessel moorings. Physical change occurs when a mooring block is placed on the surface of the seabed. The mooring block is subject to constant abrasion from the chain and aside from the physical disturbance introduces an artificial habitat in place of the natural. No specific studies were found that investigated or considered this pressure by a recent review (Griffiths *et al.* 2016).		=		**H**		
Category: Other man-made structures						
Cables and Pipelines: The cables and pipelines where these are not buried can change sediment type (Meißner *et al.* 2006). Where outflow pipes are buried, trench excavation will be required which will remove the existing habitat and if not fully reinstated this could result in habitat change. Rock armouring may also be placed over the pipe resulting in a change in habitat (Ludwig 1988).		=		**H**		
Category: Energy generation						
Offshore Windfarms: The construction of hard turbines leads to loss of associated flora and fauna species, both abundance and diversity, reducing genetic connectivity, loss of structural complexity. However, epifauna can colonize new substrates, with turbine bases and cable protection structures providing new habitats (Sanders *et al.* 2017).		=		**H**		
Oil and Gas						
Extraction of Living Resources						
No evidence for this pressure						

1. Regional to global drivers				
Evidence				
Climate	This pressure will not alter climate.			
Depth	This pressure will not alter depth.			
Geology	This pressure represents a change in the surficial substratum type from artificial or rock to sediment. This represents a significant change in habitat type.	H		
Propagule Supply	This pressure will not alter propagule supply although habitat suitability for recruitment will change.	**H**		
Water Currents	This pressure will not alter water currents although changes in bio-assemblage and substratum type will alter local hydrodynamic flows.		**M**	
Wave Exposure	This pressure will not alter water currents although changes in bio-assemblage and substratum type will alter local hydrodynamic flows.		**M**	
2. Water Column Processes				
Evidence				
Primary production Suspended Sediment Light Attenuation Water Chemistry and temperature Dissolved oxygen	No evidence for direct impacts, change in substratum type and bio-assemblage may result in changes to the overlying water column based on changed ecological processes and function.		**M**	
Sublittoral Sediment (topography)	This pressure represents a change in the surficial substratum type from artificial or rock to sediment. This represents a significant change in habitat type.	**H**		
3. Local Processes/Inputs at the seabed				
Evidence				
Food Sources	This pressure will lead to changes in the bio-assemblage. Changes in substratum type may result in changes in food source availability.	H		
Grazing and predation	Changes in substratum type will alter habitat suitability for grazers and predators. A marked increase in the number and biomass of juvenile edible crab on turbine foundations was observed at one offshore wind farm over three years of post-construction monitoring (Hooper *et al.* 2014 and references therein).	H		
Seabed Mobility	Changes in substratum type will alter seabed mobility.	H		
Recruitment	Changes in substratum type will alter habitat suitability and recruitment cues.	H		
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets.				
5. Output processes				
Evidence				
Biodeposition	Changes in habitat suitability for the bio-assemblage will alter the level of this process.		**M**	
Bioengineering	Changes in habitat suitability for the bio-assemblage will alter the level of this process.		**M**	
Hydrodynamic flow	Changes in substratum type and rugosity are likely to alter hydrodynamic flows. Degree of alteration will depend on the resulting topography.		**M**	
Bioturbation	Changes in habitat suitability for the bio-assemblage will alter the level of this process.		**M**	
Primary production	Changes in habitat suitability for the bio-assemblage will alter the level of this process.		**M**	

Secondary production	Changes in habitat suitability for the bio-assemblage will alter the level of this process.		**M**	
Sediment processing	This pressure will not alter depth.		**M**	
Habitat modification	Physical change in substratum type can lead to changes in species composition. **Cables and pipelines:** the presence of cables has led to an increase in epifaunal biota, including anemones, in sediment-dominated areas (Kogan *et al.* 2006). Fish species were also more abundant close to the cable, probably in response to increased habitat complexity (Taormina *et al.* 2018)	**H**		
Supply of propagules	The quality of spawning and nursery grounds can be damaged through physical damage to the sedimentary habitat. Changes in the condition of spawning and nursery grounds in response to pressures are not clear and it is unlikely that consistent relationships apply to different habitat types and species (eftec 2014 and references therein).		M	
6. Local ecosystem functions				
Evidence				
Food resource	Changes in habitat suitability for the bio-assemblage will alter the level of this function.		**M**	
Nutrient cycling	Changes in habitat suitability for the bio-assemblage will alter the level of this function.		M	
Biogeochemical cycling	Changes in habitat suitability for the bio-assemblage will alter the level of this function.		**M**	
Sediment stability	Changes in habitat suitability for the bio-assemblage will alter the level of this function.		**M**	
Habitat provision	Hard substratum can support dense populations of epifauna. On windfarm turbines, Krone *et al.* (2006) found that the upper 10m of all studied structures were densely colonized by a biofouling layer with large shares of the Blue mussel *Mytilus edulis*, anthozoans and tubes of the amphipods *Jassa spp.*		M	
Microbial activity	Changes in habitat suitability for the bio-assemblage will alter the level of this function.		**M**	
7. Regional to Global Ecosystem Functions				
Biodiversity Enhancement	Changes in seabed type will alter the habitat. Increases in benthic invertebrate and benthic feeding fish biomass have been reported in response to the reef effect (where sediments are replaced by hard substratum). These changes are predicted to attract and benefit apex predators (Raoux *et al.* 2017).		M	
Biotope Stability	Changes in substratum type and bio-assemblage will alter biotope stability.			**L**
Export of Biodiversity	Changes in substratum type and bio-assemblage will alter biotope stability.			**L**
Export of Organic Matter	Changes in substratum type and bio-assemblage may alter the capacity to export organic matter.			**L**
Knowledge Gaps				
Substratum/sediment type and related environmental variables are key factors structuring bio-assemblages. Changes to a substratum will profoundly alter the bio-assemblage, processes and functions. Impacts will depend on the nature of the change and site-specific factors so that the assessed changes are generic.				

Pressure proforma 7. Physical change to another sediment type

Pressure	Physical change to another sediment type

ICG pressure description

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

Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs

The benchmark for this pressure refers to a change in one Folk class. The pressure benchmark originally developed by Tillin *et al.* (2010) used the modified Folk triangle developed by Long (2006) which simplified sediment types into four categories: mud and sandy mud, sand and muddy sand, mixed sediments and coarse sediments. The change referred to is therefore a change in sediment classification rather than a change in the finer-scale original Folk categories (Folk 1954). The change in one Folk class is considered to relate to a change in classification to adjacent categories in the modified Folk triangle. For mixed sediments and sand and muddy sand habitats a change in one folk class may refer to a change to any of the sediment categories. However, for coarse sediments resistance is assessed based on a change to either mixed sediments or sad and muddy sands but not mud and sandy muds. Similarly, muds and sandy muds are assessed based on a change to either mixed sediments or sand and muddy sand but not coarse sediment.

Activities that contribute to this pressure

Category	Pressure benchmark			Confidence		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Aggregate dredging: Many dredge sites are characterised by an increase in the sand content of the sediments. Sediment composition may become finer following aggregate dredging due to: • Changes to seabed topography that slow water currents leading to an increase in the natural deposition of fine particles. • Transport of fine particles from dredging into previous dredge furrows. Where screening is employed to alter the sand to gravel ratio of the cargo, significant quantities of sediment, typically unwanted fine sediment particles, can be returned to the seabed (Hill *et al.* 2011). The settlement of these 'fines' on the seabed can significantly reduce the average sediment particle size in the local area. Alternatively, sediments at dredge site may become coarser due to: • Dredging, which exposes coarse gravel deposits below the dredged surface layer. • Removal of sand and return of coarser particles. Aggregate extraction often shifts sediment composition from gravelly sand to sandy gravel reducing the availability of attachment sites for encrusting epifaunal species such as barnacles, ascidians, hydroids and bryozoans. Mixed sediments are often the most diverse because they can provide habitat for infaunal and epifaunal organisms. A reduction in average particle size can therefore significantly reduce diversity, particularly of epifaunal animals, and shift the community to one dominated by infaunal animals such as polychaete worms.		=		H		

Conversely, aggregate dredging that removes coarse gravels, leaving mixed sediments behind, may result in an increase in diversity (Hill *et al.* 2011).						
Category: Transport						
Vessel anchorages No evidence for this pressure						
Vessel moorings. Mooring chain abrasion may alter sediment characteristics. Herbert *et al.* 2009 found changes in sediment type apparent between impacted and control areas. Samples of sediment were taken within and outside the chain radius of each buoy before removal and 15 months after removal of buoys, when differences were still apparent. Impacts are likely to be highly site specific, Latham *et al.* (in prep) recorded no size gradient in areas exposed to mooring chain abrasion.		=			M	
Category: Energy generation						
Offshore Windfarms: Direct impacts on the seabed are limited to within one to two hundred metres of a wind-farm array and bedforms between turbines are undisturbed (OSPAR, 2006). Many studies report few or no effects on sediment composition (Hooper *et al.* 2014 and references therein).	<				M	
Oil and Gas Construction of oil and gas infrastructure may involve the placement of gravel or concrete in areas of potential free span (Ivensen *et al.* 2009).		**=**			**M**	
Category: Extraction of living resources						
Following experimental otter trawling in muddy habitats, short-term alterations in the sediment size distribution were observed. In landward control sites associated with deposition of resuspended sediments (De Biasi 2004).	**<**					
1. Regional to global drivers						
Evidence - see physical change to another seabed type, Pressure proforma 6.						
2. Water Column Processes						
Evidence - see physical change to another seabed type, Pressure proforma 6.						
3. Local Processes/Inputs at the seabed						
Evidence - see physical change to another seabed type, Pressure proforma 6.						
4. Habitat and Bio-assemblages						
See Sensitivity Assessment spreadsheets. This pressure represents a change in habitat type rather than a loss of habitat through land reclamation or construction of sea walls *etc.* Any change in the environmental factors that define a habitat at a location will alter the suitability of that location for some species and increase it for others. The expected effect of habitat changes is therefore a change in the species assemblage present, with some species lost and some gained and with further indirect effects on the assemblage ramifying through these changes e.g. the presence of predators may reduce the abundance of prey species.						
5. Output processes						
Evidence - see physical change to another seabed type, Pressure proforma 6.						
6. Local ecosystem functions						
Evidence - see physical change to another seabed type, Pressure proforma 6.						
Knowledge Gaps						
The quality of spawning and nursery grounds can be damaged through physical damage to the sedimentary habitat. Changes in the condition of spawning and nursery grounds in response to pressures are not clear and it is unlikely that consistent relationships apply to different habitat types and species (eftec 2014 and references therein).						

Pressure proforma 8. Wave exposure changes - local

Pressure	**Wave exposure changes - local**					
ICG pressure description Local changes in wavelength, height and frequency. Exposure on an open shore is dependent upon the distance of open sea water over which wind may blow to generate waves (the fetch) and the strength and incidence of winds. Anthropogenic sources of this pressure include artificial reefs, breakwaters, barrages, wrecks that can directly influence wave action or activities that may locally affect the incidence of winds, e.g. a dense network of wind turbines may have the potential to influence wave exposure, depending upon their location relative to the coastline.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs						
A change in nearshore significant wave height >3% but <5% for one year						
Activities that contribute to this pressure						
Category	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	**<**	**=**	**>**	**H**	**M**	**L**
Category: Extraction (and disposal) of non-living resources						
Aggregate Dredging: Published industry guidance states that changes in wave transformation due to aggregate extraction are unlikely to be problematic at the coastline if the activity occurs in water depths of greater than 15m (Boyd *et al.* 2004). Aggregate extraction undertaken on sand or gravel banks or bars will lower the crest level so that wave attenuation across the feature may be reduced, increasing wave exposure on adjacent features (Newell and Woodcock 2013). The rate of recovery of sediments is governed by the mobility of seabed sediments within the region and the intensity (frequency and spatial extent of dredging within a seabed area) of the dredging activities.	**<**	**=**	**>**		**M**	
Category: Transport						
Vessel anchorages and Vessel moorings. No evidence for this pressure.						
Category: Other man-made structures						
Cables and Pipelines: No evidence for this pressure.						
Category: Energy generation						
Offshore Windfarms: No evidence for this pressure						
Oil and Gas: No evidence for this pressure						
Category: Extraction of living resources						
Fishing: No evidence No evidence for this pressure						
Regional to global drivers						

Evidence				
Climate	This pressure will not alter climate.			
Depth	This pressure may indirectly alter depth through sediment accretion or erosion.			**L**
Geology	Aggregate extraction undertaken on sand or gravel banks or bars will lower the crest level; wave dissipation across the feature may be reduced, potentially lessening the shelter afforded by the feature to adjacent areas of seabed and coastline (Newell & Woodcock 2013)		M	
Propagule Supply	No evidence			
Water Currents	No evidence			
Wave Exposure	**This pressure**			

2. Water Column Processes
No Evidence
3. Local Processes/Inputs at the seabed
No Evidence
4. Habitat and Bio-assemblages
Very little evidence, see sensitivity assessment spreadsheets.
5. Output processes
No Evidence
6. Local ecosystem functions
No Evidence
Knowledge Gaps
The evidence base to support assessments is scarce and there is considerable uncertainty.

Pressure proforma 9. Water flow (tidal current) changes - local, including sediment transport considerations

Pressure	**Water flow (tidal current) changes - local, including sediment transport considerations**					
ICG pressure description Changes in water movement associated with tidal streams (the rise and fall of the tide, riverine flows), prevailing winds and ocean currents. The pressure is therefore associated with activities that have the potential to modify hydrological energy flows, e.g. tidal energy generation devices remove (convert) energy and such pressures could be manifested leeward of the device, capital dredging may deepen and widen a channel and therefore decrease the water flow, canalisation and/or structures may alter flow speed and direction; managed realignment (e.g. Wallasea, England). The pressure will be spatially delineated. The pressure extremes are a shift from a high to a low energy environment (or vice versa). The biota associated with these extremes will be markedly different as will the substratum, sediment supply/transport and associated seabed/ground elevation changes. The potential exists for profound changes (e.g. coastal erosion/deposition) to occur at long distances from the construction itself if an important sediment transport pathway was disrupted. As such these pressures could have multiple and complex impacts associated with them.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014, 2015a&b) in liaison with the UK SNCBs						
A change in peak mean spring bed flow velocity of between 0.1m/s to 0.2m/s for more than 1 year						
Activities that contribute to this pressure						
Category	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	<	=	>	H	M	L
Category: Extraction (and disposal) of non-living resources						
Aggregate dredging Aggregate dredging results in this pressure through changes to topography and reductions in the depth of the seabed that may result in an impact on the local hydrodynamic regime, disrupting local current strengths and altering patterns of sedimentation (Tillin *et al.* 2011). Current speeds may increase or decrease as a result of aggregate extraction, A study showed that even in particularly extreme cases of dredging, changes in current speeds close to the coast were negligible.	<	=	>			L
Category: Transport						
Vessel anchorages and Vessel moorings. No evidence for this pressure.						
Category: Other man-made structures						
Cables and Pipelines: No evidence for this pressure						
Category: Energy generation						
Offshore Wind Farms Changes in topography can result in changes in currents that may extend over 1km (Hooper *et al.* 2014 and references therein). Around the foundations of the turbines, flow rates may increase leading to Scouring (Sanders 2017).	<	=	>	H		
Oil and Gas: No evidence for this pressure.						
Category: Extraction of living resources						
Fishing: No evidence for this pressure **Harvesting - seaweed and other sea-based food (bird eggs, shellfish, *etc.*):** No evidence for this pressure						

1. Regional to global drivers				
Evidence				
Climate	This pressure will not alter climate.			
Depth	This pressure may indirectly alter depth through sediment accretion or erosion.			L

Geology	This pressure may indirectly alter geology through sediment accretion or erosion.			**L**
Propagule Supply	Changes in water flow are likely to alter larval and gamete supply. Decline in currents surrounding windfarms can result in change in gamete transport. May extend for over 1km (Hooper *et al.* 2014). Sandy areas are usually dependent on an input of colonizing organisms and have few species with benthic reproduction. Hence, recruitment is sensitive to changes in the hydrodynamic regime. Sandbanks, in particular, may be recruitment sinks as they often occur at the centre of hydrographic gyres (Elliott *et al.* 1998).			**L**
Water Currents	This proforma.			
Wave Exposure	See Pressure proforma 8.			
2. Water Column Processes				
Evidence				
Primary production	No evidence for direct impacts. Associated changes in nutrient transport and changes in suspended sediment may alter primary production			**L**
Suspended Sediment	Changes in water flow See Pressure Proforma 5.			
Light Attenuation	See Pressure Proforma 5.			
Water Chemistry and temperature	Water currents will influence water chemistry through water column mixing, transport of nutrients and contaminants and other solutes and particulates.	**H**		
Dissolved oxygen	Wave action will influence oxygenation of the water column.	**H**		
Sublittoral Sediment (topography)	See Pressure Proforma 6.			
3. Local Processes/Inputs at the seabed				
No Evidence				
4. Habitat and Bio-assemblages				
See Sensitivity Assessment spreadsheets.				
Offshore wind Farms				
5. Output processes				
No Evidence				
6. Local ecosystem functions				
No Evidence				
7. Regional to Global Ecosystem Functions				

Pressure proforma 10. Pollution and other chemical changes

Pressure	**Pollution and other chemical changes**					
ICG pressure description						
Hydrocarbon & PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC						
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC.						
Transition elements & organo-metal (e.g. TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC.						
Pressure benchmark from Tillin *et al.* (2010) and subsequently revised by Tillin & Tyler-Walters (2014 2015a&b) in liaison with the UK SNCBs						
Compliance with all AA EQS, conformance with PELs, EACs/ER-Ls						
Activities that contribute to this pressure						
Category	**Pressure benchmark**			**Confidence**		
Activity: footprint (scale), duration of pressure, impact, recovery	<	=	>	H	M	L
Category: Extraction (and disposal) of non-living resources						
Aggregate dredging: No evidence for this pressure						
Maintenance dredging: Re-suspension of sediments and increase of turbidity. Potential impacts include spreading of sediments and associated contaminants in the surroundings, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2009). The increase in turbidity due to re-suspension of sediments caused by dredging, together with chemical quality and biological characteristics of the sediments, may be regarded as an indicator for potential ecological effects in the surroundings of the dredging sites (OSPAR 2009). Level of pressure will depend on site contamination.	<	=	>		M	
Dredge disposal Dredge disposal can introduce contaminants into an area. OSPAR (2009) highlight that particular attention should be paid to dredged material containing significant amounts of oil or other substances that have a tendency to float following resuspension in the water column as these can be dispersed.	<	=	>		M	
Category: Transport						
Vessel anchorages: No evidence for this pressure						
Vessel Moorings: La Manna *et al.* (2015) highlight the potential environmental hazards of using dump weights (typically concrete blocks or waste metal) to secure swing moorings as these can become dislodged and move along the bottom. It has also been reported that debris including engine blocks have been used for private moorings (Walker *et al.* 1989) which raises the issue of potential pollution output from the dump weights, including, but not limited to engine oil, fuel, coolant, metals *etc.* (cited from Griffiths *et al.* 2015). There was no evidence to indicate how this activity related to the pressure benchmark.						L
Category: Other man-made structures						
Cables: Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment or because of damage to cables with subsequent release of insulation fluids. Contamination may also occur due to accidents and technical faults during construction. These effects are mainly restricted	<	=	>		M	

to the installation, repair works and/or removal phase and are generally temporary. Spatial extent is limited to the cable corridor (in the order of 10m width if the cable has been ploughed into the seabed; (OSPAR 2009).						
Pipelines: Outflow pipes discharge a range of substances into the marine environment from industrial effluent, treated sewage, storm overflow and drainage Discharge from industrial outflow pipes can contain antifoulants and a range of synthetic compounds. Whilst heavily regulated there is a risk of damaging concentrations being released were issues to arise Outfall discharges can include a range of agricultural and industrial chemicals including organic and metal contaminants.	<	=	>		M	
Category: Energy generation						
Offshore Windfarms: Sediment disturbance may lead to resuspension of pollutants in sediment, this can occur through construction of turbines, ploughing for cables or through scouring of sediments.	<	=	>		M	
Oil and Gas: Construction: little evidence from construction, as with other activities that disturb the sediments, construction may remobilise sediments. **Oil and Gas: Maintenance and Operation:** The ban on discharges of diesel oil-based drilling fluids has reduced the impact, however oil may leak from old cutting piles (Ivensen *et al.* 2009). Contamination during operation will alter bio-assemblages (Olsgard % Somerfield 2009). **Oil and Gas Decommissioning**: Disturbance to drill cuttings piles during decommissioning or by subsequent activities (such as trawling) can scatter these over a wide area resulting in disturbance to marine organisms and creation of surface oil slick and resuspension of contaminated sediments (Ekins *et al.* 2006).	<	=	>		**M**	
Category: Extraction of living resources						
Fishing: No evidence for this pressure **Harvesting - seaweed and other sea-based food (bird eggs, shellfish, *etc.*):** No evidence for this pressure						

1. Regional to global drivers				
Evidence				
Climate	This pressure will not alter climate.			**L**
Depth	This pressure will not alter depth.			**L**
Geology	This pressure will not alter geology.			**L**
Propagule Supply	No evidence			
Water Currents	This pressure will not alter water currents.			**L**
LWave Exposure	This pressure will not alter wave exposure.			**L**
2. Water Column Processes				
Not assessed				
3. Local Processes/Inputs at the seabed				
Not assessed.				
4. Habitat and Bio-assemblages				
Not assessed by MarESA.				
5. Output processes				
Not assessed				
6. Local ecosystem functions				
Not assessed				
Knowledge Gaps				
There is a large, specialist literature on contaminants in marine environments, however within the project timescale it was not possible to review this.				

Appendix 9 Conservation Objective Attribute Proformas

Conservation Objective Attribute proforma 1. Extent and Distribution

Conservation Objective attribute	**Extent and distribution**

Conservation Objective attribute description

Extent refers to the total area in the site occupied by the qualifying feature and must include consideration of its distribution, i.e. how it is spread out within the site.

Conservation objective sub-attributes

Conservation objective sub-attributes for features that have been identified as relevant to extent and distribution include the following:

- substratum composition, and
- bio-assemblages.

Changes in extent and distribution that may result from the activities and pressures reviewed by this project are outlined briefly below. The pressure review Excel spreadsheet that accompanies this report contains the full references and additional information.

Pressures that interact with the Conservation objective attribute and sub-attributes

Pressure	**Pressure benchmark**			**Confidence**		
	<	**=**	**>**	**H**	**M**	**L**
Water flow (tidal current) changes - local, including sediment transport considerations. Changes in water flow can result in changes in sediment composition in aggregate dredge sites. Where current velocity is reduced by changes in topography infilling will be enhanced as finer particles can settle to the seabed (Hill *et al.* 2011). No evidence was found to assess whether the pressure meets the benchmark. Changes in sediment composition resulting from this pressure could alter extent and distribution of habitat types. Infrastructure can also alter the hydrodynamic regime, for example around offshore wind turbine bases where increases in scour and reductions in flow have been reported (Sanders *et al.* 2017).						**L**
Wave exposure changes – local Sediment composition in dredge pits and furrows can become finer- result of infilling from small particulate matter. Where current velocity is reduced by changes in topography, this infilling will be enhanced as finer particles can settle to the seabed (Hill *et al.* 2011).						L
Physical change (to another seabed/sediment type) Marine aggregate extraction can result in reductions in the extent, distribution and volume of subtidal sediment habitats. Extraction of the sediment can lead to changes in the sediment type and therefore the habitat that characterise an area of the seabed. Selective removal of gravels can lead to 'fining' of the residual sediments on the seabed, due to a relative increase in the proportion of sands (Cooper *et al.* 2007b; Hill *et al.* 2007). At a dredge site off the French coast of the Eastern English Channel the structure of the benthic community changed after dredging from one of coarse sands characterised by *Branchiostoma lanceolatum* to one of fine sands composed of many small infaunal polychaetes (Desprez 2000). Alternatively, sediments become coarser where sand is removed with no screening taking place (Hill *et al.* 2011). Sediment composition in dredge pits and furrows can become finer as a result of infilling from small particulate matter. Changes in currents may also result in long-term changes in sediment type (Hill *et al.* 2011). Changes to physical characteristics of habitat		=		H		

(sediment composition) will impact the ability of bio-assemblage to recover to pre dredge community composition (Hill *et al.* 2011). Dredge disposal can result in changes to sediments (OSPAR 2008) (see siltation and smothering below)						
Changes in suspended solids (water clarity) **Aggregate extraction** leads to this pressure, changes in suspended solids may lead to sediment/substratum alteration when deposited (see smothering and siltation pressures and physical change pressures). Changes in suspended solids may damage filter feeders altering the extent and distribution of the bio-assemblage. Construction, e.g. for offshore wind farms, can lead to reduced light penetration and reduced primary production and food supply (Sanders 2017).	<			H		
Habitat structure changes - removal of substratum (extraction) **Aggregate extraction**: Removal of substratum will remove associated bio-assemblages (Newell *et al.* 1998; Boyd *et al.* 2005; Hill *et al.* 2011). Most studies on the impact of dredging on marine benthic fauna show that dredging can result in a 40-95% reduction in the number and biomass of organisms and a 30-70% reduction in the number of species. The extent of the impact is often closely related to the intensity of dredging both in space and in time. In areas of low intensity dredging, for example where 20% of the seabed is removed in shallow dredge tracks, abundance and biomass can be reduced by 70-80% whilst species diversity may be reduced by 30%. When dredging intensity is higher, for example with repeated removal of sediment over a period of several days, reductions can be over 95% for abundance and biomass and almost 70% for diversity (Newell *et al.* 1998). Impacts are greater on benthic assemblages within coarser, stable sediment, characterised by attached epifauna. In stable areas, tracks were still visible after 5 years after cessation of dredging and sediment composition had not returned to pre-dredge conditions (Cooper *et al.* 2005). Period of recovery following cessation of dredging is site specific and depends on sediments and hydrodynamic regime (Tillin *et al.* 2011). Recovery can take less than one year in areas where sediment is more mobile or take decades or much longer where deposits are relict with no sediment transport occurring (Tillin *et al.* 2011).		=		H		
Abrasion/disturbance of the substratum on the surface of the seabed Abrasion can damage and remove epifauna from rock and sediment (Howarth *et al.* 2014; Kaiser *et al.* 2002). Chronic fishing pressure can result in long-term changes in bio-assemblage (Kaiser *et al.* 1996, Collie *et al.* 1997) although habitat sensitivity varies (Collie *et al.* 2002).		=		H		
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion Fishing activities that penetrate the substratum damage and remove species (Caddy 1973; Bergman & Hup 1992. Chronic fishing pressures can alter bio-assemblages, with loss of larger, longer-lived species, particularly those that are fragile and are epifauna. Recovery rates of sediment and bio-assemblages are more rapid in unstable, dynamic habitats than highly complex habitats found in more stable areas (Collie *et al.* 2002).		=		H		
Smothering and siltation changes (depth of vertical sediment overburden)-Light and heavy Dredge disposal can result in sediment becoming finer where silts and clays are deposited (OSPAR 2008). These habitat changes can alter the extent and distribution of habitats. Direct burial will often result in the immediate mortality of benthos (OSPAR 2008). Sessile epifauna outside of extraction areas can be eliminated by smothering (Hill *et al.* 2001).		=		H		

Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC. No evidence at the pressure benchmark.						
Transition elements & organo-metal (e.g. TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC. No evidence at the pressure benchmark.						
Introduction of other substances (solid, liquid or gas) No evidence at the pressure benchmark.						
De-oxygenation A covering layer of 1m for example, can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999). These effects will be cumulative with siltation and smothering, resulting in mortality of the benthos.			>		M	
Organic enrichment **Aggregate dredging:** organic enrichment resulting from aggregate dredging and input of damaged and dead organisms can alter composition of bio-assemblages outside the dredge area (MESL 2004, Newell *et al.* 2004). No evidence was found relevant to the pressure benchmark.						L
Nutrient enrichment No evidence was found relevant to the pressure benchmark. Sediment disturbance including cable laying (OSPAR 2012) can lead to increased nutrient releases into the water column and consequently may contribute to eutrophication effects locally.						L
Introduction or spread of non-indigenous species (INIS) Little evidence was found to assess this pressure. Human activities that introduce new hard artificial substrate can increase the numbers of non-indigenous species (Taormina *et al.* 2018).		=				L
Removal of non-target species Where non-target species characterise the habitat the loss of these through human activities may result in changes to the extent and distribution of the habitat. Examples of elimination of features include the loss of biogenic reefs. A substantial *Modiolus modiolus* reef was previously located south off the Isle of Man but was eliminated by intensive scallop dredging in the 1970s and 1980s (Rees 2009). Similarly, in Strangford Lough, Northern Ireland, reefs that used to cover extensive areas were reduced to isolated small clumps by scallop fishing (Rees 2009).		=		H		
Removal of target species Where non-target species characterise the habitat the loss of these through human activities may result in changes to the extent and distribution of the habitat. Surveys of the Port Erin closed area (closed 1989) off the Isle of Man demonstrated that the densities of some species (e.g. king scallops and edible crabs) were still increasing even after 17 years of protection after chronic fishing reduced populations.		=		H		

Conservation Objective Attribute proforma 2. Structure and Function

Conservation Objective attribute	**Structure and Function**					
Conservation Objective attribute description Structure encompasses both the physical structure of a habitat type together with the biological structure. Physical structure refers to finer scale topography and sediment composition and distribution. The biological structure refers to the key and influential species and characteristic communities present. Functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition. These functions rely on the supporting natural processes and the growth and reproduction of those biological communities which characterise the habitat and provide a variety of functional roles within it.						
Conservation objective sub-attributes						
Conservation objective sub-attributes for features that have been identified as supporting processes include the following: • physical structure: finer scale topography; • physical structure: sediment composition; • biological structure: key and Influential species; • biological structure: characteristic communities; and • ecological processes. Changes in structure and function that may result from the activities and pressures reviewed by this project are outlined briefly below. The pressure review Excel spreadsheet that accompanies this report contains the full references and additional information.						
Pressures that interact with the Conservation objective attribute and sub-attributes						
Pressure	**Pressure benchmark**			**Confidence**		
	<	=	>	H	M	L
Water flow (tidal current) changes - local, including sediment transport considerations. Changes in water flow can result in changes in physical structure by altering sediment erosion and deposition regime. In aggregate dredge sites, changes in topography may result in decreased current velocity in pits resulting in finer particles settling to the seabed (Hill *et al.* 2011). No evidence was found to assess whether the pressure meets the benchmark. Changes in sediment composition resulting from this pressure can alter extent and distribution of habitat types through changes in structure and function.						L
Wave exposure changes – local Changes in wave exposure can result in changes in physical structure by altering sediment erosion and deposition regime. No evidence was found to assess this pressure.						L
Physical change (to another seabed/sediment type) Marine aggregate extraction can result in reductions in the physical and biological structure of habitats. Cooper *et al.* (2007b) noted that a depositional 'footprint' associated with the dredging plume could be identified on the seabed for approximately 3-4km from the dredging area in a dynamic environment with strong currents re-mobilising sediments from the seabed. At a dredge site off the French coast of the Eastern English Channel the structure of the benthic community changed after dredging from one of coarse sands characterised by *Branchiostoma lanceolatum* to one of fine sands composed of many small infaunal polychaetes (Desprez 2000). Alternatively, sediments become coarser where sand is removed with no screening taking place (Hill *et al.* 2011). Sediment composition in dredge pits and furrows can		=		H		

become finer as a result of infilling from small particulate matter. Changes in currents may also result in long-term changes in sediment type (Hill *et al.* 2011). Changes to physical characteristics of habitat (sediment composition) will impact the ability of bio-assemblage to recover to pre-dredge community composition (Hill *et al.* 2011). Dredge disposal can result in changes to sediments (OSPAR 2008) (see siltation and smothering below).						
Changes in suspended solids (water clarity) **Aggregate extraction** leads to this pressure, changes in suspended solids may lead to sediment/substratum alteration when deposited (see smothering and siltation pressures and physical change pressures). Changes in suspended solids may damage filter feeders altering the extent and distribution of the bio-assemblage. Construction, e.g. for offshore wind farms can lead to reduced light penetration and reduced primary production and food supply (Sanders 2017).	<			H		
Habitat structure changes - removal of substratum (extraction) **Aggregate extraction**: Removal of substratum will remove associated bio-assemblages (Newell *et al.* 1998; Boyd *et al.* 2005; Hill *et al.* 2011). Most studies on the impact of dredging on marine benthic fauna show that dredging can result in a 40-95% reduction in the number and biomass of organisms and a 30-70% reduction in the number of species. The extent of the impact is often closely related to the intensity of dredging both in space and in time. In areas of low intensity dredging, for example where 20% of the seabed is removed in shallow dredge tracks, abundance and biomass can be reduced by 70-80% whilst species diversity may be reduced by 30%. When dredging intensity is higher, for example with repeated removal of sediment over a period of several days, reductions can be over 95% for abundance and biomass and almost 70% for diversity (Newell *et al.* 1998). Impacts are greater on benthic assemblages within coarser, stable sediment, characterised by attached epifauna. In stable areas, tracks were still visible after 5 years after cessation of dredging and sediment composition had not returned to pre-dredge conditions (Cooper *et al.* 2005). The recovery period following cessation of dredging is site specific and depends on sediments and hydrodynamic regime (Tillin *et al.* 2011). Recovery can take less than one year in areas where sediment is more mobile or take decades or much longer where deposits are relict with no sediment transport occurring (Tillin *et al.* 2011). Extraction of sediments creates furrows and pits altering the seabed topography (Boyd *et al.* 2003; Hill *et al.* 2011) and potentially associated factors such as localised currents and deposition and erosion processes.		=		H		
Abrasion/disturbance of the substratum on the surface of the seabed Abrasion can damage and remove epifauna from rock and sediment (Howarth *et al.* 2014; Kaiser *et al.* 2002). Chronic fishing pressure can result in long-term changes in bio-assemblage (Kaiser *et al.* 1996, Collie *et al.* 1997) although habitat sensitivity varies (Collie *et al.* 2002). Abrasion flattens small scale sediment features such as mounds and pits (Currie and Parry 1996). The 11-year closure of an area to scallop dredging enhanced scallop stocks but also enhanced habitat complexity and biodiversity (Bradshaw *et al.* 2003).		=		H		
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion Fishing activities penetrate the substratum and damage and remove species (Caddy 1973; Bergman & Hup 1992). Chronic fishing pressures can alter bio-assemblages, with loss of larger, longer-lived		=		H		

species, particularly those that are fragile and are epifauna. Recovery rates of sediment and bio-assemblages are more rapid in unstable, dynamic habitats than highly complex habitats found in more stable areas (Collie *et al.* 2002). Fishing activity (e.g. trawls, dredges) reduces habitat complexity and fine scale sediment topography by smoothing bedforms (e.g. sand waves and ripples), removing emergent epifauna (e.g. sponges, worm tubes, amphipod tubes, mussels, hydroids, and anthozoans) and species that produce structures such as pits and burrows (e.g. crabs and fishes) (Auster *et al.* 1999). The 11-year closure of an area to scallop dredging enhanced scallop stocks but also enhanced habitat complexity and biodiversity (Bradshaw *et al.* 2003). Penetration and disturbance may alter the functioning of marine ecosystems by reducing species richness and by negatively impacting more vulnerable functional groups (Tillin *et al.* 2006). Loss of abundant species may have impacts on marine food webs (Hinz *et al.* 2008). The loss of habitat structure generally leads to lower abundance, biomass and often species richness (Airoldi *et al.* 2008) altering the structure and function of habitats.						
Smothering and siltation changes (depth of vertical sediment overburden) - Light and heavy Dredge disposal can result in sediment becoming finer where silts and clays are deposited (OSPAR 2008). These habitat changes can alter the structure and function of habitats. Direct burial will often result in the immediate mortality of benthos (OSPAR 2008). Sessile epifauna outside of extraction areas can be eliminated by smothering (Hill *et al.* 2001). An increase in suspended particulates and subsequent increased deposition of organic matter in sheltered environments where sediments have high mud content will increase food resources to deposit feeders. This may lead to a shift in community structure with increased abundance of deposit feeders and a lower proportion of suspension feeders (as feeding is inhibited where suspended particulates are high and the sediment is destabilized by the activities of deposit feeders (Rhoads & Young 1970)).		**=**		**H**		
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC. No evidence at the pressure benchmark.						
Transition elements & organo-metal (e.g. TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC. No evidence at the pressure benchmark.						
Introduction of other substances (solid, liquid or gas) No evidence at the pressure benchmark.						
De-oxygenation A covering layer of 1m of sediment can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999). These effects will be cumulative with siltation and smothering, resulting in mortality of the benthos.			**>**		**M**	
Organic enrichment **Aggregate dredging:** organic enrichment resulting from aggregate dredging and input of damaged and dead organisms can alter composition of bio-assemblages outside the dredge area (MESL 2004; Newell *et al.* 2004). No evidence was found relevant to the pressure benchmark.						**L**

Nutrient enrichment No evidence was found relevant to the pressure benchmark. Sediment disturbance including cable laying (OSPAR 2012) can lead to increased nutrient releases into the water column and consequently may contribute to eutrophication effects locally.						**L**
Introduction or spread of non-indigenous species (INIS) Little evidence was found to assess this pressure. Human activities that introduce new hard artificial substrate can increase the numbers of non-indigenous species (Taormina *et al.* 2018). The invasive species *Crepidula fornicata* alters sediments through biodeposition. Barbier *et al.* (2017), found that banks of *C. fornicata*, supported higher species richness and abundance than sedimentary habitats, highlighting the positive influence of this habitat on bivalve recruitment dynamics but also the changes in habitat structure and function resulting from invasion.		**=**				**L**
Removal of non-target species Where non-target species characterise the habitat the loss of these through human activities may result in changes to the extent and distribution of the habitat. Examples of elimination of features include the loss of biogenic reefs. A substantial *Modiolus modiolus* reef was previously located south off the Isle of Man but was eliminated by intensive scallop dredging in the 1970s and 1980s (Rees 2009). Similarly, in Strangford Lough, Northern Ireland, reefs that used to cover extensive areas were reduced to isolated small clumps by scallop fishing (Rees 2009).		**=**		**H**		
Removal of target species Where non-target species characterise the habitat the loss of these through human activities may result in changes to the extent and distribution of the habitat. Surveys of the Port Erin closed area (closed 1989) off the Isle of Man demonstrated that the densities of some species (e.g. king scallops and edible crabs) were still increasing even after 17 years of protection after chronic fishing reduced populations.		**=**		**H**		

Conservation Objective Attribute proforma 3. Supporting Processes

Conservation Objective attribute	Supporting processes

Conservation objective attribute description

Subtidal habitats and the communities they support rely on a range of natural processes to support function (ecological processes) and help any recovery from adverse impacts. For a designated site to fully deliver conservation benefits set out in the statement on conservation benefits, the following natural supporting processes must remain largely unimpeded - hydrodynamic regime and water and sediment quality.

Conservation objective sub-attributes

Conservation objective sub-attributes for features that have been identified as supporting processes include the following:

- hydrodynamic regime including wave exposure and water currents
- water quality and,
- sediment quality.

Changes in supporting processes that may result from the activities and pressures reviewed by this project are outlined briefly below. The pressure review Excel spreadsheet that accompanies this report contains the full references and additional information.

Pressures that interact with the Conservation objective attributes and sub-attributes

Pressure	Pressure benchmark			Confidence		
	<	=	>	H	M	L
Water flow (tidal current) changes - local, including sediment transport considerations. No evidence was found to relate evidence to the pressure benchmark. Changes in water are reported from aggregate dredge sites. Changes in topography can result in changes in water velocity (Hill *et al.* 2011). Current speeds may increase or decrease as a result of aggregate extraction, A study showed that even in particularly extreme cases of dredging, changes in current speeds close to the coast were negligible. Infrastructure can also alter the hydrodynamic regime, for example around offshore wind turbine bases where increases in scour and reductions in flow have been reported (Sanders *et al.* 2017).					M	
Wave exposure changes – local **Aggregate Dredging:** Published industry guidance states that changes in wave transformation due to aggregate extraction are unlikely to be problematic at the coastline if the activity occurs in water depths of greater than 15m (Boyd *et al.* 2004). Aggregate extraction undertaken on sand or gravel banks or bars will lower the crest level so that wave attenuation across the feature may be reduced, increasing wave exposure on adjacent features (Newell and Woodcock 2013). This change is likely to exceed the pressure benchmark.			>		M	
Physical change (to another seabed/sediment type) Physical changes in sediment						
Changes in suspended solids (water clarity) Aggregate extraction, maintenance dredging and fishing activities using mobile demersal gears may result in this pressure. Changes in suspended solids may result in transport of sediments and associated contaminants in the surrounding areas, remobilisation of contaminants in the water phase enhancing the bioavailability and ecotoxicological risk, release of nutrients resulting in increase in eutrophication and direct impact on organisms due to reduced transparency and consumption of oxygen (OSPAR 2009).	<				M	

Habitat structure changes - removal of substratum (extraction) **Aggregate extraction.** The physical removal of substratum would not directly affect supporting processes, but may result in changes in wave exposure, water currents and resuspension of sediments (as outlined above). Removal of sediment may also expose underlying sediments that are anoxic, or contaminated altering sediment quality within a site.						
Abrasion/disturbance of the substratum on the surface of the seabed Not directly relevant but is likely to result in changes in suspended solids as outlined above.						
Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion Not directly relevant but is likely to result in changes in suspended solids as outlined above.						
Smothering and siltation changes (depth of vertical sediment overburden)-Light and Heavy Not directly relevant but is likely to result in changes in suspended solids as outlined above.						
Hydrocarbon & PAH contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC Disturbance to drill cuttings piles during decommissioning or by subsequent activities (such as trawling) can scatter these over a wide area resulting in disturbance to marine organisms and creation of surface oil slick and resuspension of contaminated sediments (Ekins *et al.* 2006). **Cable and pipeline laying.** Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment or because of damage to cables with subsequent release of insulation fluids. Contamination may also occur due to accidents and technical faults during construction (OSPAR 2012). **Moorings** Debris including engine blocks have been used for private moorings (Walker *et al.* 1989) which raises the issue of potential pollution output from the dump weights, including, but not limited to engine oil, fuel, coolant, metals *etc.* (cited from Giffiths *et al.* 2017).						
Synthetic compound contamination (incl. pesticides, antifoulants, pharmaceuticals). Includes those priority substances listed in Annex II of Directive 2008/105/EC. **Cable and pipeline laying.** Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment or because of damage to cables with subsequent release of insulation fluids. Contamination may also occur due to accidents and technical faults during construction (OSPAR 2012). **Moorings** Debris including engine blocks have been used for private moorings (Walker *et al.* 1989) which raises the issue of potential pollution output from the dump weights, including, but not limited to engine oil, fuel, coolant, metals *etc.* (cited from Giffiths *et al.* 2017).						
Transition elements & organo-metal (e.g. TBT) contamination. Includes those priority substances listed in Annex II of Directive 2008/105/EC. **Cable and pipeline laying.** Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment or because of damage to cables with subsequent release of insulation fluids. Contamination may						

also occur due to accidents and technical faults during construction (OSPAR 2012). **Moorings** Debris including engine blocks have been used for private moorings (Walker *et al.* 1989) which raises the issue of potential pollution output from the dump weights, including, but not limited to engine oil, fuel, coolant, metals *etc.* (cited from Giffiths *et al.* 2017).						
Introduction of other substances (solid, liquid or gas) No evidence at the pressure benchmark						
De-oxygenation **Dredge disposal:** A covering layer of 1m can change the redox conditions in the former surface layer considerably and anoxic conditions (oxygen deficiency and sulphide production) may develop shortly after the disposal (Essink 1999). These effects will be cumulative with siltation and smothering. In extreme cases sediment infilling by fine sediments can lead to 'anoxic' or low oxygen conditions in the pits and furrows. This can be a particular problem in large sediment pits, such as those created by anchor dredging, where infilling by particularly fine particles carried with tidal currents occurs (Newell *et al.* 1998). In such areas the concentration of oxygen in the porewaters declines due to biological demand (respiration) and is not replenished because of limited water movement between very fine particles.			**>**		**M**	
Nutrient enrichment Sediment disturbing activities and aquaculture may result in nutrient enrichment. Very little evidence was found to assess this pressure. Modelled responses of the plankton community to simulated trawling responses revealed that bottom trawling may trigger considerable productivity pulses, in addition to pulses from the natural seasonal cycle (Dounas *et al.* 2007). These changes alter water quality, although there was no evidence to relate this to the pressure benchmark or impacts on the conservation objective attribute.						**L**
Introduction or spread of non-indigenous species (INIS) No evidence found. Non-indigenous species may alter sediment and water quality, for example the replacement of deposit feeder dominated sediments by filter feeders may increase water quality, through clearance of contaminants and suspended solids.		**=**				**L**
Removal of non-target species Removal of species that contribute to waste remediation could result in changes in sediment and water quality.		**=**				**L**
Removal of target species Removal of species that contribute to waste remediation could result in changes in sediment and water quality.		**=**				**L**

Appendix 10 Ecosystem service review proformas

Ecosystem Service Proforma 1. Primary Production

Proforma 1	**Intermediate Service (Potts *et al.* 2014): Primary production**

Ecosystem Service Description
This service is defined as the production of plant biomass (Fletcher *et al.* 2011). This service is an intermediate service and ecosystem process that supports processes and ecosystem services and marine food webs.

Specific node in model, added to models or based on existing nodes?

Primary production is represented in the CEMs as an output process. This node is supported by bio-assemblages that are primary producers: kelp, brown algae, green algae, and red algae.

Any categories used to assess service provision.
Primary production in the water column is a node in this model. The node to assess the level of primary production by the bio-assemblage was included in the MESO BBN models.

<u>Contribution to this service: Bio-assemblage</u>
We created a four-point scale to assess contribution of bio-assemblages as follows:

- None: Bio-assemblage or component does not represent primary producers;
- Low: 0.25kg/m^2/yr e.g. Sparse *Saccharrina latissima* in sand habitats; small red algae;
- Medium: 0.5 - 2kg/m^2/yr e.g. saltmarsh/seagrass;
- High: 5 - 10kg/m^2/yr e.g. stands of canopy forming brown algae or dense macroalgal beds; 15 kg/m^2/yr e.g. Kelp forests.

1. Regional to Global Drivers		**Confidence**
Climate	Mediates (High): Temperature mediates plant growth rates and other processes such as reproduction (see water chemistry and temperature). Climate also influences storminess, wave exposure and may therefore determine habitat suitability (see sections below). Increased temperatures related to anthropogenic climate change may impact the structure of kelp forests and the ecosystem services they provide (Smale *et al.* 2016).	High
Depth	Mediates (High): Through light attenuation and habitat suitability for macroalgae with changes in community at different depths (Markager & Sand-Jensen 1992; Laffoley & Grimsditch 2009).	High
Geology	Mediates (High): Through habitat suitability, requirements for attachment vary for macroalgae and some are free living or present in sediment, e.g. *Saccharina latissima* in the Sand CEM, however the densest macroalgal stands occur on rock substratum.	High
Propagule supply	Mediates (High): Through provision of macroalgal spores.	High
Water currents	Mediates (High): Through habitat suitability for bio-assemblages that provide this service. Nutrient limitation related to low water flow can limit growth (Mann 1982, cited in Scottish Government 2016). Primary producers also alter hydrodynamic output processes by attenuating water flow (Blight & Thompson 2008), see Natural Hazard Regulation proforma.	High
Wave exposure	Mediates (High): Through habitat suitability for species including kelps (Birkett *et al.* 1998), for example, *Laminaria hyperborea* density, biomass, morphology and age are generally greater in exposed sites (Smale *et al* 2016). At high levels of exposure (EUNIS A3.1) kelp may be replaced by more robust animal communities, and at lower levels of exposure to (EUNIS A3.3) turbidity and sediment abrasion may reduce productivity (eftec 2014).	High

2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates (High): Reduced oxygen concentrations can inhibit both photosynthesis and respiration in macroalgae (Kinne 1977). Primary producers also affect dissolved oxygen levels through nutrient cycling, for example, through conversion of carbon dioxide and other inorganic dissolved nutrients into organic material and oxygen (Hasselström *et al.* 2018).	High
Primary production	Mediates (High): Primary production in the water column is directly linked to provision of this service by the ecosystem.	High
Suspended Sediment	Mediates (High): Through light attenuation (see below). Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub surface light attenuation (Kd) (Devlin *et al.* 2008) and photic zone (Cloern 1987).	High
Light Attenuation	Mediates (High): Light availability and water turbidity are principal factors in determining depth range at which macroalgae can be found (Birkett *et al.* 1998) and are key factors influencing ecosystem services based on marine primary producers (Alexander *et al.* 2016). Kelp canopy biomass and the standing stock of carbon are positively correlated with large-scale wave fetch and light levels and negatively correlated with temperature (Smale *et al.* 2016). Light attenuation by macroalgal canopies supports low light adapted algae (Alonso *et al.* 2012).	High
Water Chemistry and temperature	Mediates (High): Water temperature affects all provisioning services and is considered critical to ecosystem service generation (Alexander *et al.* 2016). Temperature may mediate habitat suitability setting the range limits for a species (Hoek 1982; Müller *et al.* 2009), temperature may also determine other biological processes such as rates of growth and reproduction (Lee & Brinkhuis 1988). Smale *et al.* (2016) found that kelp canopy biomass and the standing stock of carbon were positively correlated with large-scale wave fetch and light levels and negatively correlated with temperature. Water chemistry also affects nutrient availability, with nutrient limitation identified as a limiting factor for growth (Mann 1982, cited in Scottish Government 2016). Alterations to features such as dissolved oxygen, pH, and dissolved compounds caused by a poor state of the environment are likely to have knock-on effects on marine flora and fauna (Alexander *et al.* 2016).	High
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Not relevant: However, the following food sources are primary producers; diatoms, phytobenthos, plankton. Primary producers do not directly consume the identified food sources.	NR
Grazing and predation	Mediates (Low): Grazing as a pressure mediates the supply of primary production. Excessive grazing by sea urchins can denude entire kelp forests. However, in more persistent stands grazers typically consume only a small fraction of the kelp that is produced (Reed & Brzezinski 2009). Herbivory is generally low in kelp forests, with less than 10% of live kelp biomass thought to be consumed by grazers (Norderhaug & Christie 2011), and 80% being exported as detritus (Burrows *et al.* 2014; Wernberg & Filbee-Dexter 2018).	High
Seabed Mobility	Mediates (habitat suitability): In the natural environment, values for maximum productivity are 10 times higher for a seaweed stand than for a plankton population due to the fixed position of a seaweed on a substrate (Lüning 1990). This ecological advantage allows macroalgae to form a stable, multi-layered, perennial vegetation capturing almost every photon falling on a	High

	square metre of rocky bottom, as in a dense terrestrial forest, where almost no light reaches the forest floor (Lüning & Pang 2003).	
Recruitment	Mediates (High) supply of primary producers. See larval and gamete supply (proforma 2).	High
4. Habitat and Bio-assemblages		
Kelp	Kelp forests are acknowledged as one of the most productive ecosystems on earth (Dayton 1985; Steneck *et al.* 2002; Smale *et al.* 2013). On Atlantic coasts, kelp primary production can be in excess of 1,000gC/m^2/yr (Mann 1973; Smale *et al.* 2013), and that from *Laminaria* species has been estimated at between 110 and 1,780gC/m^2/yr (Mann 1973, 2000), while primary production from phytoplankton in coastal temperate regions is typically between 100 and 300gC/m^2/yr (Mann 2000). In Scotland, kelp biotopes are estimated to cover 8000km^2 (Walker 1953), and account for around 45% of primary production in UK coastal waters (Smale *et al.* 2013). *Laminaria hyperborea* is grazed directly by species such as *Patella pellucida*, however approximately 80% of primary production is consumed as detritus or dissolved organic material (Krumhansl 2012) which is both retained within and transported out of the parent kelp forest, providing valuable nutrition to potentially low productivity habitats such as sandy beaches (Smale *et al.* 2013). Walker (1954) estimated an area of 2,900km^2 of kelp habitat in Scotland alone out of a total sublittoral area of 8,000km^2, which may produce 3.6Mt/C/yr at typical production rates of 1,300gC/m^2/yr (Dayton 1985). Kelps therefore make a substantial contribution to primary production in coastal waters off the UK and Ireland. The categories for primary production are based on production rates of *Laminaria hyperborea* in the Isle of Man (Kain 1977), where annual productivity (dry weight) of dense kelp patches was estimated as 15kg/ m^2/yr. Primary production rates vary between species, seasons and regions (Pessarrodona *et al.* 2019). Deriving estimates of standing stock biomass, and therefor primary production, is challenging because the biomass density and the cross-shore width varies greatly with species, time (both seasonally and inter-annually) and location (both within and among sites) (Reed & Brzezinski 2009). *Laminaria hyperborea* has a typical seasonal growth pattern with growth starting in January, peaking in March and ending in June (Schaffelke & Lüning 1994). *Laminaria hyperborea* reaches a maximum height of 2–4m (Abdullah *et al.* 2017). Due to extensive recent peer reviewed literature, confidence is assessed as high.	
Brown Algae	Limited evidence was found on the primary production rates of brown algae. As large primary producers capable of fast growth, they are assessed to provide high levels of primary production at low confidence.	
Green Algae	Limited evidence was found on the primary production rates of green algae. As primary producers which generally reach smaller sizes than kelp or brown algae, they are assessed to provide low levels of primary production at low confidence.	
Red Algae	Limited evidence was found on the primary production rates of red algae. As primary producers which generally reach smaller sizes than kelp or brown algae, they are assessed to provide low levels of primary production at low confidence. Bamber and Irving (1993, cited in Tillin *et al.* 2015) reported that *Corallina officinalis* reached a biomass of between 3.3 - 6.7kg/m². Littler *et al.* (1979, cited in Tillin *et al.* 2015) determined the total daily productivity of an intertidal	

	algal population in California, which peaked in autumn at 1.22gC fixed /m²/day, and declined in winter to a spring low of 0.47gC fixed /m²/day.
Grazers	Mediates output: Herbivory appears to be low in kelp and influence is assessed as low but with low confidence.
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Not relevant: However, macroalgae may trap sediments supporting biodeposition which in turn supports nutrient cycling (see proforma 3).
Bioengineering	Not relevant: Primary producers do support bioengineering, (see proforma 4).
Hydrodynamic flow	Mediates: Macroalgae may alter hydrodynamic flows, (see proforma 5).
Bioturbation	Mediates: Bioturbation supports primary production in the marine environment through nutrient cycling (see proforma 3).
Primary production	Provision: Marine primary producers contribute at least 50% of the world's carbon fixation and may account for as much as 71% of all carbon storage (Chung *et al.* 2011). Primary production at the seabed occurs through microphytobenthos and macroalgae. Benthic algae contribute some 10% of the total marine primary production (Charpy-Roubaud & Sournia 1990). Kelp may conservatively account for around 45% of primary production in UK coastal waters and 12% of marine production in the entire UK EEZ. This estimate for annual UK kelp production does not include the extensive shallow subtidal rocky reef habitats found off England and Wales and will therefore be an underestimate. Although these coarse estimates should be interpreted with caution, it is clear that kelps make a substantial contribution to primary production in coastal waters off the UK and Ireland (Smale *et al.* 2013).
Secondary production	Not relevant: Kelp detritus, as broken plant tissue, particles and dissolved organic material supports soft bottom communities outside the kelp bed itself (Stamp & Hiscock 2015).
Habitat modification	Not relevant (but see geology above). Macroalgae primary producers create habitat (see proforma 4). Kelp forests are the primary habitat for many commercial and recreational fisheries that include a wide diversity of molluscs, crustaceans, and finfish (Laffoley & Grimsditch 2009 and references therein).
Supply of propagules	Not relevant to service but primary producers support propagules that may be transported to other habitats (see proforma 2).
6. Local ecosystem functions	
Biogeochemical cycling	Supports: Primary production underpins marine food webs and supports biogeochemical cycling (see proforma 3).
Control of algal growth	Not relevant: Primary production is an output of algal growth. Excessive grazing by sea urchins can denude entire kelp forests however, in more persistent stands grazers typically consume only a small fraction of the kelp that is produced (Reed & Brzezinski 2009).
Food resource	Not relevant: Primary production provides food to other species. However, herbivory is generally low in kelp forests, with less than 10% of live kelp biomass thought to be consumed by grazers (Norderhaug & Christie 2011), and 80% being exported as detritus (Burrows *et al.* 2014; Wernberg & Filbee-Dexter 2018). The flow of detritus between habitats is an important form of connectivity that affects regional productivity and the spatial organization of marine ecosystems. Kelps produce detritus through incremental blade erosion, fragmentation of blades, and dislodgement of whole fronds and thalli. Rates of detrital production range from 8 to 2657gC/m^2/yr for blade erosion and fragmentation, and from 22 to 839gC/m^2/yr for loss of fronds and thalli. The estimated global average rate of detrital production by kelps is 706 gC/m^2/yr, accounting for 82% of annual kelp productivity (Krumhansl & Scheibling 2012) (see Nutrient Cycling proforma 3). Detrital production rates are regulated by current and wave-driven hydrodynamic forces and are highest during severe storms and following blade weakening through damage by grazers and encrusting epibionts. Detritus settles within kelp beds or forests and is exported to neighbouring or distant habitats, including sandy beaches, rocky intertidal shores, rocky and sedimentary subtidal areas, and the deep sea. Exported kelp

	detritus can provide a significant resource subsidy and enhance secondary production in these communities ranging from tens of meters to hundreds of kilometres from the source of production. Loss of kelp biomass is occurring worldwide through the combined effects of climate change, pollution, fishing and harvesting of kelp, which can depress rates of detrital production and subsidy to adjacent communities, with large-scale consequences for productivity (Krumhansl & Scheibling 2012).
Habitat provision	Primary production indirectly supports habitat provision through the growth of algae that provide habitat for other species including photosynthesising epiphytes (see proforma 4).
Microbial activity	Provision: Where primary producers are maintained or enhanced.
Nutrient cycling	Supports: The availability of nutrients is a key component in controlling the abundance and diversity of marine flora which produce provisioning ecosystem services. A reduction in nutrient availability is therefore likely to reduce the delivery of any ecosystem services produced, and a total absence of nutrients is likely to result in non-delivery of any ecosystem service (Alexander *et al.* 2016). Nutrients are transported by water movement and *in situ* primary production may not rely on nutrient cycling within the biotope.
Population control	Mediates: Control of local grazers will support biomass production of algae.
Sediment stability	Supports: Where sediment stability supports primary producers.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: Where biodiversity increases support primary production.
Biotope maintenance	Supports: Where the biotope that is maintained supports primary production.
Biotope stability	Supports: Where stability refers to a biotope supporting primary production.
Carbon sequestration	Marine primary producers contribute at least 50% of the world's carbon fixation and may account for as much as 71% of all carbon storage (Chung *et al.* 2011). Kelps are the major primary producers in UK marine coastal waters producing nearly 75% of the net carbon fixed annually on the shoreline of the coastal euphotic zone (Birkett *et al.* 1998). Kelp plants produce 2.7 times their standing biomass per year. The kelps reduce ambient levels of nutrients, although this may not be significant in exposed sites, but increase levels of particulate and dissolved organic matter within the bed.
Export of biodiversity	Not relevant.
Export of organic matter	Not relevant to primary production within habitat. Mediates as part of wider marine food webs supporting nutrient cycling. Primary production may lead to the export of organic matter. The vast majority (>80%) of kelp-derived organic matter is typically exported from the kelp forest, rather than being consumed or remineralised within the source habitat (Krumhansl & Scheibling 2012).
Knowledge Gaps	
Production by kelp has been estimated by a number of studies and is well supported (see Smale *et al.* 2013 for overview), estimates of primary production by other components including microphytobenthos are less understood.	

Ecosystem Service Proforma 2. Larval and gamete supply

Ecosystem Service	**Larval and gamete supply Intermediate service** **CICES 2.2.2.1 Pollination (or 'gamete' dispersal in a marine context)**

Ecosystem Service Description
Transport of larvae and gametes (Fletcher *et al.* 2011).

CICES 2.2.2.1 Pollination (or 'gamete' dispersal in a marine context). The CICES service description is clear that this service relates to species that people use or enjoy. The examples selected refer to commercially harvested species and those of specific conservation interest.

Specific node in model, added to models or based on existing nodes?
This intermediate service is not included in the MESO BBN model.

Any categories used to assess service provision.
The ecological components, supply of propagules and recruitment relate to this ecosystem service. As part of the assessment factors that influence settlement and recruitment have been considered.

Notes: All members of the bio-assemblage are considered to support this service, although no attempt has been made to quantify this service. Recruitment will also be supported by habitat provision (see Ecosystem Service proforma 4).

1. Regional to Global Drivers		**Confidence**
Climate	Mediates: Spawning of organisms is frequently related to temperature. In association with rising mean spring temperatures in the Irish Sea, a time-series of juvenile scallop *Pecten maximus* density around the Isle of Man showed a significant increasing trend since 1991 (Shepard *et al.* 2010).	High
Depth	Mediates: Habitat suitability for recruits and is likely to affect dispersal.	Medium
Geology	Mediates: Recruitment of polychaetes and crustaceans is known to be impacted by a number of factors including the sediment grain size, organic and chemical content, porosity and contour of subtidal sediment ecosystems (Fletcher *et al.* 2012 and references therein).	High
Propagule supply	Provides: This ecological component represents this ecosystem service, the supply of propagules represents the service, while habitat suitability and other factors will determine the level of recruitment (survival).	Not relevant
Water currents	Mediates: High. Effects will depend on habitats and species considered and may be habitat specific. Larvae may be concentrated by the hydrographic regime or swept to neighbouring or removed sites (Olaffson *et al.* 1994). Larval transport by water currents is relevant to species that have pelagic larval stages and will act for longer on species where the duration of the pelagic stage is prolonged. The ratio of species with benthic vs pelagic life stages may vary between habitats. Eliott *et al.* (1998) note that sandy areas are usually dependent on an input of colonizing organisms and have few species with benthic reproduction. Hence, recruitment is sensitive to changes in the hydrodynamic regime. Sandbanks in particular may be recruitment sinks as they often occur at the centre of hydrographic gyres (Elliott *et al.* 1998). *Ostrea edulis* restoration research programmes agree that successful natural recovery is dependent on a suite of factors: larval recruitment, local environmental conditions, hydrographic regime, and most crucially the presence of suitable settlement substrate, in particular, adult shells or shell debris.	High

Wave exposure	Mediates (high): Site suitability and recruitment success and may transport larvae and juveniles. Juvenile *Cerastoderma edule* may be transported by currents until 2mm in size and high densities of juveniles may be swept away by winter storms resulting in subsequent patterns of adult distribution (Olaffsson *et al.* 1994)	Medium
2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates (High): Water column conditions will influence larval and gamete survival.	
Primary production	Supports (High): Larvae that feed on plankton.	
Suspended Sediment	Mediates: Water column conditions will influence larval and gamete survival.	
Light Attenuation	Mediates: Water column conditions will influence larval and gamete survival, settlement and feeding.	
Water Chemistry and temperature	Mediates (High): Water chemistry and temperature will influence spawning and survival of larvae within the water column.	
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Mediates: Chemical cues from food sources induce settlement (Hadfield *et al.* 2001). Confidence is assessed as medium for each individual food source.	
Grazing and predation	Mediates: The reproductive success and recruitment of scallops (i.e. the number of individuals surviving juvenile development and entering the fishery) is influenced by a multitude of factors including ecological interactions such as predator density (Howarth and Stewart, 2014 and references therein).	
Seabed Mobility	Mediates: The reproductive success and recruitment of scallops (i.e. the number of individuals surviving juvenile development and entering the fishery) is influenced by a multitude of factors including the availability of suitable settlement habitat (Howarth and Stewart 2014, and references therein). Surface sediment geochemistry can have significant effects on recruitment rates of benthic invertebrates (Hadfield *et al.* 2001; Engstrom & Marninelli 2005).	
Recruitment	Provision: This component supports larval and gamete supply.	
4. Habitat and Bio-assemblages		
Preferential settlement on adults of same species	Studies have shown that mature Ostreidae produce chemical signals that are conveyed by adult conspecifics and induce the settlement of larvae (Tamburri *et al.* 2008; Walne 1958). The concentrated release of these chemicals by adult conspecifics from oyster assemblages is the driver for dense gregarious localized settlements. *Mytilus edulis* was identified as a settlement substrate at Kilkienan and Bertraghboy Bays, Connemara, Ireland, when it was reported that large numbers of oyster spat (>78) were attached to single mussel valves. *Mytilus edulis* shells were used the following year as a cultch material on barren mud substrates within the bays, and as a result spat settlement increased by >40%.	
Deposit and suspension feeders	High densities of adults, suspension feeders and surface deposit feeders together with epibenthic predators and physical disturbance result in high post settlement mortality rate of larvae and juveniles (Olafsson *et al.* 1994).	
5. Output processes relevant to ecosystem service		
Evidence		
Biodeposition	Mediates: Increased sedimentation has been shown to have a negative impact on the recruitment and survival of sessile invertebrates (Teagle *et al.* 2017 and references therein). Biodeposition will provide chemical cues that influence larval settlement (Hadfield *et al.* 2001).	
Bioengineering	Mediates: See Proforma 4 for more information on habitat provision.	
Hydrodynamic flow	Mediates: Changes in hydrodynamics caused by macroalgae and seagrass canopies may alter the supply and dispersal of algal propagules and invertebrate larvae, thereby affecting settlement processes (Teagle *et al.* 2017	

	and references therein). Mussel beds may alter water flow, which can influence the recruitment of macrofauna including the settlement of larvae as well as redistribution of settled individuals (Salomidi *et al.* 2012 and references therein).
Bioturbation	Mediates: Chemical cues that influence larval settlement (Hadfield *et al.* 2001).
Primary production	Mediates: Chemical cues that influence larval settlement (Hadfield *et al.* 2001).
Secondary production	Mediates: Chemical cues that influence larval settlement (Hadfield *et al.* 2001).
Habitat modification	Mediates: Habitat suitability, hydrodynamics and recruitment. Physical disturbance caused by the scouring of the seabed by kelp thalli has been shown to have negative effects on the abundance of some morphological (i.e. erect) forms of understorey algae (Teagle *et al.* 2017 and references therein). The invasive species *Crepidula fornicata* alters sediments through biodeposition. Barbier *et al.* (2017), found that banks *of C. fornicata*, supported higher species richness and abundance than sedimentary habitats, highlighting the positive influence of this habitat on bivalve recruitment dynamics. See Proforma 4 for more information on habitat provision.
Supply of propagules	Provision.
6. Local ecosystem functions	
Biogeochemical cycling	Mediates: Surface sediment geochemistry can have significant effects on recruitment rates of benthic invertebrates (Engstrom and Marninelli, 2005; Hadfield *et al.* 2001).
Control of algal growth	Mediates: Food resources and chemical cues that influence settlement (Hadfield *et al.* 2001).
Food resource	Mediates: Habitat quality for larvae and provides chemical cues that influence settlement (Hadfield *et al.* 2001).
Habitat provision	Mediates: Habitat provision will enhance larval and gamete supply from the species that it supports. Habitat quality is species specific and will depend on a range of factors (see Proforma 4 for further information).
Microbial activity	Mediates: Biofilms provide chemical cues that influence settlement (Hadfield *et al.* 2001).
Nutrient cycling	Mediates: Food resources and chemical cues that influence settlement (Hadfield *et al.* 2001).
Population control	Mediates: Many benthic invertebrates will consume larvae and gametes. For example, the feeding activities of high densities of *Polydora ciliata* may inhibit the establishment of other benthic species by removing settling and developing larvae (Daro & Polk 1973). Similarly, grazers can remove or prevent propagules establishing on rock surfaces; grazing by littorinid snails prevents algal canopies establishing (Jones *et al.* 1994).
Sediment stability	Mediates: Surface sediment geochemistry can have significant effects on recruitment rates of benthic invertebrates (Engstrom & Marninelli 2005).
7. Regional to global ecosystem functions	
Biodiversity enhancement	Mediates: Biodiversity is likely to enhance the supply of larvae and gametes, but this may not result in enhanced recruitment.
Biotope maintenance	No evidence
Biotope stability	No evidence
Carbon sequestration	No evidence
Export of biodiversity	Provision of service to adjacent habitats
Export of organic matter	Not relevant to service provision

Knowledge Gaps
While the factors that drive larvae and gamete supply and provide settlement cues are relatively well understood. There is little evidence on recruitment success related to ecological processes and functions. Recruitment for some species will be episodic and patchy. It is considered likely that all biological components have the capacity to provide this service, although some populations that are subject to stress may not be reproducing or recruiting.

Ecosystem Service Proforma 3. Nutrient cycling

<table>
<tr><td>Proforma 3</td><td colspan="2">Nutrient cycling (Intermediate Service, Potts et al. 2014)</td></tr>
<tr><td colspan="3">Ecosystem Service Description
Nutrient cycling refers to the transformation of chemical elements from inorganic form in the environment to organic form in organisms and, via decomposition, back to inorganic form (Begon et al. 1996). The best-studied aquatic nutrient cycles are those of carbon, nitrogen and phosphorus.

Nutrient cycling is classified as an intermediate ecosystem service (Potts et al. 2014) and does not have a direct CICES equivalent. Nutrient cycling underpins food webs and hence, function and productivity of the system. This ecosystem service therefore links to other ecosystem services (Armstrong et al. 2012) including provisioning ecosystem services such as wild harvested and cultivated organisms such as fish (Beaumont et al. 2007), shellfish and plants. Nutrient cycling also supports other regulating services such as waste breakdown and carbon absorption, reducing CO_2 in the atmosphere and thereby diminishing the rate of the anthropogenic climate change (eftec 2014).

Nutrient cycling is undertaken in many components of the marine environment, particularly within seabed sediments in shallow coastal waters and in the water column in deeper, offshore waters (Beaumont et al. 2007). Important processes supporting nutrient cycling are bacterial processing of nutrients, nitrification and denitrification supported by bioturbation, the turnover of sediments which moves nutrients at the surface to deeper layers and returns buried nutrients to the sediment surface (Covich et al. 2004). this final function is supported mainly by burrowing polychaete worms (eftec 2014).</td></tr>
<tr><td colspan="3">Specific node in model, added to models or based on existing nodes?
The MESO BBN includes nutrient cycling as a local ecosystem function node supported by secondary and primary production, biodeposition and bioturbation processes resulting from the bio-assemblage.</td></tr>
<tr><td colspan="3">Any categories used to assess service provision.
Primary and secondary production, biodeposition and bioturbation. Contribution to primary and secondary production by biota was assessed and the assessment values were used to parameterise the MESO BBN and are presented in the accompanying Excel spreadsheet.</td></tr>
<tr><td colspan="3">Comments and notes: This review focuses on the carbon and nitrogen cycle.</td></tr>
<tr><td colspan="3">1. Regional to Global Drivers</td></tr>
<tr><td>Climate</td><td>Mediates: The net effect of climate change on carbon and nitrogen cycles is difficult to predict because the interaction of processes is too complex to evaluate (Voss et al. 2013). Climate mediates water column stratification, nutrient transport and mixing through winds, waves and currents. Ocean acidification and decreased gas solubility temperature mediates plant growth rates and other biological processes (see water chemistry and temperature). Climate also influences storminess, wave exposure and may therefore determine habitat suitability (see sections below).</td><td>High</td></tr>
<tr><td>Depth</td><td>Mediates: Through light attenuation and habitat suitability for macroalgae with changes in community at different depths (Markager & Sand-Jensen 1992; Laffoley & Grimsditch 2009).

As dissolved organic matter sinks, the bioavailable organic matter decreases as it is assimilated by bacteria and at depth the fraction of the substrate that is remineralised to CO_2 vs assimilated increases.</td><td>High</td></tr>
<tr><td>Geology</td><td>Mediates: Sediments play a fundamental role in recycling fixed nitrogen to the water column: it is estimated that up to 80% of the nitrogen needed by primary producers in shallow shelf seas is provided by benthic (sea floor) remineralisation reactions. Through habitat suitability, the contribution to different aspects of nutrient cycling will vary between habitat types. Mud habitats provide a significant contribution to nitrification and denitrificaton.</td><td>High</td></tr>
<tr><td>Propagule supply</td><td>Mediates: Through maintenance of bio-assemblages that provide this service.</td><td>High</td></tr>
<tr><td>Water currents</td><td>Mediates: Through supply and distribution of nutrients from riverine inputs (Voss et al. 2013), including dissolved and particulate forms.</td><td>High</td></tr>
</table>

	Currents will also mediate habitat suitability for bio-assemblages that provide this service. Nutrient limitation related to low water flow can limit growth of macroalgae (Mann 1982, cited in Scottish Government 2016). Detrital production rates by kelp (and presumably other macroalgae) are regulated by current and wave-driven hydrodynamic forces and are highest during severe storms and following blade weakening through damage by grazers and encrusting epibionts (Krumhansl & Scheibling 2012). Primary producers also alter hydrodynamic output processes by attenuating water flow (Blight & Thompson 2008), see Natural Hazard Regulation proforma.	
Wave exposure	Mediates: Through habitat suitability for species including kelps (Birkett *et al.* 1998). For example, *Laminaria hyperborea* density, biomass, morphology and age are generally greater in exposed sites (Smale *et al.* 2016). At high levels of exposure (EUNIS A3.1) kelp may be replaced by more robust animal communities, and at lower levels of exposure (EUNIS A3.3) turbidity and sediment abrasion may reduce productivity (eftec 2014). Wave exposure will also influence transport of nutrients.	High
2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates: Oxygen controls the distributions of nitrogen cycle processes by virtue of some microbial reactions requiring oxygen and others being inhibited by it. Denitrification and anammox, occur only in the near or total absence of oxygen (Voss *et al.* 2013). Reduced oxygen concentrations can inhibit both photosynthesis and respiration in macroalgae (Kinne 1977). Primary producers also affect dissolved oxygen levels through nutrient cycling, for example, through conversion of carbon dioxide and other inorganic dissolved nutrients into organic material and oxygen (Hasselström *et al.* 2018). Low oxygen and anoxia that result in the loss of macrofauna will result in the loss of secondary production and contribution to nutrient cycling by these organisms. Low oxygen removes large bioturbating organisms reducing bioturbation and consequently loss of that function which supports nutrient cycling (see bioturbation below).	High
Primary production	Provision: Phytoplankton living in surface waters drive the nitrogen cycle (Voss *et al.* 2013). Production by phytoplankton is the first step in organic matter cycling in the upper ocean whereby dissolved inorganic carbon and other chemical elements (e.g., reactive nitrate, ammonia, phosphorous, silicon and iron) are fixed into organic matter. Ultimately, this organic matter is either respired or remineralised by microbial activity in the water column leading to high levels of nutrient cycling. Organic matter may also sink to the sea floor where it is processed by the bio-assemblages (see below).	High
Suspended Sediment	Mediates: Suspended sediment mediates primary production in the water column. Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub-surface light attenuation (Kd) (Devlin *et al.* 2008) and controls the photic zone (Cloern 1987).	Medium
Light Attenuation	Mediates: Suspended sediment mediates primary production in the water column and the rate of nutrient mineralisation. Phytoplankton living in surface waters often consumes all inorganic nutrients down to a depth where ambient light level is 1–0.1% of the surface (Voss *et al.* 2013).	High
Water Chemistry and temperature	Mediates: The temperature of the water influences habitat suitability for bio-assemblages through physiological thermal tolerances and mediates biological processes such as microbial activity and rates of primary production (Voss *et al.* 2013). Stratification mediates the interaction between water column and substratum and the degree of exchange of dissolved nutrients and particulate matter between these. Below the thermocline, oxygen levels may reduce (see dissolved oxygen node).	High

3. Local Processes/Inputs at the seabed	
Evidence	
Food Sources	Provision: Pelagic marine organisms produce carbon compounds that are both organic (POC and DOC) and inorganic (mostly CaCO3). They respire part of the organic compounds within the upper ocean and these dissolved compounds will be remineralised either within the water column or in marine sediments. When organisms die and sink decomposition and remineralisation will begin in the water column or on, or within, sediments. The sinking of organic material from the water column contributes to the deep transfer of organic and inorganic materials. Respiration by organisms leads to the remineralisation of organic carbon back to CO_2, and in the case of organic nitrogen (i.e. proteins and amino acids), the release of NH4 and urea. The latter are nutrients assimilated by phytoplankton and sometimes bacteria (Legendre & Rivkin 2005).
Grazing and predation	Provision: Heterotrophic organisms change the size and bioavailability of organic matter. Changes in size may be due to the processing of organic substrate or food (Legendre & Rivkin 2005). Grazers and predators contribute to nutrient cycling through respiration and excretion of organic matter and by breaking organic matter into smaller parts while feeding that can be broken down by decomposers.
Seabed Mobility	Mediates: Flux of organic matter and other nutrients by governing rates of sequestration and storage and re-suspension and solute fluxes to the water column. Disturbance by fishing will have a similar effect and re-suspend organic matter and nutrients.
Recruitment	Mediates: Supply of primary and secondary producers that underpin nutrient cycling. See larval and gamete supply (see Ecosystem Service proforma 2).
4. Habitat and Bio-assemblages	
Bioturbators	Bioturbating organisms play an important role in nutrient cycling. Benthic macrofauna stimulate sediment/water column fluxes of dissolved species through bioturbation of burrow structures. Bioturbation mixes sediment and porewater causing vertical transport of dissolved solutes at rates very much greater than could be achieved by diffusion alone (Braeckman *et al.* 2010). Bioirrigation - the flushing of a burrow by its occupant, leading to the transport of solutes within the burrow and into the surrounding sediment
Filter feeders/ suspension feeders (biodeposition)	Filter feeding organisms capture organic matter from the water column and re-deposit this either as faeces or pseudofaeces on or within sediments. This organic matter can then be remineralised by microbes. A study of natural patches of mussels showed that carbon and nitrogen content of sediment was higher in mussel patches compared to the surrounding sand community. Measurements of community metabolism showed that the associated community found in mussel patches depends on mussel biodeposition for 24 to 31% of its energy demand (Norling & Kautsky 2007).
Primary production	Primary production by macroalgae and benthic microphytobenthos. Although less well studied production by microphytobenthos is likely to be a significant component of total marine primary production (eftec 2014).
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Supports: Biodeposition by filter feeders captures organic material from the water column and deposits it on the surface as faeces and pseudofaeces where organic matter will be recycled by detritivores and decomposers and remineralised by microbes.
Bioengineering	Mediates (Low). Bioengineering traps sediments and organic matter and, in the cases of filter feeding reefs, biodeposition is further enhanced supporting nutrient cycling (Norling & Kautsky 2007).
Hydrodynamic flow	Mediates (Low): Supply of dissolved and particulate organic matter and nutrients.
Bioturbation	Supports (High): The density and size of animal burrows in sediments can substantially affect both the direction and magnitude of nitrogen flux across the sediment-water interface (Aller 1982, 1988). Nitrate fluxes out of the sediment

	appear to increase substantially with increasing burrow wall thickness, defined as burrow abundance divided by burrow radius (Pilskaln *et al.* 1998).
Primary production	Provision: (High) Primary production is a route by which carbon (as CO_2) and all other nutrient elements (as simple organic molecules), ions in the atmosphere or as dissolved ions in water) can enter the trophic structure of a food web through photosynthesis. These are released when complex compounds are metabolised and released in simple inorganic form which may be rapidly recycled by other plants.
Secondary production	Provision: Secondary Production consumers incorporate nutrients into biomass and also respire, excrete and return these to the ecosystem. Excretion or diffusion releases nutrients into the water column or incorporated into detrital or faecal matter. The particulate organic matter may be consumed by filter or detrital feeding benthos. Rates of secondary production of benthic macroinvertebrates are indicative of the trophic transfer of nutrients between autotrophs and heterotrophs through the direct consumption of plant biomass or plant detrital material (captured as phytoplankton, microphytobenthos or as detrital or dissolved matter) and the cycling of nutrients between secondary consumers through the consumption of prey and decaying organic matter from other secondary consumers. Some macroinvertebrates may also capture dissolved nutrients. The size of this pool also indicates the relative availability of biomass to higher trophic consumers including larger, mobile macroinvertebrates, fish and birds.
Habitat modification	Mediates (Low): Changes to habitat can alter factors that influence nutrient cycling. The presence of shells of *Mytilus edulis* influence the benthic boundary layer by creating microturbulence) and physically trapping drifting matter resulting in an increase in organic and nutrient content of sediments (Norling & Kautsky 2007).
Supply of propagules	Supports: Propagule supply supports this service by maintaining the bio-assemblages that deliver the service. Propagules may be ingested by heterotrophs and therefore are part of organic matter cycling through food chains.
6. Local ecosystem functions	
Biogeochemical cycling	Provision: Processes of biogeochemical cycling and nutrient cycling overlap. This node is therefore directly relevant to the ecosystem service nutrient cycling.
Control of algal growth	Supports: Primary production and consumption
Food resource	Provision (High): Directly supports nutrient cycling.
Habitat provision	Supports: Through support for bio-assemblage.
Microbial activity	Provision: Microbes play a key role in nutrient cycling. Microbes mediate nitrification (oxidation of ammonium to nitrite and nitrate). Across the globe, microbes account for almost half of primary production and in the marine environment they form a major part of ecosystem respiration and nutrient recycling (Holmlund & Hammer 1999).The efficiency of the microbial loop is determined by the density of marine bacteria within it (Taylor and Joint, 1990). It has become clear that bacterial density is mainly controlled by the grazing activity of small protozoans and various taxonomic groups of flagellates.
Nutrient cycling	Provision: Node represents this service.
Population control	Mediates: Population control may alter rates and pathways of nutrient cycling.
Sediment stability	Mediates: Sediment stability is likely to change rates of nutrient cycling. Increases in disturbance may favour smaller, opportunistic species over larger species with lower productivity/biomass ratios (see Jennings *et al.* 2002, fishing references).
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: biodiversity enhancement supports nutrient cycling.
Biotope maintenance	No evidence.
Biotope stability	No evidence.
Carbon sequestration	Mediates: Carbon sequestration removes carbon from nutrient cycling.

Export of biodiversity	No evidence.
Export of organic matter	Provision: The flow of detritus between habitats is an important form of connectivity that affects regional productivity and the spatial organization of marine ecosystems. The estimated global average rate of detrital production by kelps is 706gC/m^2/yr, accounting for 82% of annual kelp productivity (Krumhansl & Scheibling 2012) (see primary production proforma 1). Detritus settles within kelp beds or forests and is exported to neighbouring or distant habitats, including sandy beaches, rocky intertidal shores, rocky and sedimentary subtidal areas, and the deep sea. Exported kelp detritus can provide a significant resource subsidy and enhance secondary production in these communities ranging from tens of meters to hundreds of kilometres from the source of production. Loss of kelp biomass is occurring worldwide through the combined effects of climate change, pollution, fishing, and harvesting of kelp, which can depress rates of detrital production and subsidy to adjacent communities, with large-scale consequences for productivity (Krumhansl & Scheibling 2012).
Knowledge Gaps	
This service is relatively well understood and underpins other ecosystem services provided by the biota. Effects of ecosystem processes and functions are less understood.	

Ecosystem Service Proforma. 4 CICES 2.2.2.3 Maintaining nursery populations and habitats

Ecosystem Service	**Intermediate Service (Potts *et al.* 2014): Formation of Species habitats. CICES 2.2.2.3 Maintaining nursery populations and habitats**

Ecosystem Service Description
Potts *et al.* (2014) identified formation of species habitats as an intermediate service, that is defined as formation of the physical properties of the habitats necessary for the survival of species (Fletcher *et al.* 2011).

The CICES service "maintenance of nursery populations and habitats" or "habitats for species" has been identified as controversial to assess by Liquete *et al.* (2016) who reviewed the definition and indicators across assessments. The main reasons behind this are that this ecosystem service could be interlinked or correlated with other services that directly rely on it (e.g. fisheries) or can be interpreted as referring to biodiversity components and ecosystem functions (i.e. nursery function). In the UK NEA, follow on nursery habitats were not included as a final service and the functions were split between two intermediate services 'larval and gamete supply' and 'formation of species habitats' (Liquete *et al.* 2016). For the purposes of this project we have assessed the provision of habitat complexity by species as habitat complexity increases nursery functions and species richness across a range of biological groups (see bio-assemblage sections for relevant examples).

A nursery can be defined as a habitat that contributes more than the average, compared with other habitats, to the production of individuals of a particular species that recruit to adult populations (Beck *et al.* 2001). The main factors that facilitate reproduction and recruitment are density, growth and survival of juveniles, movement to adult habitats, or a combination of those (Beck *et al.* 2001). Most habitats are likely to provide this service at some level.

For this project we have used habitat provision by biota as a proxy for the supply of this service. Marine organisms can create complex habitats above and below the sediment surface. Below sediment surface structures (burrows) are assessed through the bioturbation node in the MESO BBN models. Biological habitats can provide nursery functions and provide refugia from predators and increase feeding (Beaumont *et al.* 2007). The bioengineering/habitat provision node is understood to refer to above surface habitat structural elements include the presence of large bivalves, sponges, hydroids and surficial sediment characteristics (Thrush *et al.* 2001; Auster 1998).

Habitats identified as providing notable nursery area functions include maerl beds seagrass beds (and areas of dense macrophytes), all of which have been shown to harbour high densities of commercially exploited species such as spider crabs, juvenile cod, *Gadus morhua*, edible crabs, *Cancer pagurus* and edible sea urchins, *Echinus esculentus* (Howarth & Stewart 2014 and references therein).

<u>Contribution to this service: Bio-assemblage</u>
A number of classification schemes exist for habitat complexity. We created a 4-point scale informed by Auster *et al.* (1998) with bio-assemblages assigned as follows:
None: infauna, predatory epifauna, mobile epifauna
Low: mounds/pits
Medium: tube building, low reef/mat forming
High: Solitary epifauna/sparse epiflora
High: Biogenic reef forming organisms/dense macroalgae

Specific node in model, added to models or based on existing nodes?
The ecological component nodes linked to this service are habitat provision which is defined as 'provision of living space for other organisms through surface attachment of increased habitat complexity'. Bioengineering which was present in some of the original CEM models and defined as 'faunal modification of the natural habitat e.g. tube building, burrow creation *etc.*', was not used in the final MESO models. This service was considered captured through habitat provision and bioturbation model nodes.

Comments: The factors that create high quality nursery areas will be species specific. However, given the evidence base that suggest more complex habitats provide nursery habitats for some commercial species the intermediate and final CICES ecosystem services were considered for purposes of assessment to be equivalent.		
1. Regional to Global Drivers		**Confidence**
Climate	Mediates: Through habitat suitability for bio-assemblages that provide this service. Responses to climate are species specific. For example, De Raedemaecker *et al.* (2012) found that high quality nursery grounds for dab and plaice differed and anthropogenic and climatic impacts on flatfish nurseries are likely to have a different impact on plaice and dab populations. Decreases in the average size of populations of gorgonians (through thermal stress-related mortalities) may negatively affect habitat complexity, which may in turn have significant effects on local biodiversity (Fletcher *et al.* 2012 and references therein).	High
Depth	Mediates: Through habitat suitability for bio-assemblages that provide this service. Recruited assemblages differ between habitats according to sediment grain-size composition and bathymetric levels (Barbier *et al.* 2017). De Raedemaecker *et al.* (2012) found that plaice and dab differ in depth associations.	High
Geology	Mediates: Through habitat suitability for bio-assemblages that provide this service. Recruited assemblages differ between habitats according to sediment grain-size composition and bathymetric levels (Barbier *et al.* 2017). Many commercially targeted fish species, such as Atlantic cod and sand eels, utilize coarse (sand and gravel) sedimentary habitats. For example, gravel habitats provide spawning substrate for the eggs of some demersal fish species and act as nursery grounds for other fish species (Fletcher *et al.* 2012). Sedimentary preferences are likely to be species specific, Hooper *et al.* (2017), were able to score potential nursery area quality for different sediment types across several commercially targeted species in the North Devon Biosphere.	High
Propagule supply	Mediates: Through supply and subsequent recruitment of bio-assemblages that provide this service.	Medium
Water currents	Mediates: Through habitat suitability for bio-assemblages that provide this service. For example, *Sabellaria spinulosa* tend to occur in areas of high-water movement where larvae, tube building materials and food particles are suspended and transported. Armonies and Reise, (2003) found a distinct patch of high macrobenthic species richness occurred where flood waters persistently form a large gyre which may enhance larval settlement.	High
Wave exposure	Mediates: Through habitat suitability for bio-assemblages that provide this service.	High
2. Water Column Processes		
Evidence		
Primary production	Mediates: Through habitat food provision for some bio-assemblages that provide this service.	High
Suspended Sediment	Mediates: Through habitat suitability for some bio-assemblages that provide this service. Some tube building species such as *Sabellaria spinulosa* rely on the water transport of suspended sediment particles.	High
Light Attenuation	Mediates: Through habitat suitability for bio-assemblages that provide this service.	High
Water Chemistry and temperature	Mediates: Through habitat suitability for bio- assemblages that provide this service.	High
Dissolved oxygen	Mediates: Through habitat suitability for bio-assemblages that provide this service.	High

3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Mediates (High): Through habitat suitability for bio-assemblages that provide this service. Confidence in individual food sources is low as the importance of each in providing the service is unclear.	High
Grazing and predation	Mediates: Through biological control of bio-assemblages that provide this service.	Low
Seabed Mobility	Mediates: Through habitat suitability for bio-assemblages that provide this service. Habitat provision may feedback to this node and enhance sediment stability.	Low
Recruitment	Mediates: Through supply of recruits that supply this service. A study has found that not all suitable sites are occupied by macrobenthos possibly due to limitations affecting larval settlement and/or juvenile survival (Armonies & Reise 2003). Habitat provision will feedback to this node and enhance recruitment of some species.	High
4. Habitat and Bio-assemblages		
Tube building fauna	Tube building fauna vary from colonial reef building worms (*Sabellaria spp.)* that build large, relatively robust reefs to fragile tubes constructed by solitary organisms. In areas of mud, the tubes built by *Polydora ciliata* can agglomerate and form layers of mud an average of 20cm thick, occasionally up to 50cm (Daro & Polk 1973). Key reef building organisms that enhance species richness include *Sabellaria spinulosa* (Atrill *et al.* 1996) and *Lanice conchilega* (Callaway 2006; Rabaut *et al.* 2009, cited from Fletcher *et al.* 2012).	
Erect epifauna	Organisms that attach to the seabed are functionally important to marine ecosystems as they provide an element of 3-dimensional structure to often otherwise featureless seafloors. In doing so, they supply important refuges for small / juvenile fish from predators and unfavourable environmental conditions (Monteiro *et al.* 2002; Ryer *et al.* 2004; Cacabelos *et al.* 2010), represent important feeding sites for fish and invertebrates (Bradshaw *et al.* 2003; Warren *et al.* 2010) and provide essential habitat for the settlement of scallop spat and a range of other organisms, including the settlement of further epifauna (Howarth *et al.* 2011). Upright hydroids, for example, have been found to provide an attachment surface for scallops, nudibranchs, bryozoans, barnacles, sponges, tube-dwelling worms and other hydroids (Bradshaw *et al.* 2001).	
Bivalve reefs	Marine bivalves are common in many benthic sedimentary environments and have major modifying effects on localised ecosystems that produce habitats for other organisms. They are, therefore, an important group of ecosystem engineers. Mussel beds form complex sub-habitats made up of shells and a byssus thread network. They are found intertidally and subtidally and harbour an associated micro- and macro-faunal and floral community. Commercially important whelks (*Buccinum undatum*) catches were three times higher on Horse mussel (*Modiolus modiolus*) reef sites and a greater number of smaller individuals were caught on the reefs compared to off-reef habitats (Kent *et al.* 2016).	
Macroalgae	Kelp forests are the primary habitat for many commercial and recreational fisheries that include a wide diversity of molluscs, crustaceans and finfish (Laffoley & Grimsditch 2009 and references therein). Shape and structural complexity of macroalgae are important factors in determining patterns of abundance and size structure of associated epifaunal organisms. The most structurally complex algae harbour more abundant and diverse assemblages of invertebrates because among other effects, they provide a larger availability of surface for colonisation by fauna and epiphytic algae (Cacabelos *et al.* 2010 and references therein).	
Burrowing species	Burrowing species that do not produce structures (tubes or alterations in sediment topography) were not considered to provide this service.	
Mobile and sessile epifauna, predators and scavengers	Predatory species were not considered to provide this service as they would consume other species and larvae.	

5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Not relevant to service supply. Bioengineering may enhance biodeposition; for example, the tubes of *Lanice conchilega* retain fine sediment particles (Rabaut *et al.* 2007).
Bioengineering	Provision: Species that contribute to habitat provision are bioengineers.
Hydrodynamic flow	Not relevant to service provision. Bioengineers may alter hydrodynamic flows.
Bioturbation	Not relevant: Habitat provision may alter the rate of this service by excluding bioturbators through space occupancy.
Primary production	Not relevant to service provision. Species that provide this service may be primary producers.
Secondary production	Not relevant to service provision. Species that provide this service may be secondary producers.
Habitat modification	Provision: Species that contribute to habitat provision modify the habitat.
Supply of propagules	Not relevant: Note that habitat provision, by definition, may enhance supply of propagules and recruitment (see Proforma 2).
6. Local ecosystem functions	
Biogeochemical cycling	Not relevant to service provision. Species that provide habitat are part of nutrient cycles and bioengineering may enhance rates of biogeochemical cycling. For example, underlying sediments may become oxygenated by the activities of amphipods within their tubes (Mills,1967).
Control of algal growth	Not directly relevant to service provision. Note bioengineering may provide or enhance this service.
Food resource	Not relevant to service provision. Note bioengineering may provide or enhance this service.
Habitat provision	Provision. Node relates to this service.
Microbial activity	Not relevant to service provision. Note bioengineering may enhance this service.
Nutrient cycling	Not relevant to service provision. Species that provide habitat are part of nutrient cycles and bioengineering may enhance rates of biogeochemical cycling. Note bioengineering may enhance rates.
Population control	Not relevant to service provision. Note habitat providers may provide or enhance this function.
Sediment stability	Not relevant to service provision. Bioengineering may provide or enhance this service For example, in the Thames estuary, Attrill *et al.* (1996) discovered that in an area where *Sabellaria spinulosa* was among the most abundant fauna, species richness in this area was much higher than in surrounding areas due to the stability of the sediment and the high number of available niches. More than 200 species of invertebrates were recorded over a three-year period in <5m² (Attrill *et al.* 1996).
7. Regional to global ecosystem functions	
Biodiversity enhancement	Not relevant to service provision. Biodiversity and associated bioengineering may provide or enhance this service. For example, *Sabellaria spinulosa* reefs enhance species richness (Atrill *et al.* 1996). In offshore circalittoral sand habitats, the high densities of one tube-building polychaete, *Owenia fusiformis*, has been shown to increase the number and abundance of other polychaetes as their tube structures provide refuge from predators and improve sediment stability (Paramour and Frid, 2006 and references therein). Thrush *et al.* (2001) found a positive relationship between soft-sediment biodiversity and habitat structures. Small-scale macrofaunal biodiversity is affected directly or indirectly by attached epifauna (sponges, hydroids, *etc.*) (Thrush *et al.* 2001). Microhabitats may enhance individual survival through predator avoidance and prey capture (Auster *et al.* 1995). Norling (2009) found that *Mytilus spp.* enhance species diversity, with scale of effects depending on substratum.
Biotope maintenance	Not relevant to service provision. Note bioengineering may provide or enhance this function.

Biotope stability	Not relevant to service provision. Note bioengineering may provide or enhance this function.
Carbon sequestration	Not relevant to service provision. Note habitat provision may provide or enhance this function, through carbon fixation and storage.
Export of biodiversity	NR: Note bioengineering may provide or enhance this service.
Export of organic matter	NR: Note bioengineering may provide or enhance this service.
Knowledge Gaps	
The level of service supplied is difficult to quantify and provision of habitat complexity has been used as a proxy for this service. All habitats may support nursery functions not just those where organisms create habitat complexity. For example, subtidal gravel and sand sediments are often important as nursery areas for fish such as plaice (*Pleuronectes platessa*) (Jones *et al.* 2000). Fine sand sediment can also provide refuge for juvenile flatfish, which are able to bury themselves in the sand to avoid predators (Paramour & Frid 2006 and references therein). Contribution to this service by different ecological components is likely to vary spatially and temporally. Work by Armonies and Reise (2003) shows that organisms are not always present in suitable services and therefore, even similar habitats judged to have the same capacity to provide the service will provide different, site-specific realised levels of the service that may vary over time.	

Ecosystem Service Proforma 5. CICES 2.2.1 Regulation of baseline flows and extreme events

Ecosystem Service	Intermediate Service (Potts *et al.* 2014): Formation of Physical barriers; Natural Hazard Regulation CICES 2.2.1 Regulation of baseline flows and extreme events (biotic) CICES 5.2.1.2 Regulation of baseline flows and extreme events: Liquid flows (abiotic)

Ecosystem Service Description

Potts *et al.* 2014 describe two intermediate services relevant to this pressure:
Formation of physical barriers. Formation of structures that attenuate (or block) the energy of water or wind flow (Fletcher *et al.* 2011) and Natural Hazard Regulation 'Regulating the formation of physical barriers service'.

The relevant (biotic) CICES Group: Regulation of baseline flows and extreme events, recognises three classes of service:

- CICES 2.2.1.1. Control of erosion rates; provided by macroalgae, microphytobenthos, macrophytes and biogenic reef structures (epifauna) that all contribute through sediment stabilisation.
- CICES 2.2.1.2 Buffering and attenuation of mass movement, described as the reduction in the speed of movement of solid material by virtue of the stabilising effects of the presence of plants and animals (this service class was considered not relevant); and
- CICES 2.2.1.3 Hydrological cycle and water flow regulation (Including flood control and coastal protection). The CICES description refers to the regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems. We have considered that wave attenuation is part of this service. Wave attenuation is defined as the reduction in wave energy or wave height resulting from friction when a wave passes over intertidal or shallow subtidal features (including shallow sandbanks) (eftec 2014).

CICES also recognises an abiotic dimension to this service which is captured as CICES 5.2.1: Regulation of baseline flows and extreme events. Within this group only the class 'Liquid flows' (CICES 5.2.1.2) was considered relevant to sublittoral habitats.

Specific node in model, added to models or based on existing nodes?

The original CEM nodes that relate to provision of this service are the output processes biodeposition and bioengineering and the elements of the bio-assemblage that support these. These nodes contribute to the relevant local ecosystem functions sediment stability and habitat provision. THE MESO BBN models did not include bioengineering as this refers to both habitat provision by epifauna and within sediment structures such as burrows. A separate bioturbation node was added.

CICES 2.2.1.1 Control of erosion rates is provided by the bio-assemblage and the node biodeposition. Sediment erodability, is dependent on the interactions between physical processes, sediment properties and biological processes, particularly, the balance between two functional groups of biota, the stabilisers and the destabilisers (Widdows & Brinsley 2002). Bio-stabilisers can influence the hydrodynamics and provide some physical protection to the bed (e.g. mussel beds, macroalgae) or can enhance cohesiveness and alter the critical erosion threshold (e.g. microphytobenthos). In contrast, bio-destabilisers (e.g. bioturbators such as *Macoma balthica*, *Hydrobia ulvae*) increase surface roughness, reduce the critical erosion threshold and enhance the erosion rate. The CEM node 'habitat provision' at high levels was considered to relate to this ecosystem service but confidence in the link is medium as it is likely to be highly variable. The MESO BBN includes a bioturbation node, this node is inversely related to control of erosion as bioturbating organisms destabilise sediments (Rhoads & Young 1974).

CICES 2.2.1.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection) is provided by epifaunal elements of the bio-assemblage that by friction reduce water current and wave energy. The level of attenuation will depend on depth and density.

CICES 5.2.1.2 Liquid flows was considered represented by the geology node.

<table>
<tr><td colspan="3">This service is delivered by the biological and the abiotic habitat assemblage:
CICES 2.2.1.1. Control of erosion rates: categories relate to the presence of epifauna, their size, robustness, physical complexity and other characteristics. Categories relate to habitat provision (low, medium and high) as a proxy for this service except for bio-assemblages found on rock, which also include the abiotic habitat and provision is assessed as High. Confidence is medium in this link.

CICES 2.2.1.3 Hydrological cycle and water flow regulation; categories relate to habitat provision (low, medium and high) as a proxy for this service. Confidence is medium in this link.

CICES 5.2.2: Regulation of baseline flows and extreme events. Provision of the abiotic service regulation of liquid flows, was categorised within the MESO model based on Liquete et al. (2013) as:
High: Rock, hard substratum or biogenic reef; coarse or mixed substrata (as well as bio-assemblages that are found on rock).
Medium: shallow sands
Low: shallow muds</td></tr>
<tr><td colspan="3">1. Regional to Global Drivers</td></tr>
<tr><td>Climate</td><td>Mediates habitat suitability for biota that provide the biotic service.</td><td>High</td></tr>
<tr><td>Depth</td><td>Mediates habitat suitability for biota that provide the biotic service and the degree of wave attenuation that bio-assemblages and habitats provide. Habitats below the wave base will not support wave attenuation.</td><td>High</td></tr>
<tr><td>Geology</td><td>Provision: The presence of hard substratum that ‘armours’ the coastline and the extent of this protection supports this service. Wave attenuation occurs when a wave passes over intertidal or shallow subtidal features (including shallow sandbanks). All coastal habitats potentially contribute to wave attenuation. Contribution to this service was categorised within the MESO model based on Liquete et al. (2013) (see above).

Offshore sand banks shelter adjacent coasts by increased friction reducing wave energy and storm surges. The degree of attenuation is situation specific and may vary temporally depending on water depth above the bank. The extent of these features relative to inshore coastline provides an indication of the extent of the area that is afforded reduced wave attenuation. Similarly, inshore coastal habitats all provide some degree of wave attenuation with the level varying between habitat types as some lead to greater friction and wave energy dissipation.</td><td>High</td></tr>
<tr><td>Water Currents</td><td>Mediates both requirements for service and provision by sediment transport.</td><td>High</td></tr>
<tr><td>Wave Exposure</td><td>Mediates both requirements for service and provision by sediment transport.</td><td>High</td></tr>
<tr><td>Propagule supply</td><td>Mediates: Via supply of biota that provide the biotic service.</td><td>High</td></tr>
<tr><td colspan="3">2. Water Column Processes</td></tr>
<tr><td colspan="3">Evidence</td></tr>
<tr><td>Dissolved oxygen</td><td>Mediates: Habitat suitability for species that provide this service.</td><td>High</td></tr>
<tr><td>Primary production</td><td>Not relevant: Primary production in the water column does not support this service.</td><td>Not relevant</td></tr>
<tr><td>Suspended Sediment</td><td>Mediates: Benthic diatom and macroalgae growth through light attenuation (see below).</td><td>High</td></tr>
<tr><td>Light Attenuation</td><td>Mediates: At depth, light attenuation prevents the growth of benthic diatoms; at sites studied at 19m and 25m depth, light was likely to be insufficient for phototrophic growth on the seafloor for microphytobenthos and hence micro-biostabilisation effects of benthic microalgae play a minor role at these depths and mass erosion is not likely to be affected by benthic diatoms. Vegetated</td><td>High</td></tr>
</table>

	habitats (seagrass and kelps) are important providers of this service (see below) and light attenuation is a key factor controlling distribution.	
Water Chemistry and temperature	Mediates: Through habitat suitability for bio-assemblage components that provide the biotic service.	High
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Erosion control: The presence of microalgae (identified as a food source) in subtidal sediment ecosystems plays a role in stabilisation of the habitat which in turn can reduce incident wave energy and reduce erosion (Tait & Dipper 1998; Ziervogel & Forster 2006; Widdows & Brinsley 2002). Micro-biostabilisation effects of sediment surfaces, reported increased diatom biomass with concurrent increase in erosion thresholds occurred at higher levels of light availability in the intertidal. The greatest increase in sediment stability occurred at high-shore stations and this was most extreme where there were also dense populations of diatoms present at the surface of the sediment (Paterson *et al.* 1990). Field studies in the Humber (England) and Westerschelde (Netherlands) have shown that interannual changes in sediment erodability were a result of a shift from a stabilised sediment dominated by microphytobenthos to a destabilised sediment dominated by *Macoma balthica* (Widdows & Brinsley 2002).	Medium
Grazing and predation	Mediates: Via biological control of biota that provide the biotic service.	Low
Seabed Mobility	Mediates: This node relates to the ecosystem service and is supported by bioengineering where structures stabilise sediments and reduced where bioturbators burrow and destabilise sediments. Wave attenuation occurs when a wave passes over intertidal or shallow subtidal features (including shallow sandbanks). All coastal habitats potentially contribute to wave attenuation.	Medium
Recruitment	Mediates: Via supply of biota that provide the biotic service.	High
4. Habitat and Bio-assemblages		
CICES 2.2.1.1. Control of erosion rates**:** Bioturbating organisms	Bio-destabilisers (e.g. bioturbators such *as Macoma balthica*, *Hydrobia ulvae*) increase surface roughness, reduce the critical erosion threshold and enhance the erosion rate (Widdows & Brinsley 2002; Wendelboe *et al.* 2013). Such actions create a more open sediment fabric with a higher water content which affects the rigidity of the seabed and can affect rates of particle resuspension (Rowden *et al.* 1998). Some bio-destabilisation by bioturbators may be offset by the stabilising effects of mucus within faeces and pseudofaeces which increase the cohesiveness of the sediment reducing its susceptibility to erosion (Hall 1994). Field studies in the Humber (England) and Westerschelde (Netherlands) have shown that interannual changes in sediment erodability were a result of a shift from a stabilised sediment dominated by microphytobenthos to a destabilised sediment dominated by *Macoma balthica* (Widdows *et al.* 2002). In rock habitats, the presence of piddock (*Pholas dactylus)* burrows has a destabilising effect on reef structures which can result in increased rates of coastal erosion (Trudgill 1983; Trudgill & Crabtree 1987, cited in Salomidi *et al.* 2012).	
CICES 2.2.1.1. Control of erosion rates: Epifauna contributing to habitat complexity	**Epifauna/biogenic reefs - sediment stabilisation/sediment trapping** Coastal vegetation and shellfish reefs can stabilize shorelines by promoting sediment deposition and/or reducing erosion and sediment movement (Morris *et al.* 2018). The increased drag created by structures protruding into the near-bed water flow and active feeding currents generated by suspension feeders, influences localized rates of erosion and deposition (Thrush *et al.* 2002 and references therein).	

	Bivalve reefs have a strong stabilizing effect on the sediment and structures can last for many years which support contribution to natural hazard regulation (Fletcher *et al.* 2012 and references therein).
CICES 2.2.1.1. Control of erosion rates: Macroalgae contributing to habitat complexity	**Macroalgae - sediment stabilisation/sediment trapping** Macroalgae beds reduce current velocities both within and adjacent to the beds, resulting in increased sedimentation and reduced turbidity. Additionally, macrophytes affect the distribution, composition and particle size of sediments in both freshwater and marine environments stabilizing sediments, reducing sediment resuspension and erosion (Madsen *et al.* 2001).
CICES 2.2.1.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	**Wave attenuation** Kelp beds can cause significant wave damping and the degree of wave breaking is reduced. It was also found that the kelp modifies the water velocity profile (Løvås & Tørum 2001; Jackson 1997). As a result, currents should have different properties in the region of a kelp bed than in a similar kelp-free region (Jackson 1997). Wave attenuation by kelp forests in shallow waters has been substantiated by measurements at Hustadvika, at a site which is strongly exposed to waves from the open ocean. The reduction of wave energy from the outer to inner part of kelp belt over a distance of 258m was 70-85 %, with highest value at low tide. Velocity measurements at two levels, above and below canopy, reveal almost identical results (Mork 1996). The level of protection provided by macroalgae varies seasonally, particularly during winter months, when they shed their blades or leaves or suffer storm damage and physical disturbance. This reduces the amount of biomass in the water column (Christianen *et al.* 2013, cited from Scottish Government 2016). Reefs provide protection for coasts through reduction of incoming wave energy (McManus 2001). The surfaces of bivalve reefs can be topographically rough, with fractal complexity capable of reducing wave energy and erosion. The reef structures can act as barriers that generate dams, to hold pools of water and increase immersion time above the shoreward bank margin, facilitating sediment deposition. Extensive shellfish banks and beds can minimize the impacts of direct water flow, extreme waves, storm surges, and can stabilize the shoreline (Gracia *et al.* 2018 and references therein). Mussel beds can influence tidal flow and wave action within estuaries, and modify patterns of sediment deposition, consolidation, and stabilization. In the Netherlands, mussels are being investigated for their abilities as ecosystem engineers and show promising possibilities for a sustainable coastal protection (Gundersen *et al.* 2016 and references therein). Oyster reefs, installed to combat both natural and anthropogenic erosion, attenuated 25% of the wave height caused by boating pressures, in comparison to controls with no reefs and were equivalent to a natural reef (23% attenuation) (Garvis 2009). As might be expected, wave energy reduction significantly increased from immediate deployment of the oyster reef (18.7%) to one year after establishment (44.7% reduction) (Morris *et al.* 2018 and references therein).
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Supports: Biodeposition by suspension feeders supports this service.
Bioengineering	Supports: Above substratum structures support delivery of this service through habitat provision.
Hydrodynamic flow	Supports: Bio-assemblages alter hydrodynamic flow rates and hence support the service: CICES 2.2.1.3 Hydrological cycle and water flow regulation
Bioturbation	Not relevant: Bioturbation destabilises sediments and increases erosion.
Primary production	Supports: Via the growth of macroalgae that provide this service.
Secondary production	Supports: Via the growth of epifaunal biota that provide this surface.
Habitat modification	Supports: Via erosion control (through sediment stabilisation) reducing currents and wave energy.

Supply of propagules	Not relevant to this service.
6. Local ecosystem functions	
Biogeochemical cycling	Not relevant to this service.
Control of algal growth	Mediates: Changes in the growth of macroalgae that deliver this service will alter service provision.
Food resource	Not relevant.
Habitat provision	Supports: Changes in habitat provision will alter the level of service provision.
Microbial activity	Supports: Biofilms may reduce sediment erosion.
Nutrient cycling	Not relevant
Population control	Not relevant
Sediment stability	Supports: Sediment stability supports this service. Changes in the level of service will alter the level of this function.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Not relevant
Biotope maintenance	Not relevant
Biotope stability	Not relevant
Carbon sequestration	Not relevant: Enhanced carbon sequestration is likely to reflect an increase in level of this service.
Export of biodiversity	Not relevant
Export of organic matter	Not relevant
Knowledge Gaps	
This service is largely measured through proxies (habitat provision) and bioturbation (inverse relationship). Austen *et al.* (2011) and eftec (2014) found no values for wave attenuation by offshore sandbanks or reefs. More information for this service is available for saltmarsh and seagrass habitats and offshore habitats are likely to have a low contribution to this service due to depth and distance from shore.	

Ecosystem Service Proforma 6. CICES 2.2.3.1 Pest and disease control

<table>
<tr><td colspan="2">Ecosystem Service</td><td colspan="2">Intermediate Services (Potts et al. 2014): Biological control.
CICES 2.2.3 Pest and disease control</td></tr>
<tr><td colspan="4">Ecosystem Service Description
There is some variance between CICES and the service ‘biological control’ assessed by Potts et al. (2014) and defined as ‘the contribution of coastal and marine biota to the maintenance of population dynamics, resilience through food web dynamics, disease and pest control’.

In CICES, the final ecosystem service is assessed through two components:
CICES 2.2.3.1 Pest control (including invasive species)
CICES 2.2.3.2 Disease control

The UK NEA (Smith et al. 2014), identified that factors contributing to this service include biotic (predators and pathogens, competitors and hosts) and abiotic (climate, resource use) as well as socio-economic (disease and pest management)</td></tr>
<tr><td colspan="4">Specific node in model, added to models or based on existing nodes?
Predation, grazing and microbial ecological components support this service.</td></tr>
<tr><td colspan="4">Any categories used to assess service provision.
None: Not directly assessed in JNCC MESO</td></tr>
<tr><td colspan="4">Comments
Notes: This service presents a key knowledge gap. There is little evidence to identify species components that form this service. Higher component levels in the model hierarchy are assessed based on generic support for bio-assemblages. Bio-assemblage contribution to this service could not be assessed.</td></tr>
<tr><td colspan="3">1. Regional to Global Drivers</td><td>Confidence</td></tr>
<tr><td colspan="4">No specific evidence. Suitability of habitat for biota as outlined in Proformas 4 will equally apply to this service.</td></tr>
<tr><td colspan="4">2. Water Column Processes</td></tr>
<tr><td colspan="4">No specific evidence. Suitability of habitat for biota as outlined in Proforma 4 will equally apply to this service.</td></tr>
<tr><td colspan="4">3. Local Processes/Inputs at the seabed</td></tr>
<tr><td colspan="4">Evidence</td></tr>
<tr><td>Food Sources</td><td colspan="3">No evidence found. Food sources will support the biota that provide this service. However, presence of suitable food may also support pest species. Confidence is medium for each food source.</td></tr>
<tr><td>Grazing and predation</td><td colspan="3">The feeding activities of high densities of Polydora ciliata may inhibit the establishment of other benthic species by removing settling and developing larvae (Daro & Polk 1973). Similarly, grazers can remove or prevent propagules establishing on rock surfaces; grazing by littorinid snails prevents algal canopies establishing (Jones et al. 1994).</td></tr>
<tr><td>Seabed Mobility</td><td colspan="3">Mediates: Seabed mobility may control the spread and establishment of pest species. Valentine et al. (2007) describe how Didemnum spp. on the Georges Bank (US/Canada boundary) have been restricted by areas of more mobile sands that do not appear to be suitable habitats.</td></tr>
<tr><td>Recruitment</td><td colspan="3">Recruitment will mediate biological control.</td></tr>
<tr><td colspan="4">4. Habitat and Bio-assemblages</td></tr>
<tr><td>CICES 2.2.3.1 Pest control (including invasive species)</td><td colspan="3">In some instances, introduced species may make little difference to a biotope. The north American razor shell Ensis directus (syn. Ensis americanus) was introduced into Britain via Europe and was found in Norfolk in 1989 (Palmer 2004). Although it is widespread and has successfully established large populations, no direct impacts on native species or communities have been reported (Armonies & Reise 1999; Palmer 2004). Similarly, Shelley et al. 2008), found no effect on biological functioning in mesocosm experiments after the introduction of the polychaete Sternapsis scutata and a doubling of its biomass.</td></tr>
</table>

	No direct evidence on the effect of non-native species on mud communities was found (Shelley *et al.* 2008). Examples of population control include sediment reworking by deposit feeders; for example, *Arenicola marina* makes the substratum less stable, increases the suspended sediment and makes the environment less suitable for suspension feeders (Rhoads & Young 1970). Similar disturbance competition is demonstrated by grazers including the periwinkle, *Littorina littorea* which is known to "bulldoze sediments from rocky beach hard substrates" in New England (Bertness 1984). This prevents sediment accumulation and hence growth and establishment of algal canopy; algae are bioengineers and further increase sedimentation rates; faunal composition is markedly different with and without snails Enclosure experiments in a sea loch in Ireland have shown that high densities of swimming crabs such as *Liocarcinus depurator*, that feed on benthic polychaetes, molluscs, ophiuroids and small crustaceans, led to a significant decline in infaunal organisms (Thrush 1986).
CICES 2.2.3.2 Disease control	Many pathogens constitute a pressure emanating from outside a system often as a result of human activities, such as unregulated sewage disposal or dumping of ballast water. Many of these biological wastes entering the marine environment lose viability, under the relatively harsh conditions and may be ingested and utilised for food (therefore being remineralised) by other organisms in the environment without detrimental effects (Watson *et al.* 2016).
5. Output processes relevant to ecosystem service	
Only evidence relevant to the service is presented	
Bioengineering	Mediates: Many studies show significant variations in predator-prey interactions associated with variations in habitat complexity (Thrush *et al.* 2002 and references therein). Habitat structure influences predation rates on fish, particularly juvenile life stages (Thrush *et al.* 2002 and references therein).
6. Local ecosystem functions	
Control of algal growth	Provision: Mesograzers feeding on macrophyte surfaces remove smaller epiphytes like diatoms and foliose algae and are thus important for keeping the larger macrophytes free from being overgrown by epiphytic competitors (Moksnes *et al.* 2008). However, in some cases the grazers increase in density to an extent that they start to overgraze the macrophytes which are then grazed to extinction (Christie *et al.* 2009). By filtering phytoplankton, including toxic algae, filter feeders like blue mussels can inhibit or even prevent harmful blooms. Algal blooms make the water more turbid and reduce the amount of light to plants, algae or corals that live at the bottom, but this effect can be strongly reduced by the short- (acute) and long-time (preventive) effects of filtering blue mussels (Gundersen *et al.* 2016).
Food resource	Provision: Biota may ingest pest species and pathogens.
Habitat provision	Mediates: Many studies show significant variations in predator-prey interactions associated with variations in habitat complexity (Thrush *et al.* 2002 and references therein). Habitat structure influences predation rates on fish, particularly juvenile life stages (Thrush *et al.* 2002 and references therein).
Microbial activity	Provision: Microbial activity may degrade and breakdown pathogens (Watson *et al.* 2016; Dash *et al.* 2013).
Nutrient cycling	Not directly relevant to service provision.
Population control	Population control represents an aspect of this service. Biota may ingest pest species and pathogens.
Sediment stability	Mediates: Habitat suitability. The colonial ascidian *Didemnum vexillum* is present in the UK but appears to be restricted to artificial surfaces such as pontoons; this species may, however, have the potential to colonize and smother offshore gravel habitats. Valentine *et al.* (2007) describe how *Didemnum spp.* appear to have rapidly colonized gravel areas on the Georges Bank (US/Canada boundary). Colonies can coalesce to form large mats that may cover more than 50% of the seabed in parts. Areas of mobile sand border

	some communities of *Didemnum spp*. and these therefore do not appear to be suitable habitats (Valentine *et al.* 2007).
7. Regional to global ecosystem functions	
Biodiversity enhancement	Mediates. Biodiversity may result in more pathways to control pest and disease species.
Biotope maintenance	Mediates: Maintaining biodiversity and biotope supports this service. For example, loss of top predators such as large lobsters and large finfish that predate sea urchins can lead to overgrazing and loss of kelp beds (Burrows *et al.* 2013).
Biotope stability	No evidence: Biotope stability may reduce settlement and recruitment of pest species.
Carbon sequestration	Not relevant to service provision.
Export of biodiversity	Not relevant to service provision.
Export of organic matter	Not relevant to service provision.
Knowledge Gaps	
Maes *et al.* (2013) identified key gaps in knowledge for this service. The introduction of non-native species is a pressure assessed in the sensitivity assessments, but very little information was found in any of the sources used to support assessments (see pressure- sensitivity assessment spreadsheets).	

Ecosystem Service Proforma 7. CICES 2.2.6.1 Regulation of chemical composition of atmosphere and oceans (Carbon sequestration)

<table>
<tr><td colspan="2">Ecosystem Service</td><td colspan="2">Carbon sequestration (Intermediate service Potts et al. 2014)
CICES 2.2.6.1 Regulation of chemical composition of atmosphere and oceans
CICES 5.2.2.1 Maintenance and regulation by inorganic natural chemical and physical processes</td></tr>
<tr><td colspan="4">Ecosystem Service-Description
The intermediate (regulating) service ‘Carbon Sequestration’ is defined as the large, slowly changing store of carbon. Marine organisms act as a reserve or sink for carbon in living tissue and by facilitating burial of carbon in seabed sediments (Brown et al. 2011). The ecosystem service of ‘carbon sequestration’ can regulate climate and mitigate the effects of global warming by capturing atmospheric CO_2.

The ecosystem service of ‘carbon sequestration’ is identified in the Potts et al. 2014 framework, and was included within “climate regulation” by the UK's National Ecosystem Assessment classification (NEA). CICES includes this service as:
CICES 2.2.6.1 Regulation of chemical composition of atmosphere and oceans; and
CICES 5.2.2.1 Maintenance and regulation by inorganic natural chemical and physical processes.

The main factors contributing to carbon sequestration in the UK continental shelf is the inorganic carbon pump which exports carbon offshore. Sequestration in shallow sediments, subject to wave disturbance, is likely to be short term as carbon will be resuspended and subject to nutrient cycling.</td></tr>
<tr><td colspan="4">Specific node in model, added to models or based on existing nodes?
Carbon sequestration is based on sediment type in the MESO BBN models.</td></tr>
<tr><td colspan="3">1. Regional to Global Drivers</td><td>Confidence</td></tr>
<tr><td>Climate</td><td colspan="2">Mediates: Via seasonal stratification of surface waters, habitat suitability and cycling rates. Climate will also mediate wave action and sediment disturbance of shallow areas reducing capacity to store carbon in areas <50m (eftec 2014).</td><td>High</td></tr>
<tr><td>Depth</td><td colspan="2">Mediates: Via seasonal stratification and off-shelf transport of carbon rich subsurface water. The remineralisation (transformation of carbon from organic to inorganic form by bacteria activity or other detritivores and decomposers in the water column) of organic matter, including dead matter and faecal pellets, leads to the production of CO_2. Depth will also mediate disturbance from waves.</td><td>High</td></tr>
<tr><td>Geology</td><td colspan="2">Mediates: Few empirical studies exist that quantify rates of sequestration of carbon by different subtidal sedimentary habitats. An indicator of capacity to deliver this service is the availability of mud within the sediment based on the known relationship between smaller sediment grain sizes and increased concentrations of total organic carbon (Hooper et al. 2014 and references therein) and the limited capacity of coarse sediments to store carbon resulting from the rapid processing of biomass (Alonso et al. 2012).</td><td>High</td></tr>
<tr><td>Propagule supply</td><td colspan="2">Not relevant to service provision but will mediate supply of organisms that support this service.</td><td>High</td></tr>
<tr><td>Water currents</td><td colspan="2">Mediates: Via seasonal stratification and off-shelf transport of carbon rich subsurface water.</td><td>High</td></tr>
<tr><td>Wave exposure</td><td colspan="2">Mediates: Via sediment disturbance and resuspension of organic matter.</td><td>High</td></tr>
<tr><td colspan="4">2. Water Column Processes</td></tr>
<tr><td colspan="4">Evidence</td></tr>
<tr><td>Primary production</td><td colspan="3">Supports: Primary production by phytoplankton is transported as organic and inorganic carbon to deeper ocean waters this process is the ‘biological carbon</td></tr>
</table>

	pump'. All phytoplankton can synthesize organic matter from inorganic compounds, and light (Legendre & Rivkin 2005).
Suspended Sediment	Mediates: Primary production (see Proforma 1)
Light Attenuation	Mediates: Primary production (see Proforma 1)
Water Chemistry and temperature	Mediates: The solubility of gases in water decreases with increasing temperature. Increased surface water temperatures will progressively reduce the effectiveness of the ocean sink for CO_2. Temperature changes can also drive biologically mediated effects (Legendre & Rivkin 2005). Ocean acidification may impact the biota and affect other ecosystem services. Concentrations of nitrogen, phosphorous and silicon are major factors limiting primary production in the sea (O'Neill 1998) and primary production underpins carbon cycling in the marine environment (Legendre & Rivkin 2005).
3. Local Processes/Inputs at the seabed	
Evidence	
Food Sources	Supports: Benthic organisms of sedimentary habitats form an important part of the food chain and transfer organic carbon back into the pelagic realm (Snelgrove 1999). During calcification the precipitation of $CaCO_3$ is accompanied by the release of CO_2. The main planktonic marine calcifiers are coccolithophorids (phytoplankton), foraminifers (microzooplankton; protists) and pteropods (microphagous macrozooplankton; molluscs). The deep transfer of CaCO3 includes calcareous parts from calcifying organism.
Grazing and predation	Grazing and predation cycles organic matter and mediates bio-assemblages but does not directly support carbon sequestration.
Seabed Mobility	Mediates: Marine sediments, particularly those located in estuarine and coastal zones, are key locations for the burial of organic carbon. However, carbon cycling rates and relative importance, vary markedly between sites and are difficult to predict, (Woulds *et al.* 2016). Sediment disturbance and mobility is a key factor governing sequestration. Any activity that affects the mixing of the sediments, including disturbing the infauna, will affect carbon storage (Alonso *et al.* 2012). For example, commercial fishing using bottom trawling will shift the infauna towards short lived small species and can change amount of carbon in the food web and how much carbon goes into detritus (Duplisea 2001). Storm events that resuspend sediments will also result in a loss of stored carbon (Duplisea 2001) as it is remineralised in the water column.
Recruitment	Recruitment will support this service via recruitment of species that support this service.
4. Habitat and Bio-assemblages	
Carbon storage	Blue mussels bind CO_2 when building their shells and this carbon is stored in the shell until the animal dies and are decomposed and released back to the ecosystem. The Lysefjord at the west coast of Norway, a mussel cultivation test facility takes up 2,000 tons of CO_2 in one season. However, there is great uncertainty about whether this method has a long-term effect and/or if CO_2 is being reduced in the atmosphere (Gundersen *et al.* 2016). Other biogenic habitat formers such as corals, oysters and horse mussels are likely to store carbon. Maerl beds store carbon in living tissues and fixed within what are sometimes thick deposits of dead maerl, some of which is thousands of years old (eftec 2014).

Carbon deposition and burial	Filter feeders and complex habitats that trap organic matter will enhance the supply of carbon to the seabed where it may be buried by bioturbating organisms. Bioturbators in the sediment affect sediment-water fluxes of carbon and degradation and storage of carbon (Beaumont *et al.* 2007). Bioturbation may result in organisms such as head down deposit feeders, bringing organic matter from within the sediment to the surface (Braeckman *et al.* 2010; Haines-Young & Potschin 2010). However, these activities may also draw surficial organic matter into sediments (Kristensen *et al.* 2012).
Carbon export	Macroalgae, due to their high rates of production, fragmentation, and ability to be transported, appear to be able to make a significant contribution as carbon donors to blue carbon habitats (Trevathan-Tackett *et al.* 2015). Marine primary producers contribute at least 50% of the world's carbon fixation and may account for as much as 71% of all carbon storage (Chung *et al.* 2011). Kelps are the major primary producers in UK marine coastal waters producing nearly 75% of the net carbon fixed annually on the shoreline of the coastal euphotic zone (Birkett *et al.* 1998). Kelp detritus settles within kelp beds and is also exported to adjacent and distant habitats, such as sandy beaches and the deep-sea where the kelp carbon may accumulate and be stored (Abdullah *et al.* 2017).
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Supports: Biodeposition enhances supply of carbon to the sediment surface where it may become buried.
Bioengineering	Supports: Biogenic habitats of maerl and bivalves may store carbon within the maerl matrix or shells. Sediment trapping will also increase the flux of carbon the seabed where it may be trapped or buried.
Hydrodynamic flow	Supports: Changes in hydrodynamic flow and sediment trapping by epifauna and flora will increase sedimentation of carbon (see Proforma 5).
Bioturbation	Supports: Burial of organic matter.
Primary production	Supports: Macroalgae have a relevant role as carbon sinks. Worldwide, marine macroalgae occupy about an area of 6.8 × 106km^2 (Duarte & Cebrian 1996). The overall standing crop of kelp forests is estimated to be between 0.015 and 0.039 PgC, but it could be much higher (Reed & Brzezinski 2009). Seaweed assemblages have higher biomass and larger turnover times (ca. 1 year) than phytoplankton (several days). Seaweed assemblages may act as valuable carbon sinks compared to phytoplankton due to its higher biomass and larger turnover time (ca. 1 year compared to days), but they are not as efficient as terrestrial plants or seagrasses (e.g. Pergent *et al.* 2014), with longer turnover times.
Secondary production	Mediates: Somatic production results in carbon storage in organisms.
Habitat modification	No evidence
Supply of propagules	Supports: Provision of species that provide this service.
6. Local ecosystem functions	
Biogeochemical cycling	Provision: Carbon cycling pathways.
Control of algal growth	Mediates: Grazers cycle carbon from kelp but will reduce short-term standing stock.
Food resource	Supports: Benthic organisms of sedimentary habitats form an important part of the food chain and transfer organic carbon back into the pelagic realm (Snelgrove 1999).
Habitat provision	No evidence
Microbial activity	Supports: Microbes are an integral part of nutrient cycles.
Nutrient cycling	Mediates: Nutrient cycling results in fixation of carbon within organisms and the cycling of carbon.

Population control	No evidence
Sediment stability	Provision: Undisturbed sediments can store carbon, see sediment mobility above.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: Changes in marine biodiversity influence the biogeochemical cycling of carbon and nutrients within seabed sediments, in the overlying water column, and at the interfaces between sediment and water. This can ultimately result in changes in the capacity of the marine environment to act as a carbon sink and has a strong feedback on the atmosphere and the climate (Legendre & Rivkin 2005, cited from Austen *et al.* 2011).
Biotope maintenance	No evidence.
Biotope stability	Provision: Carbon sinks are considered ephemeral in shallow water (<50m depth) as biota are relatively short-lived and sediments are subject to frequent disturbance (eftec 2014). Increased sediment and biotope stability would support higher rates of carbon storage.
Carbon sequestration	Provision: This node represents this service.
Export of biodiversity	Supports: Short term carbon storage.
Export of organic matter	Supports: The large biomass turnover of kelp habitats results in large amounts of kelp-derived detritus being produced. Approximately 80% of this detritus is exported to adjacent habitats (Scottish Government 2016 and references therein).
Knowledge Gaps	
Despite 55% of CO_2 being captured by living marine organisms, there is no readily available data for the UK that quantifies total living biomass in marine and estuarine sediments or the water column. The majority of research focuses on marine phytoplankton productivity in UK ocean, shelf and coastal waters, which has been used as an indicator of the climate regulation service and links to primary production.	

Ecosystem Service Proforma 8. CICES 1.1.2 Cultivated aquatic plants for nutrition, materials or energy

Proforma 8	**CICES 1.1.2 Cultivated aquatic plants for nutrition, materials or energy**	
Ecosystem Service-Description Aquaculture is the farming or culturing of aquatic organisms (fish, molluscs, crustaceans, plants) using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment, such as through regular stocking, feeding and protection from predators (ONS 2007b). This ecosystem service is divided by CICES into three classes • CICES 1.1.2.1 Plants cultivated by *in situ* aquaculture grown for nutritional purposes; • CICES 1.1.2.2 Fibres and other materials from *in situ* aquaculture for direct use or processing (excluding genetic materials); and • CICES 1.1.2.3 Plants cultivated by *in situ* aquaculture grown as an energy source.		
Specific node in model, added to models or based on existing nodes? This service is supported by the marine ecosystem but is not a direct output of any of the nodes.		
Any categories used to assess service provision. The aquaculture sector relies on various ecosystem services that support its productivity, Including the physical environment, chemical cycling, water purification and biological productivity (Saunders 2010).		
1. Regional to Global Drivers		**Confidence**
Climate	Mediates (High): Temperature mediates plant growth rates and other processes such as reproduction (see water chemistry and temperature). Climate also influences storminess, wave exposure and may therefore determine habitat suitability (see sections below). Increased temperatures related to anthropogenic climate change may impact the structure of kelp forests and the ecosystem services they provide (Smale *et al.* 2016).	High
Depth	Mediates: Suitability for operations.	Low
Geology	Not relevant: Most macroalgal culture is likely to be long-line and independent of the substratum.	Low
Propagule supply	Not relevant: However, deployment of seaweed lines could assist in habitat restoration by supplying spores and gametophytes to wild kelp beds that have been damaged by anthropogenic impacts (Walls *et al.* 2016).	Not relevant
Water currents	Mediates: Suitability for operations.	Low
Wave exposure	Mediates: Suitability for operations.	Low
2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates: Suitability for operations.	Medium
Primary production	Mediates: Suitability for operations.	Medium
Suspended Sediment	Mediates: Suitability for operations.	Medium
Light Attenuation	Mediates: Suitability for operations.	Medium
Water Chemistry and temperature	Mediates: Suitability for operations.	Medium
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Not relevant.	
Grazing and predation	Mediates: Control of local grazers will support biomass production of algae. Confidence is Medium.	
Seabed Mobility	Not relevant: Most macroalgal culture is likely to be long-line and independent of the substratum.	
Recruitment	Aquaculture unlikely to rely on propagules supplied by the environment.	

4. Habitat and Bio-assemblages	
CICES 1.1.2.1 Plants cultivated by *in situ* aquaculture grown for nutritional purposes;	The Crown Estate has begun to investigate the potential for mass production of macroalgae (Capuzzo *et al.* 2012). Currently seaweed production for food is at a low level in the UK compared to other nations (Buschmann *et al.* 2017) but is likely to increase. Seaweed can be consumed directly or processed into food additives (Hasselström *et al.* 2018).
CICES 1.1.2.2 Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); and	Macroalgae can provide a range of ingredients including the development of complex materials and pharmaceuticals (Hasselström *et al.* 2018). Kelps can grow very quickly (up to 50cm per day), are rich in polysaccharides and do not compete with land-based crops for space, fertilizers, and water (Smale *et al.* 2013). The use of microalgae is currently at the research stage (Schlarb-Ridley & Parker 2013.)
CICES 1.1.2.3 Plants cultivated by *in situ* aquaculture grown as an energy source.	Within the UK and Ireland, the potential for kelp biomass to be used for conversion to biofuels has reignited interest in large scale kelp production. In Ireland, for example, the EnAlgae project (enalgae.eu) is cultivating macroalgae in and around Strangford Lough for biofuel development and similar projects are underway in Scotland (Smale *et al.* 2013). A realistic contribution to energy markets through bioethanol production may require more kelp than can be harvested from natural habitats, prompting efforts to develop methods of farming kelp (Burrows *et al.* 2014). A recent cradle-to-grave analysis of the carbon footprint of the production of biofuels (ethanol and methane) from seaweeds, however, indicated that production of biofuels from other sources (e.g. corn, wheat and sugar cane) is more efficient (Fry *et al.* 2012, cited from Smale *et al.* 2013).
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Not relevant to service provision: Most macroalgal culture is likely to be long-line and independent of the substratum.
Bioengineering	Not relevant to service provision: Most macroalgal culture is likely to be long-line and independent of the substratum.
Hydrodynamic flow	Not relevant to service provision.
Bioturbation	Not relevant to service provision: Most macroalgal culture is likely to be long-line and independent of the substratum.
Primary production	Not relevant to service provision: The service relates to primary production by cultivated rather than wild plants.
Secondary production	Supports: Secondary production by filter and suspension feeders may reduce suspended sediments supporting primary production.
Habitat modification	Not relevant to service provision: Most macroalgal culture is likely to be long-line and independent of the substratum.
Supply of propagules	Not relevant to service provision.
6. Local ecosystem functions	
Biogeochemical cycling	Supports: Biogeochemical cycling may support *in situ* primary production.
Control of algal growth	Supports: May be beneficial where this relates to epiphytes or negative where the cultivated algae is grazed.
Food resource	Not relevant to service provision.
Habitat provision	Not relevant to service provision: Most macroalgal culture is likely to be long-line and independent of the substratum.
Microbial activity	Supports: may support in-situ primary production through nutrient cycling
Nutrient cycling	A reduction in nutrient availability is likely to reduce the delivery of any ecosystem services produced and a total absence of nutrients is likely to result in non-delivery of any ecosystem service (Alexander *et al.* 2016). Nutrients are

	transported by water movement and *in situ* primary production may not rely on nutrient cycling within the biotope.
Population control	Mediates: Control of local grazers will support biomass production of algae. Confidence is Medium.
Sediment stability	Not relevant: Most macroalgal culture is likely to be long-line and independent of the substratum.
7. Regional to global ecosystem functions	
Not relevant: Cultivated plant biomass is likely to be removed and the functions are not relevant to this service.	
Knowledge Gaps	
Although seaweeds are cultivated this sector was considered to be relatively under-developed in comparison with the more mature fish and shellfish aquaculture sectors. Previous reports have found that quantitative information on aquaculture of seaweed (e.g. locations and amounts) was difficult to source (eftec 2014).	

Ecosystem Service Proforma 9. CICES 1.1.4 Reared aquatic animals for nutrition, materials or energy

Ecosystem Service	**CICES 1.1.4 Reared aquatic animals for nutrition, materials or energy**
Ecosystem Service-Description Aquaculture is the farming or culturing of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment, such as through regular stocking, feeding and protection from predators (ONS 2007b). This ecosystem service is divided by CICES into three classes • CICES 1.1.4.1 Animals reared by *in situ* aquaculture for nutritional purposes; • CICES 1.4.2 Fibres and other materials from animals grown by *in situ* aquaculture for direct use or processing (excluding genetic materials); • CICES 1.1.4.3 Animals reared by *in situ* aquaculture as an energy source No evidence was found that animals are being reared as an energy source and this service is not assessed.	
Specific node in model, added to models or based on existing nodes? This service is supported by the marine ecosystem but is not a direct output of any of the nodes within the CEM. The service is not included in the MESO BBN.	
Any categories used to assess service provision. The aquaculture sector relies on various ecosystem services that support its productivity including the physical environment, chemical cycling, water purification and biological productivity (for fish feed and seed stock) (Saunders 2010).	
Comments: Aquaculture requires human input to realise this service. Service provision was considered independent of output processes and functions identified in the CEM.	

1. Regional to Global Drivers		**Confidence**
Climate	Mediates: Given the current projections, climate change is unlikely to have a significant effect on UK mariculture over the next decade. Further into the future however, the forecast changes are likely to result in noticeable effects (MCCIP 2008). Rising average water temperatures could result in faster growth rates for some species which are more tolerant of higher temperatures (e.g. Atlantic salmon, mussels, oysters) but prolonged periods of warmer summer temperatures may well adversely affect some cold-water species (e.g. cod, Atlantic halibut) and intertidal shellfish (oysters) as the thermal optima for the animals physiology may be exceeded for long periods of time. The culture of species which are currently of marginal (but growing) value to UK market but which thrive in warmer conditions such as sea bass, sea bream and hake could be a positive new opportunity caused by climate change (MCCIP 2008, cited from Saunders 2010). Current knowledge of the threats and opportunities of climate change for aquaculture in the UK and Ireland, focusing on the most commonly farmed species, blue mussels (*Mytilus edulis*) and Atlantic salmon (*Salmo salar*) were reviewed by Callaway *et al.* (2012).	High
Depth	Mediates: Suitability for operations.	Low
Geology	Mediates: Suitability for operations, relevant to on-substrate shellfish cultivation.	Medium
Propagule supply	Not relevant to service provision.	NR
Water currents	Mediates: Local habitat suitability to support operations, flushing by currents may reduce build-up of organic matter and environmental impacts, particularly with fin-fish aquaculture (Saunders 2010).	Low
Wave exposure	Mediates: Local habitat suitability to support operations.	Low

2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates: Local habitat suitability to support operations.	High
Primary production	Supports: Shellfish such as oysters and clams are suspension feeders thus, aquaculture will be supported where levels of primary production are high.	Medium
Suspended Sediment	Mediates (habitat quality for shellfish): high levels of suspended sediment may reduce feeding efficiency.	Medium
Light Attenuation	Mediates: Not directly relevant but could affect supply of plankton to support shellfish.	Low
Water Chemistry and temperature	Mediates: Local habitat suitability to support operations. An increase in ocean acidification caused by anthropogenic CO_2 dissolving in the ocean could impact on aquaculture species in the future. Experiments designed to test the impacts of acidification on Pacific oyster and mussels found that oysters have a higher tolerance to ocean acidification than mussels. It was shown that mussels exhibited a decrease in shell formation of 30% with raised pH levels that are likely to be reached during this century (Fernand & Brewer 2008). One reason for this difference in tolerance is the composition of the shells; approximately 50% of a mussel shell is made from aragonite which dissolves more easily than calcite, which constitutes most of the oyster shells (Fernand & Brewer 2008).	High
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Supports: Although feed for fish will be supplemented by feeding.	Low
Grazing and predation	Mediates (habitat suitability): The presence of shell-fish predators threaten the success of aquaculture.	Medium
Seabed Mobility	Mediates: Habitat suitability of substrates for shellfish cultivation.	High
Recruitment	Not relevant to service provision.	Not relevant
4. Habitat and Bio-assemblages		
Benthic fauna Sand CEM Sand eels	Supports: Sand eels may be fished to provide a feedstock to aquaculture operations (Saunders 2010). As sand eels have ecological importance as food for fish and birds, fisheries are increasingly managed to reduce catches and protect vulnerable stocks.	
Bio-assemblage: *Mytilus edulis*	Supports: May be dredged as spat to provide stock for relaying.	
5. Output processes relevant to ecosystem service		
Evidence		
Not relevant to service provision.		
6. Local ecosystem functions relevant to ecosystem service		
Not relevant to service provision.		
7. Regional to global ecosystem functions		
Not relevant to service provision.		
Knowledge Gaps		
Unlike other ecosystem services considered in this project, aquaculture represents a human use of the environment and may result in pressures on habitats and alteration to the local ecosystem, including changes to processes and functions. These have not been assessed.		

Ecosystem Service Proforma 10. CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition and materials

Proforma 10	**CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition and materials**	
The CICES group 1.1.5 Wild plants (terrestrial and aquaculture for nutrition and materials contains three classes: • CICES 1.1.5.1 Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; • CICES 1.1.5.2 Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); • CICES 1.1.5.3 Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy. The provision of food (wild and farmed) represents a good/benefit that is derived from an ecosystem and is directly linked to final (provisioning) ecosystem services and intermediate (supporting) services. This final ecosystem service is supported by the following intermediate services: Primary production, Nutrient cycling, Formation of Species Habitat and Larval and Gamete Supply. The intermediate service: The rate of primary production determines the potential level of the final ecosystem services by determining the biomass of macroalgae present. Macroalgae play further roles in supporting final ecosystem services within the CICES classification. Macroalgae may capture sediment particles (biodeposition) reducing erosion and dense beds reduce wave strength through friction providing a role in natural hazard regulation. Mucilage produced by microphytobenthos also stabilises benthic sediments. Macroalgae also contribute to nutrient cycling, bioremediation (proforma 13), produce genetic material (proforma 12) and propagule supply (proforma 2).		
Specific node in model, added to models or based on existing nodes? This final ecosystem service is supported by the following intermediate services: Primary production, Nutrient cycling, Formation of Species Habitat and Larval and Gamete Supply (eftec 2014). The CEMs do not include seagrass and within the existing CEM models this service is represented by the biomass or standing stock of macroalgae present within the following model bio-assemblages: Sand: Submodel 4: Bio-assemblage: kelp Mud: None Mixed: None Coarse: None Reef: (Sub-model 1) Kelp, brown, red and green algae.		
Any categories used to assess service potential: Service provision was assessed based on a three-point scale: **None**: Animal is not known to be commercially targeted **Medium**: Animal is targeted, it may be sparse in the habitat under consideration OR it may be a species that is only targeted in parts of its range or sporadically. **High**: Species has high commercial value and is targeted across most, or all, of the range.		
Comments/ Notes: This service was not considered to be provided by the Coarse sediment, Mixed sediment or Mud habitats as these do not include macroalgae.		
1. Regional to global drivers		
Evidence		
Climate	Mediates: Temperature mediates plant growth rates and other processes such as reproduction (see water chemistry and temperature). Climate also influences storminess, wave exposure and may therefore determine habitat suitability (see sections below). Increased temperatures related to anthropogenic climate change may impact the structure of kelp forests and the ecosystem services they provide (Smale *et al.* 2016).	High

Depth	Mediates: Through light attenuation and habitat suitability for macroalgae with changes in community at different depths (Markager & Sand-Jensen 1992; Laffoley & Grimsditch 2009).	High
Geology	Mediates: Through habitat suitability, requirements for attachment vary for macroalgae.	High
Propagule Supply	Mediates: Through provision of macroalgal spores.	High
Water Currents	Mediates: Through habitat suitability for bio-assemblages that provide this service. Nutrient limitation related to low water flow can limit growth (Mann 1982, cited in Scottish Government 2016). Primary producers also alter hydrodynamic output processes by attenuating water flow (Blight & Thompson 2008).	High
Wave Exposure	Mediates: Through habitat suitability for species including kelps (Birkett *et al.* 1998), for example, *Laminaria hyperborea* density, biomass, morphology and age are generally greater in exposed sites (Smale *et al.* 2016). At high levels of exposure (EUNIS A3.1) kelp may be replaced by more robust animal communities, and at lower levels of exposure (EUNIS A3.3) turbidity and sediment abrasion may reduce productivity (eftec 2014).	High
2. Water Column Processes		
Evidence		
Primary production	Not relevant: Primary production in the water column does not support primary production in the benthic habitat.	
Suspended Sediment	Mediates (High): Through light attenuation (see below). Suspended Particle Matter (SPM) concentration has a positive linear relationship with sub-surface light attenuation (Kd) (Devlin *et al.* 2008) and controls the photic zone (Cloern 1987)	
Light Attenuation	Mediates (High): Light availability and water turbidity are principal factors in determining depth range at which macro-algae can be found (Birkett *et al.* 1998) and is a key factor influencing ecosystem services based on marine primary producers (Alexander *et al.* 2016). Kelp canopy biomass and the standing stock of carbon are positively correlated with large-scale wave fetch and light levels and negatively correlated with temperature (Smale *et al.* 2016). Light attenuation by macrolagal canopies supports low light adapted algae (Alonso *et al.* 2012).	
Water Chemistry and temperature	Direct water chemistry and temperature will influence rates of primary production. Smale *et al.* (2016) found that kelp canopy biomass and the standing stock of carbon were positively correlated with large-scale wave fetch and light levels and negatively correlated with temperature. Water chemistry also affects nutrient availability, with nutrient limitation identified as a limiting factor for growth (Mann 1982, cited in Scottish Government 2016). Alterations to factors such as dissolved oxygen, pH, and dissolved compounds caused by a poor state of the environment are likely to have knock-on effects on marine flora and fauna (Alexander *et al.* 2016).	
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Not relevant	
Grazing and predation	Mediates (Low): Grazing as a pressure mediates the supply of primary production. Excessive grazing by sea urchins can denude entire kelp forests. Lobsters, fish and other However, in more persistent stands grazers typically consume only a small fraction of the kelp that is produced (Reed & Brzezinski 2009). Herbivory is generally low in kelp forests, with less than 10% of live kelp biomass thought to be consumed by grazers (Norderhaug & Christie 2011), and 80% being exported as detritus (Burrows *et al.* 2014; Wernberg & Filbee-Dexter 2018).	
Seabed Mobility	Mediates (habitat suitability): In the natural environment, values for maximum productivity are 10 times higher for a seaweed stand than for a plankton population which is due to the fixed position of a seaweed on a substrate (Lüning 1990). This ecological advantage allows macroalgae to form a stable, multi-layered, perennial vegetation capturing almost every photon falling on a	

	square metre of rocky bottom, as in a dense terrestrial forest, where almost no light reaches the forest floor (Lüning & Pang 2003).
Recruitment	Mediates (supply of primary producers): See larval and gamete supply (proforma 2).
4. Habitat and Bio-assemblages	
CICES 1.1.5.1 Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	It is estimated that 2000–3000 dry tonnes (equivalent to 25,000–40,000 tonnes wet weight) of macroalgae is harvested from the wild per year in the United Kingdom to produce food and feed products as well as speciality chemicals and fertilisers (Schlarb-Ridley & Parker 2013). There is limited utilisation of specific wild harvested seaweeds as food, although exploitation is increasing, and seaweeds are also used as a source of chemicals for industries. Alginate, agar and carrageenan are gelatinous extracts that are used as food additives (Austen *et al.* 2010). In coastal communities in the UK, non-kelp seaweeds have been consumed for at least 4000 years, particularly *Palmaria palmata* ("Dulse"), *Chondrus crispus* ("Carageen"), *Porphyra umbilicalis* ("Purple laver") and *Ulva lactuca* ("Green laver"). Although all kelps in the UK and Ireland are edible, *Saccharina latissima* is considered the most palatable due to its sweet taste. Kelps including *Alaria esculenta* and *Saccharina latissima* are being marketed as "sea vegetables" by health food companies, due to their high levels of vitamins and minerals and low levels of salt and digestible sugars (Jaspars & Folmer 2013). As such, some suppliers in Scotland and Ireland harvest kelps for human consumption, but these operations are currently small scale (Smale *et al.* 2013).
CICES 1.1.5.2 Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	Current harvesting of marine species for use as fertiliser is small scale and primarily based in Northern Ireland and some of the Scottish islands. A site-specific example of a species that is used as fertiliser is *Laminaria hyperborea*, which has been used historically and currently as a fertiliser on machair in Scotland (UK NEA 2011). The Seaweed Industry Association (www.seaweedindustry.com) report that *Sargassum muticum* is often gathered from the shore or floating mats to be used as fertilizer or compost and that many coastal populations make use of *Sargassum muticum* as food source. A breed of sheep on North Ronaldsay (Orkney Islands, Scotland) feeds almost entirely on beach wrack (principally *L. hyperborea*) for most of the year. Stable isotope analysis suggests that the North Ronaldsay breed has been consuming kelp since the fourth millennia BC, during which time it has adapted its rumen bacteria to facilitate the breakdown of laminarin (the storage glucan in brown algae) and adapted an unusual pattern of grazing and ruminating that follows the tidal cycle rather than the (more typical) diurnal cycle (Balasse *et al.* 2005, cited from Smale *et al.* 2013). Macro- and microalgae may be used in the cosmetic industry by small businesses with innovative products based on raw materials (e.g. seaweed soaps) and multinationals. *Halidrys siliquosa* extracts are used within skin beauty products, however information regarding large scale extraction of *Halidrys siliquosa* from the seabed is lacking (Stamp & Tyler-Walters 2015). Kelp is exploited in a range of European and Asian countries for the production of alginate, food, biofuels, medicine and other chemicals (McHugh 2003). French and Norwegian kelp industries, for example, harvest 50,000 tonnes of *Laminaria digitata* and 200,000 tonnes of *L. hyperborea* annually for alginate production (Edwards & Watson 2011, cited from Alexander *et al.* 2016).
CICES 1.1.5.3 Wild plants (terrestrial and aquatic, including fungi, algae)	Large scale harvesting of marine species for biofuel is not currently undertaken, however some assessments of the potential resource have been undertaken for the UK and Ireland (Saunders *et al.* 2010). The only contributing factor considered relevant to this project is macroalgae with the potential level of service based on the available biomass (cited from eftec 2014).

used as a source of energy	
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Not relevant: However, macroalgae may trap sediments supporting biodeposition which in turn supports nutrient cycling (see proforma 3).
Bioengineering	Not relevant: Primary producers do support bioengineering, (see proforma 4).
Hydrodynamic flow	Mediates? Macroalgae may alter hydrodynamic flows, (see proforma 5).
Bioturbation	Not relevant: However, bioturbation supports primary production in the marine environment through nutrient cycling (see proforma 3).
Primary production	Provision: Marine primary producers contribute at least 50% of the world's carbon fixation and may account for as much as 71% of all carbon storage (Chung *et al.* 2011). Primary production at the seabed occurs through microphytobenthos and macroalgae. Benthic algae contribute some 10% of the total marine primary production (Charpy-Roubaud & Sournia 1990). Kelp may conservatively account for around 45% of primary production in UK coastal waters, and 12% of marine production in the entire UK EEZ. This estimate for annual UK kelp production does not include the extensive shallow subtidal rocky reef habitats found off England and Wales and will therefore be an underestimate. Although these coarse estimates should be interpreted with caution, it is clear that kelps make a substantial contribution to primary production in coastal waters off the UK and Ireland (Smale *et al.* 2013).
Secondary production	Not relevant: Kelp detritus, as broken plant tissue, particles and dissolved organic material supports soft bottom communities outside the kelp bed itself (Stamp & Hiscock 2015).
Habitat modification	Not relevant (but see 'geology' above): Macroalgae primary producers create habitat (see proforma 4). Kelp forests are the primary habitat for many commercial and recreational fisheries that include a wide diversity of molluscs, crustaceans, and finfish (Laffoley & Grimsditch 2009 and references therein).
Supply of propagules	Not relevant to this service: However, primary producers support propagules that may be transported to other habitats (see proforma 2).
6. Local ecosystem functions	
Biogeochemical cycling	Supports: Primary production underpins marine food webs and supports biogeochemical cycling (see proforma 3).
Control of algal growth	Mediates: Control of algal growth by grazers could reduce the level of service. Loss of predators can increase grazer populations (Burrows *et al.* 2013) reducing this service.
Food resource	Not relevant to primary production. However, primary production provides food to other species. Herbivory is generally low in kelp forests, with less than 10% of live kelp biomass thought to be consumed by grazers (Norderhaug & Christie 2011), and 80% being exported as detritus (Burrows *et al.* 2014; Wernberg & Filbee-Dexter 2018). The flow of detritus between habitats is an important form of connectivity that affects regional productivity and the spatial organization of marine ecosystems. Kelps produce detritus through incremental blade erosion, fragmentation of blades, and dislodgement of whole fronds and thalli. Rates of detrital production range from 8 to 2657gC/m^2/yr for blade erosion and fragmentation, and from 22 to 839gC/m^2/yr for loss of fronds and thalli. The estimated global average rate of detrital production by kelps is 706gC/m^2/yr, accounting for 82% of annual kelp productivity (Krumhansl & Scheibling 2012) (see Nutrient Cycling proforma 3). Detrital production rates are regulated by current and wave-driven hydrodynamic forces and are highest during severe storms and following blade weakening through damage by grazers and encrusting epibionts. Detritus settles within kelp beds or forests and is exported to neighbouring or distant habitats, including sandy beaches, rocky intertidal shores, rocky and sedimentary subtidal areas and the deep sea. Exported kelp detritus can provide a significant resource subsidy and enhance secondary production in these communities ranging from tens of meters to hundreds of kilometres from the source of production. Loss of kelp biomass is

	occurring worldwide through the combined effects of climate change, pollution, fishing and harvesting of kelp, which can depress rates of detrital production and subsidy to adjacent communities, with large scale consequences for productivity (Krumhansl & Scheibling 2012).
Habitat provision	Primary production indirectly supports habitat provision through the growth of algae that provide habitat for other species including photosynthesising epiphytes (see proforma 4). Beaches with wrack were associated with enriched benthic infauna (polychaetes) on the lower shore and wrack mounds supported abundant macroinvertebrates (mainly *Diptera* larvae and oligochaetes). Such fauna are valuable prey to shorebirds as demonstrated by a strong positive relationship between wader abundance and the percentage cover of wrack on beaches (Orr 2013). The volume of drifting macroalgae inshore was a significant predictor (along with physical beach characteristics) for the abundance of decapods and fish (Orr 2013)
Microbial activity	Provision: Where primary producers are maintained or enhanced.
Nutrient cycling	Mediates: The availability of nutrients is a key component in controlling the abundance and diversity of marine flora which produce provisioning ecosystem services. A reduction in nutrient availability is therefore likely to reduce the delivery of any ecosystem service produced; a total absence of nutrients is likely to result in non-delivery of any ecosystem service (Alexander *et al.* 2016). Nutrients are transported by water movement and *in situ* primary production may not rely on nutrient cycling within the biotope.
Population control	Supports: Where grazers are controlled by higher trophic levels e.g. otters feeding on urchins. Mesograzers feeding on macrophyte surfaces remove smaller epiphytes like diatoms and foliose algae and are thus important for keeping the larger macrophytes free from being overgrown by epiphytic competitors (Moksnes *et al.* 2008). However, in some cases the grazers increase in density to an extent that they start to overgraze the macrophytes which are then grazed to extinction (Christie *et al.* 2009).
Sediment stability	Supports: Where sediment stability supports primary producers.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: Where biodiversity increases support primary production. Maintaining biodiversity and biotope supports this service, top predators control grazers supporting this service (Burrows *et al.* 2013).
Biotope maintenance	Supports: Where the biotope that is maintained supports primary production. Maintaining biodiversity and biotope supports this service, top predators control grazers supporting this service (Burrows *et al.* 2013).
Biotope stability	Supports: Where stability refers to a biotope supporting primary production.
Carbon sequestration	Marine primary producers contribute at least 50% of the world's carbon fixation and may account for as much as 71% of all carbon storage (Chung *et al.* 2011). Kelps are the major primary producers in UK marine coastal waters producing nearly 75% of the net carbon fixed annually on the shoreline of the coastal euphotic zone (Birkett *et al.* 1998). Kelp plants produce 2.7 times their standing biomass per year. The kelps reduce ambient levels of nutrients (although this may not be significant in exposed sites) but increase levels of particulate and dissolved organic matter within the bed. Kelps harvested by trawling/dredging/sledging leaves small kelps *in situ* allowing regrowth. As a result, any reduction in carbon storage is only likely to last a few years if appropriate management is in place (Scottish Government 2016)
Export of biodiversity	Not relevant.
Export of organic matter	Not relevant: To primary production within habitat. Mediates: As part of marine food webs supporting nutrient cycling. Primary production may lead to the export of organic matter. The vast majority (>80%) of kelp-derived organic matter is typically exported from the kelp forest rather than being consumed or remineralised within the source habitat (Krumhansl & Scheibling 2012).
Knowledge Gaps	

Ecosystem Service Proforma 11. CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy

Ecosystem Service	**CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy**

Ecosystem Service Description
The CICES group CICES 1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy, consists of three classes:
CICES 1.1.6.1 Wild animals (terrestrial and aquatic) used for nutritional purposes;
CICES 1.1.6.2 Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); and
CICES 1.1.6.3 Wild animals (terrestrial and aquatic) used as a source of energy.

Most of the service provision relates to the class nutrition where species are harvested for food. A few uses were found of animals being used for other purposes (cultch to support bivalve restoration and sand eels for aquaculture feedstock, see below). Despite historic harvesting of the hydroid *Sertularia cupressina* as an ornamental in the Wadden Sea (Wagler *et al.* 2009), no evidence for harvesting of the characterizing hydroids could be found in the UK and targeted extraction is highly unlikely.

No current examples were found of the use of animals for energy; historic use includes that of whales for oil and candles (Roman *et al.* 2014).

Realisation of this service may lead to physical damage to habitats and loss of both directly targeted animals and damage and mortality of associated species.

Specific node in model, added to models or based on existing nodes?

This final ecosystem services is supported by the following intermediate services: Primary production, Nutrient cycling, Formation of Species Habitat and Larval and Gamete Supply (eftec 2014).

Any categories used to assess service provision.
Service provision was assessed based on a three-point scale:
None: Animal is not known to be commercially targeted
Medium: Animal is targeted, it may be sparse in the habitat under consideration OR it may be a species that is only targeted in parts of its range in the UK or sporadically.
High: Species has high commercial value and is targeted across most, or all, of the range.

1. Regional to Global Drivers		**Confidence**
Climate	Mediates: Habitat suitability for commercially targeted species. In association with rising mean spring temperatures in the Irish Sea, a time-series of juvenile scallop *Pecten maximus* density around the Isle of Man showed a significant increasing trend since 1991 (Shepard *et al.* 2010).	High
Depth	Mediates: Habitat suitability for commercially targeted species and operations. For example, intertidal and subtidal populations may be subject to different levels of fishing effort and some gear types cannot be deployed in both habitats.	High
Geology	Mediates: Habitat suitability for commercially targeted species and operations.	High
Propagule supply	Supports: Propagule supply of commercially targeted species supports this ecosystem service.	High
Water currents	Mediates: Habitat suitability for commercially targeted species and operations.	High
Wave exposure	Mediates: Habitat suitability for commercially targeted species and operations.	High
Dissolved oxygen	Mediates: Habitat suitability for commercially targeted species and operations.	High

2. Water Column Processes	
Evidence	
Primary production	Supports: Primary production in the water column can support this service where the species targeted feed either on phytoplankton or organic detritus. Confidence is Medium as this requirement is likely to vary.
Suspended Sediment	Mediates (habitat suitability): Habitats with high levels of suspended sediment may not be suitable for filter feeding bivalves a key commercially targeted group of species. Confidence is Medium; there is little information on suspended sediments and commercially targeted species other than bivalves.
Light Attenuation	Mediates (habitat suitability): Not relevant for many species but will determine general habitat characteristics, habitat suitability and levels of competition with primary producers. Confidence is Medium.
Water Chemistry and temperature	Mediates: Habitat suitability for commercially targeted species. Confidence is High.
3. Local Processes/Inputs at the seabed	
Evidence	
Food Sources	Supports: Provision of food supports the growth of commercially targeted species. Analysis of fish stomach data show that commercially targeted fish species feed on a wide range of benthic invertebrates (Speybroek *et al.* 2007; Shucksmith *et al.* 2006; Shephard *et al.* 2010; Pinnegar 2014). Benthic invertebrates that are targeted will feed on a variety of food sources and all types are considered to support this service but with medium confidence for specific food groups in the CEM.
Grazing and predation	Mediates: Predation will influence the recruitment and survival of commercially targeted species.
Seabed Mobility	Mediates habitat suitability. Confidence is high.
Recruitment	Mediates: Recruitment of commercially targeted species that provide this service. Confidence is High.
4. Habitat and Bio-assemblages	
Sand	Animals that may be harvested in this habitat include the bivalves, *Spisula spp.* (Fahy *et al.* 2003), *Chamelea gallina* (Ballarin *et al.* 2003; Salomidi *et al.* 2012) and *Ensis spp.* (Fowler 1999) This targeting does not occur through the UK range and level of provision is assessed as Medium at High confidence. Sand eels (*Ammodytes tobianus*) may be targeted to provide food for fish raised in aquaculture.
Coarse	The targeted species in this habitat are the bivalves *Pecten maximus* (Shephard *et al.* 2010) and *Spisula subtruncata* (Degraer *et al.* 2007). Although some evidence indicates that *Echinus esculentus* has been targeted in the past it is not considered to currently be targeted and has not been identified as providing this service. The deployment of waste shell cultch to a dredged area to the east of the Isle of Wight was carried out to determine the potential for enhanced restoration (Hill *et al.* 2011 and references therein). Crushed whelk and scallop shells were deployed and whilst some of the material was found to be very mobile, scallop shells were used as attachment and as habitat for a range of epifaunal and crevice dwelling animals. The volume of shell waste produced by the shell processing industry is thought to be sufficient to make shell enhancement at the end of an aggregate licence term a possibility (Hill *et al.* 2011).
Mud	Targeted species in this habitat include the cockle *Cerastoderma edule,* that is harvested both intertidally and subtidally (Salomidi *et al.* 2012) and *Nephrops norvegicus* (Salomidi *et al.* 2012). The lugworm *Arenicola marina,* is harvested by bait diggers where it occurs in the intertidal (Salomidi *et al.* 2012) but no references to subtidal harvesting were found. The crab *Carcinus maenas* is harvested in some parts of the range. The evidence for *Echinus esculentus* exploitation is patchy and the current situation is unclear. Kelly *et al.* (2001) suggested that commercial harvesting of *Echinus esculentus* would be impractical, however, see rock (below).

Mixed	Species targeted in this biotope for food include the edible crab *Cancer pagurus and* the whelk *Buccinum undatum*. Burrowing bivalves may be targeted in some parts of the range, for example *Chamelea gallina* (Ballarin *et al.* 2003; Salomidi *et al.* 2012) and *Venerupis corrugata* (Jara-Jara *et al.* 2000), while the epifaunal bivalves *Pecten maximus* (Shephard *et al.* 2010) and *Ostrea edulis* have a high commercial value. The potential to use bivalve shells, particularly *Mytilus edulis*, (but not *Ostrea edulis* due to scarcity) has been identified (Smyth *et al.* 2018), however this use is on very small scales; provision is assessed as Low and confidence as Medium. The evidence for *Echinus esculentus* exploitation is patchy and the current situation is unclear. Kelly *et al.* (2001) suggested that commercial harvesting of *Echinus esculentus* would be impractical, however, see rock (below).
Rock	Animals that may be harvested from this habitat include: blue mussels *Mytilus edulis* (Cranfield *et al.* 1999, cited in Fletcher *et al.* 2012; Salomidi *et al.* 2012), edible crab *Cancer pagurus* (Hunter *et al.* 2013), European lobster, *Homarus gammarus* (Smith *et al.* 2001), sea urchin *Echinus esculentus,* (Kelly *et al.* 2001; Jimmy *et al.* 2003). The shrimp *Pandalus montagui* has certainly been harvested in England in the past, but no current records were found for this fishery. Sea urchins have been examined as a source of biologically active compounds with biomedical applications. Sea urchin gonads are also rich in valuable bio-actives, such as polyunsaturated fatty acids (PUFAs) and *β*-Carotene. PUFAs, especially eicosapentaenoic acid (EPA, C20:5) (n3)) and docosahexaenoic acid (DHA C22:6 (n-3)), have significant preventive effects on arrhythmia, cardiovascular diseases and cancer. *β*-Carotene and some xanthophylls have strong pro-vitamin A activity and can be used to prevent tumour development and light sensitivity. Sea urchin fisheries have expanded so greatly in recent years that the natural population of sea urchins in Japan, France, Chile, the north-eastern United States, the Canadian Maritime Provinces, and the west coast of North America from California to British Colombia have been overfished to meet the great demand. In Europe, the sea urchin stocks (*Paracentrotus lividus*) of first France and then Ireland were overfished to supply the French markets. There has also been recent interest in extraction of chemicals from corals and sea squirts for applications as antifouling paint. These chemicals prevent the settlement of barnacles which are the main fouling organisms on boat hulls, oil platforms and cooling water intakes. Globally, this fouling costs more than 1.4 billion USD annually (Rönnbäck *et al.* 2007). The isolation of biologically active molecules from marine animals is also an emerging field. The snakelocks anemone *Anemonia viridis*, possess unique cells for attack and protection producing various bioactive substances including neurotoxins (Nicosia *et al.* 2018). This species has also been studied to investigated for the presence of natural products with anticancer activity (Bulati *et al.* 2016). Although some sponge species are cultured for drug production (Page *et al.* 2011, cited in Wulff 2012) and wild harvested from the Mediterranean for use as bath sponges, no evidence was found for commercial scale wild harvesting of sponges from the UK (Readman 2016).

5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Not directly relevant to service provision: However, biodeposition will support nutrient cycling.
Bioengineering	Supports: Bioengineering and habitat provision may support recruitment of targeted species. See Proforma 4 for more information on habitat provision.
Hydrodynamic flow	Not relevant to service provision.

Bioturbation	Not directly relevant to service provision: However, bioturbation levels will influence habitat suitability and support nutrient cycling.
Primary production	Supports: Primary production will support this service through nutrient cycling and provision of food where targeted species are grazers.
Secondary production	Provision: Somatic production by targeted individuals provides this service.
Habitat modification	See Proforma 4 for more information on habitat provision. Commercially important whelk (*Buccinum undatum*) catches were three times higher on Horse mussel (*Modiolus modiolus*) reef sites and a greater number of smaller individuals were caught on the reefs compared to off-reef habitats (Kent *et al.* 2016).
Supply of propagules	Supports: Where propagules of commercially targeted species are retained within the habitat and support recruitment (although some may be consumed by targeted species). Many benthic species may have pelagic larvae and recruit from outside the habitat, particularly in more disturbed coarse and sand sediments (Eliott *et al.* 1998). Confidence is Medium.
6. Local ecosystem functions	
Biogeochemical cycling	Supports: Through nutrient cycling.
Control of algal growth	Supports: In shallower habitats where algae may outcompete targeted species for space. Grazing of epiphytes that occur on sedentary species may also support growth were these are detrimental and could lead to loss of individuals.
Food resource	Supports: Analysis of fish stomach data show that commercially targeted fish species feed on a wide range of benthic invertebrates (Speybroek *et al.* 2007; Shucksmith *et al.* 2006; Shephard *et al.* 2010; Pinnegar 2014). Confidence is High.
Habitat provision	Supports: (see Habitat provision proforma 4). Confidence is high.
Microbial activity	Supports: Microbial activity can enhance nutrient cycling (see proformas 3). Confidence is Medium.
Nutrient cycling	Supports: Nutrient cycling by primary and secondary producers underpins the food webs that support this service. Confidence is High.
Population control	Supports: Where predators or pests and diseases of commercially targeted species are controlled. There is little evidence to assess this component (see Proforma 6) and confidence is Low.
Sediment stability	Not assessed, no evidence: Targeted species will have species specific requirements, changes species in sediment stability may increase habitat suitability for some through provision of food or nursery habitats while decreasing suitability for others.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Not assessed, no evidence: Targeted species will have species specific requirements, changes in biodiversity enhancement may increase habitat suitability for some species through provision of food or nursery habitats while decreasing suitability for others.
Biotope maintenance	Not assessed, no evidence: Targeted species will have species specific requirements, changes in biotope stability may increase habitat suitability for some species through provision of food or nursery habitats while decreasing suitability for others.
Biotope stability	Not assessed, no evidence: Targeted species will have species specific requirements; changes in biotope stability may increase habitat suitability for some species through provision of food or nursery habitats while decreasing suitability for others.
Carbon sequestration	Not relevant to service provision.
Export of biodiversity	Not relevant to service provision: However, export of biodiversity, including propagules such as pelagic fish larvae, will support this service in adjacent habitats.
Export of organic matter	Not relevant to service provision: However, export of organic matter may support this service in adjacent habitats.

Knowledge Gaps

Ecosystem Service Proforma 12 CICES 1.2.2 Genetic material from all biota (including seed, spore or gamete production)

CICES 1.2.2 Genetic material from all biota (including seed, spore or gamete production)

Ecosystem Service Description

The CICES ecosystem services refer to both plants and animals.

CICES 1.2.1 Genetic material from plants, algae or fungi:
1.2.1.1 Seeds, spores and other plant materials collected for maintaining or establishing a population
1.2.1.2 Higher and lower plants (whole organisms) used to breed new strains or varieties
1.2.1.3 Individual genes extracted from higher and lower plants for the design and construction of new biological entities

CICES 1.2.2. Genetic material from animals:
1.2.2.1 Animal material collected for the purposes of maintaining or establishing a population
1.2.2.2 Wild animals (whole organisms) used to breed new strains or varieties

CICES 1.2.2. Genetic material from organisms:
CICES 1.2.2. 3 Individual genes extracted from organisms for the design and construction of new biological entities

Provision of genetic resources may be supported by other services, such as biologically mediated habitats (eftec 2014).

Specific node in model, added to models or based on existing nodes?

This service is not included in wither the original CEM models. It was not included in the MESO BBN due to the difficulties in separating contribution in a meaningful way.

Any categories used to assess service provision.

Not relevant. Specific information was sourced for a few species.

Comments/ Notes: All biota have the capacity to provide this service, but unless the capacity is realised it remains an option rather than a service. The decision was made to only assess biota that have evidence for service provision rather than providing a blanket assessment of potential. The capacity to support this service by the ecosystem (ecological components at levels 1-3) is based on generic assessments of mediation of habitat suitability for biota (see Proforma 10 and 11). Habitats which do not contain primary producers identified in the CEM bio-assemblage (coarse sediment, mixed sediment and mud) were not considered to provide genetic material from plants.

1. Regional to Global Drivers

2. Water Column Processes

Based on Ecosystem Service proformas 10 and 11.

3. Local Processes/Inputs at the seabed

Based on Ecosystem Service proformas 10 and 11.

4. Habitat and Bio-assemblages

Suspension and deposit feeding fauna	Aquaculture of bivalves often requires the collection of spat from the wild, for example in rope culture of Blue mussels *Mytilus edulis* (Dare & Davies 1975).
Temporary or permanently attached epifauna and macroalgae	Aquaculture of kelps and other macroalgae is supported by wild harvest of fertile material as well as selective breeding (Hasselström *et al.* 2018; Patway & van der Meer 1992). Research into algal cultivation as a cultural service also relies on collection of reproductive material from wild populations, for example Kraan *et al.* (2000).
Mobile epifauna, predators and scavengers	Recent developments in aquaculture techniques have demonstrated the potential for aquaculture of the European lobster, *Homarus Gammarus,* which is currently unexploited for culture (Daniels *et al.* 2015). These systems require the collection of fertile material from the wild.

5. Output processes relevant to ecosystem service

Evidence

Not relevant to service provision.

6. Local ecosystem functions
Not relevant to service provision.
7. Regional to global ecosystem functions
Not relevant to service provision.
Knowledge Gaps
Previous studies (eftec 2014, Maes *et al.* 2012) have found that a lack of evidence has meant that defining the current contribution of species and habitats and their future potential importance to genetic and biotechnology research in a meaningful way is problematic. Specific UK examples are limited, the technology is at an early stage and identifying contribution from different elements is difficult as potentially all biota may be used for genetic research and as ingredients (eftec 2014).

Ecosystem Service Proforma 13 CICES 2.1.1.: Mediation of wastes or toxic substances of anthropogenic origin by living processes

CICES 2.1.1. Mediation of wastes or toxic substances of anthropogenic origin by living processes
CICES 5.1.1.3 Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)

Ecosystem Service Description
In the marine environment, the ecosystem service of waste remediation enables humans to utilise the natural functioning of ecosystems to process and detoxify a large number of waste products and therefore avoid harmful effects on human wellbeing and the environment (Watson *et al.* 2016). Previously the ecosystem service of waste remediation has been defined by the Millennium Ecosystem Assessment as the service of "Water purification and waste treatment" but as "Water quality regulation" by the UK's National Ecosystem Assessment classification (NEA). The ecosystem service of waste remediation is identified in both the CICES and Potts *et al.* 2012 framework.

Within the CICES framework this service is described as Mediation of wastes or toxic substances of anthropogenic origin by living processes (CICES v5.1). In the more detailed CICES framework this service is identified as being delivered by both abiotic and biotic components and is separated into the following services:

- Bioremediation by micro-organisms, algae, plants, and animals
- Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals

Although services delivered by abiotic and biotic components are separated in CICES in the models it was considered that these were not separated as the biological components that perform the service are supported by the substratum. Watson *et al.* (2016) divided wastes into three types:
1) Nutrients and organic matter;
2) Biological wastes/contaminants; and
3) Persistent contaminants.

Waste disposal is dependent on the sea's ability to assimilate wastes and provides positive economic benefits to communities where it allows industries to function. Ecosystem benefits provided directly or indirectly by the service include clean water, recreational amenity, shoreline protection, fish and shellfish (food) (Watson *et al.* 2016).

Specific node in model, added to models or based on existing nodes?
Ecosystem processes and functions within the CEM that directly contribute or are linked to this service are: Nutrient Cycling, Microbial activity, Habitat, (especially muds) presence of bio-assemblages and storage). This service is assessed in the MESO BBN based on nutrient cycling, biodeposition and bioturbation.

Any categories used to assess service provision.
This service is delivered by the bio-assemblage and the habitat through feeding, burrowing and storage. Nodes used to assess provision are: bio-assemblage (and links to) nutrient cycling, secondary production, bioturbation and habitat.

Links to other ecosystem services, processes and functions
Notes: The value of this service depends on demand. In areas with no waste materials present, the ecosystem will not be delivering this service. The model indicates the potential capacity to deliver this service and whether it is declining under the assessed scenarios.

1. Regional to Global Drivers		
Climate	Mediates: Via habitat suitability and influences on metabolic rates and breakdown processes. Biodegradation rates have been reported to decrease at colder temperatures, presumably due to a decrease in the microorganisms' metabolic rate (Alexander *et al.* 2016 and references therein). Filtration in *Mytilus edulis* is influenced by water temperature (Broszeit *et al.* 2016).	High

Depth	Mediates: Via habitat suitability for species that provide this service. In deeper waters wastes may be degraded in the water column by microbial activity or may sink and be sequestered.	Medium
Geology	Mediates: Sediment type determines level of sequestration. Organically enriched muddy sediments, where productivity may be relatively high, in sheltered, low energy areas (e.g. enclosed bays or estuaries), may act as a sink for sediment and a wide variety of contaminants. In these areas, heavy metal ions bind to sulphides and organic matter, including dissolved organic carbon (DOC) to form organic complexes, rendering the metals non-bioavailable (eftec 2014). The higher the levels of fine particles (silt and clay) and the higher the amount of sulphide in the sediments, the less bioavailable the metals will be. The presence of coastal habitats and mud or muddy mixed sediments and sands with high levels of burrowing macrofauna, were considered indicative of where sequestration (as organic complexes for metals) and bacterial breakdown of compounds in muddy habitats is occurring and therefore the extent of these habitats serves as an indicator for this contributing factors (eftec 2014).	High
Propagule supply	Supports: Via supply or organisms that support this service	Medium
Water currents	Mediates: Via transport of into the marine environment but also in their dilution, degradation and dispersal (Watson *et al.* 2016).	Medium
Wave exposure	Mediates: Via transport of into the marine environment but also in their dilution, degradation and dispersal (Watson *et al.* 2016).	Medium
2. Water Column Processes		
Evidence		
Dissolved oxygen	Mediates: Waste and breakdown processes and pathways.	High
Primary production	Provision: Through the cycling of nutrient wastes, thus controlling eutrophication (see evidence for macroalgae below).	Medium
Suspended Sediment	Mediates: Relates to resuspension of sediments and redistribution of wastes (see Pressure proforma 5).	High
Light Attenuation	Mediates: Capacity for phytoremediation and primary production (see below)	High
Water Chemistry and temperature	Mediates: Temperature is linked to thermal degeneration of wastes, activity rates for microbes and macroinvertebrates and chemistry describes the condition of overlying waters; state will be altered by wastes. Many wastes will be broken down in the pelagic environment (Watson *et al.* 2016 and references therein).	High
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Organic wastes may be utilised as foods. Nutrient cycling by primary and secondary producers supports eutrophication control. A variety of organisms ingest, accumulate and bind contaminants. Biosorption and bioaccumulation are physio-chemical processes which involve interactions and concentration of toxic xenobiotic contaminants in the biomass, of either living (bioaccumulation) or non-living (biosorption) matter. Both these processes play an important role in natural storage and export of wastes in the marine environment (Watson *et al.* 2016 and references therein).	
Grazing and predation	Supports: Grazers and predators cycle organic matter and nutrients to higher trophic levels utilising them within the ecosystem.	
Seabed Mobility	Mediates: Indicator of capacity for storage/sequestration within sediments.	
Recruitment	Mediates: Via recruitment of biota that provide this service.	
4. Habitat and Bio-assemblages		
Suspension feeding epifauna	Bioturbation activity (reworking and mixing of sediments) of mega- and macrofaunal organisms within the seabed can bury, sequester and	

	process waste material through assimilation and/or chemical alteration (Beaumont *et al.* 2007). Filtering and detoxification services are provided by suspension feeders and macroalgae. The loss of filtering services is linked to declining water quality, the increasing occurrence of harmful algal blooms, fish kills, shellfish, beach closures and oxygen depletion (Barbier 2012). The bivalve *Mytilus edulis* is an important contributor to this service and is used in managing eutrophic waters. They transform the filtered material into somatic and reproductive growth and aid the deposition of particulate matter to the benthos through faeces and pseudofaeces (Broszeit *et al.* 2016 and references therein). Mussels bioaccumulate and can store and process a wide range of wastes (Broszeit *et al.* 2016). For example, a study by Tedesco *et al.* (2010, cited from Broszeit *et al.* 2016) showed that gold nanoparticles fed to *Mytilus edulis* accumulated in the digestive gland, a smaller portion in the gills and none in the mantle tissue. This means that *M. edulis* remove nanoparticles from the system by accumulation. The establishment of mussel beds has led to improved water quality in areas such as Liverpool docks which previously suffered from phytoplankton blooms due to organic enrichment and subsequent development of anoxic bottom waters (Wilkinson *et al.* 2008).
Infauna	In general, fauna residing in sediments can influence the concentration and distribution of pollution by pelletizing sediment as faeces or stabilising sediment through mucus excretion (Snelgrove 1999).
Macroalgae	Macroalgae is also frequently used as indicator organisms in environmental monitoring, particularly in relation to heavy metals, due to its ability to bioaccumulate contaminants (Gundersen *et al.* 2016 and references therein). A laboratory environment, (Murphy 2007, cited from Bullock & O'Shea 2013) found that the seaweeds *Fucus versiculosus* and *Polysiphonia lanosa* were most effective at removing cations and anions in high solutions with *Palmaria palmata* performing well in low solutions. In general, adult fucoid algae accumulate heavy metals and are generally robust in the face of chemical pollution although, germlings appear to be intolerant of heavy metal pollution. However, local variation exists in the tolerance to copper. Plants from highly copper-polluted areas can be very tolerant, while those from unpolluted areas suffer significantly reduced growth rates at 25 micrograms per litre (eftec 2014 and references therein). Cultivation of kelps adjacent to salmon farms can generate significant yields of algal biomass while simultaneously removing waste nitrogen.
Mobile epifauna, predators and scavengers	Some echinoderms accumulate metals or PCBs as a function of the contamination level of the environment (Coteur *et al.* 2003 and references therein). *Asterias rubens* accumulate contaminants via seawater, food and sediments and are an efficient bioindicator of these contaminants (Coteur *et al.* 2003 and references therein).
5. Output processes relevant to ecosystem service	
Evidence	
Biodeposition	Supports: The benthic–pelagic coupling induced by biodeposition also influences pollutant dynamics because contaminated particles in free water are accumulated in faecal pellets and pseudofaeces and deposited at the sediment surface (Cho *et al.* 2004; Schaller *et al.* 2010).
Bioengineering	See habitat modification and bioturbation below.
Hydrodynamic flow	Mediates: Changes in hydrodynamic flows and associated changes in sediment erosion and deposition will alter waste transport (see wave exposure and water currents above) (Watson *et al.* 2016).
Bioturbation	Mediates: Bioturbation and bioirrigation processes play a pivotal role in delivering the service through the storage and degradation of organic matter, mediating the exchange of gases to the atmosphere, storing, degrading and transforming materials as well mediating the water and habitat quality (Watson *et al.* 2016). In general, bioturbation increases all fluxes at the sediment–water

	interface, including both particulates and solutes (Norkko & Shumway 2011). Bioturbation potential is becoming increasingly used as an indicator of seabed integrity and function and has been used as a proxy for the ability of a habitat to process waste material (Hooper *et al.* 2017).
Primary production	Provision: Macroalgae and other primary producers cycle nutrients reducing eutrophication and improving water quality.
Secondary production	Provision: Secondary production is an indicator of the level of bioremediation and sequestration of pollutants, including the capacity to absorb additional inputs of organic matter. Secondary producers ingest organic matter and other pollutants, fixing a proportion within living biomass and returning smaller, metabolised amounts to the environment, where these may be sequestered or subject to further bacterial breakdown (eftec 2014). Organic matter can usually be completely broken down into its basic components and, in the form of nutrients, can be used by the biological components of a system (Watson *et al.* 2016).
Habitat modification	Mediates: Habitat modification may alter breakdown processes and transport and sequestration of waste materials.
Supply of propagules	Supports: Provision of bioremediators.
6. Local ecosystem functions	
Biogeochemical cycling	Provision: Biogeochemical cycling provides waste remediation via mineralisation of contaminants.
Control of algal growth	Mediates: Removal of algae will reduce waste remediation capacity.
Food resource	Mediates: Via cycling, assimilation and breakdown of wastes especially organic wastes.
Habitat provision	Supports: Where the assemblages maintained provide waste breakdown services.
Microbial activity	Provision: Almost any chemical substance introduced into the marine environment will eventually be attacked by adapted microorganisms, which excrete enzymes capable of breaking them down into simpler molecules; these molecules may then be taken up by microorganisms and metabolised for energy (Alexander *et al.* 2016).
Nutrient cycling	Provision: Organic matter and nutrient uptake and processing
Population control	No evidence.
Sediment stability	Mediates: Seabed stability modifies the ability of the sediment to act as sinks of contaminants and therefore their upward redistribution into the environment (Watson *et al.* 2016).
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: Where biodiversity increases waste remediation capacity.
Biotope maintenance	Supports: Where biotope provides waste remediation.
Biotope stability	Supports: Increased stability will increase waste storage and sequestration within sediments (Watson *et al.* 2016),
Carbon sequestration	Not relevant to service provision: However, sequestration capacity is an indicator of contaminant sequestration potential.
Export of biodiversity	Not relevant to service provision.
Export of organic matter	Not relevant to service provision.

Ecosystem Service Proforma 14 CICES 4.3.1 Mineral substances used for nutrition, materials or energy

Proforma 14	**CICES 4.3.1 Mineral substances used for nutrition, materials or energy**	
Ecosystem Service Description • Mineral substances used for nutritional purposes • Mineral substances used for material purposes • Mineral substances used for as an energy source Sodium chloride (NaCl), occurs naturally in the marine environment in solution. The extraction of sea salt from the surrounding marine waters occurs at two sites in England and one site in Wales (Saunders 2010). Aggregates: The mineral extraction sector includes the extraction of marine aggregates (sands and gravels) from the seabed Oil and Gas: UK production of oil and gas, principally from the UK continental shelf (UKCS), was equal to nearly two thirds of UK primary energy demand in 2008 (94% of oil demand and 74% of gas demand) (Saunders 2010).		
Specific node in model, added to models or based on existing nodes? This service is not delivered by the biota and no nodes within the CEM models represent the services.		
Any categories used to assess service provision. This service is not delivered by the biota and no nodes within the CEM models represent the services.		
1. Regional to Global Drivers		**Confidence**
Climate	Aggregates: Mediates: Suitability for operation. Possibility for increased storm and wave activity could reduce the calm weather windows available for dredging aggregates (Saunders 2010). Oil and gas: Mediates: Suitability for operation. Resources are dependent on a physical environment in which to operate. The offshore oil and gas industry could be vulnerable to both changes in sea level and increases in waves and winds, leading to greater stresses on oil and gas structures in the marine environment (Saunders 2010). Changes in storminess could also affect air and sea access to offshore installations and pose operational issues in terms of health and safety.	High
Depth	Aggregates: Mediates: Suitability for operation. The maximum depth that dredgers can practically operate in is around 50m and is limited by available technology and vessel size (Saunders 2010).	High
Geology	Provision: Aggregates: The mining and quarrying sector relies on various ecosystem services that support its productivity, including: (1) physical environment; and (2) erosion-deposition cycles (of sediment) although most aggregate resources are relict and as such fall outside of contemporary erosion/deposition cycles (Saunders 2010). Primary aggregate is defined as a 50/50 blend on production suitable for use as concreting aggregates and typically contains >20% gravel *in situ* on the seabed. Sand is defined as a product suitable for use as concreting aggregates or concreting/building sand, typically composed of 0% to 40% gravel on production and containing 0% to 20% gravel *in situ* on the seabed (Saunders 2010). Oil and Gas: Oil and gas resources are considered relict features (Saunders 2010).	High

Propagule supply	Not relevant	
Water currents	Oil and Gas: Mediates: Suitability for operations: Changes to currents could result in changes to scour around the legs and supports of offshore installations (Rees, 2008). Aggregates: Mediates: Suitability for operations and presence of resource (Saunders 2010)	High
Wave exposure	Salt extraction: Mediates: Suitability for use of tidal pans where this is the method of extraction. Oil and Gas: The offshore oil and gas industry could be vulnerable to both changes in sea level and increases in waves and winds, leading to greater stresses on oil and gas structures in the marine environment (Rees 2008). Aggregates: Mediates suitability for operations and presence of resource (Saunders 2010)	High
2. Water Column Processes		
Evidence		
Dissolved oxygen	Not relevant	
Primary production	Not relevant	
Suspended Sediment	Not relevant	
Light Attenuation	Not relevant	
Water Chemistry and temperature	Salt Extraction: Mediates: Suitability for operations/use - salt for food use cannot be extracted from highly contaminated environments. Oil and Gas: Are dependent on chemical cycling/water purification to assimilate wastes (Saunders 2010).	High
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Not relevant	
Grazing and predation	Not relevant	
Seabed Mobility	Mediates (Low): The mining and quarrying sector relies on various ecosystem services that support its productivity including erosion-deposition cycles (of sediment); however, most aggregate resources are relict and as such fall outside of contemporary erosion/deposition cycles (Saunders 2010).	
Recruitment	Not relevant	
4. Habitat and Bio-assemblages		
Not relevant.		
Habitat: Sublittoral sand, coarse sands, gravels	Provision of aggregates	High
5. Output processes relevant to ecosystem service		
Not relevant		
6. Local ecosystem functions		
Not relevant		
7. Regional to global ecosystem functions		
Not relevant		
Knowledge Gaps		
Aggregate: Low	There are no significant knowledge gaps associated with this service.	

Salt Extraction: High	Very little specific information exists regarding salt extraction from the marine environment and the information provided in Saunders (2010) was obtained through individual consultation with the three sea salt production companies in the UK.
Oil and Gas	There are no significant knowledge gaps associated with provision of this service.

Ecosystem Service Proforma 15 CICES 3.1.1.1 Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions

<table>
<tr><td>Ecosystem Service</td><td colspan="2">CICES 3.1.1.1 Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions;

CICES 6.1.1.1 Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions</td></tr>
<tr><td colspan="3">Ecosystem Service Description
The CICES service class ‘Direct, in situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting’, has a biotic and abiotic component:

CICES 3.1.1.1 Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions

CICES 6.1.1.1 Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions

As Austen et al. (2011) identify, most people experience the sea from the coast and the only people who directly experience the underwater seascapes around the UK are divers. Recreational boat users and fishers do not experience the underwater environment in the same way (Austen et al. 2011) and the assessment for this service is based on SCUBA diving for recreation.</td></tr>
<tr><td colspan="3">Specific node in model, added to models or based on existing nodes?
Not assessed in MESO BBN models.</td></tr>
<tr><td colspan="3">Any categories used to assess service provision.
Based on the definitions only the bio-assemblage was considered to provide CICES 3.1.1.1 although other aspects of the ecosystem support or mediate the service. For CICES 6.1.1.1, only ‘geology’ as the setting was considered to provide the service although other aspects mediate or support.</td></tr>
<tr><td colspan="2">1. Regional to Global Drivers</td><td>Confidence</td></tr>
<tr><td>Climate</td><td>Mediates: Warmer sea conditions and milder air temperatures in the future are likely to increase the extent and level of participation in these activities (particularly through the colder winter months) (Knights 2007).</td><td>High</td></tr>
<tr><td>Depth</td><td>Mediates: Nitrogen narcosis reduces diver's cognitive function; limiting safe recreational diving to 40-50m depth (Schwerzmann & Seiler 2001). Water depths <5m are considered too shallow (Cited from Alexander et al. 2016).</td><td>High</td></tr>
<tr><td>Geology</td><td>Mediates: SCUBA diving mainly occurs along rocky coastlines in areas with good water visibility (Saunders 2010; Ruiz-Frau et al. 2013). SCUBA diving mainly occurs along rocky coastlines in areas with good water visibility with particularly popular spots including St Abbs, Berwickshire, Weymouth, Plymouth, the Isles of Scilly, Sussex, Scapa Flow (Orkney), the Pembrokeshire islands, the Inner Hebrides and Strangford Lough. Amenity value of sites is therefore variable (Saunders 2010). Alexander et al. (2016), suggested that within the possible depth range (5-50m), areas characterised by hard substrate (i.e. infralittoral and circalittoral rock, EUNIS biotope classifications A3.1 – A3.3 and A4.1 – A4.3), as well as stony and biogenic reef habitat (Annex I reef habitat), are considered areas of interest for SCUBA diving. Sandy or muddy areas are less attractive to divers due to the potential for low visibility or potential lack of features of diving interest.</td><td>High</td></tr>
<tr><td>Propagule supply</td><td>Mediates: Attractiveness of habitats for divers.</td><td>Medium</td></tr>
<tr><td>Water currents</td><td>Mediates: Strong currents may inhibit diving in an area and/or affect safety (Alexander et al. 2016).</td><td>High</td></tr>
</table>

Wave exposure	Mediates: Dive site suitability	High
2. Water Column Processes		**Confidence**
Dissolved oxygen	Mediates: In areas with low oxygen levels	Medium
Primary production	Mediates: Phytoplankton blooms mediate suitability via reduction of visibility. Harmful algal blooms (HABs) mediate suitability via preventing dive opportunities (Willis *et al.* 2018)	Medium
Suspended Sediment	Mediates: SCUBA diving mainly occurs along rocky coastlines in areas with good water visibility (Saunders 2010).	Medium
Light Attenuation	Mediates: SCUBA diving mainly occurs along rocky coastlines in areas with good water visibility (Saunders 2010).	Medium
Water Chemistry and temperature	Mediates: The temperature of the water has an impact on anyone who enjoys water-sports particularly 'full immersion' water-sports such as surfing, SCUBA diving and swimming (Saunders 2010)	Medium
3. Local Processes/Inputs at the seabed		
Evidence		
Food Sources	Not directly relevant: However, where food webs support species that attract divers, this component supports the service.	Low
Grazing and predation	Not directly relevant: However, where food webs and population control support species that attract divers, this component supports the service.	Low
Seabed Mobility	Mediates: Hard substrate or reefs are preferred destinations for diving activity (Kenter *et al.* 2015).	High
Recruitment	Mediates: Biodiversity and dive site attractiveness.	High
4. Habitat and Bio-assemblages		
Species that enhance amenity value	Epifauna that are attractive to divers will increase site amenity value. In Lyme Bay the pink sea fan and sunset coral were identified (Russi *et al.* 2016). Gundersen *et al.* 2016 indicate that kelp and mussel beds in Norway attract snorkelers and SCUBA divers and mitigate eutrophication improving dive site quality. In the UK kelp beds are of importance for recreational divers and anglers, contributing to an estimated value of £11.7 billion for the UK alone (Beaumont *et al.* 2006, cited from Salomidi *et al.* 2012; Laffoley & Grimsditch 2009).	
Species targeted by divers and fishers.	Divers may be attracted to some sites that provide opportunities for hand collection of edible species such as scallops, lobsters and crabs. Recreational fishers will target areas with a supply of preferred fish.	
5. Output processes relevant to ecosystem service		
Evidence		
Biodeposition	Not relevant to ecosystem service provision.	
Bioengineering	Supports: Amenity value of dive and snorkelling sites.	
Hydrodynamic flow	Mediates: Site suitability for recreational activities.	
Bioturbation	Not relevant to ecosystem service provision.	
Primary production	Supports: Kelp beds that support this service through the provision of attractive dive and snorkelling sites and sites that support supply of fish for recreational fishers.	
Secondary production	Supports: Provision of fish and other targeted species for divers, hand collectors and fishers.	
Habitat modification	Supports: Amenity value of dive and snorkelling sites.	
Supply of propagules	Supports: Epifauna and other species support and enhance recreation experiences.	
6. Local ecosystem functions		
Biogeochemical cycling	Supports: Where biogeochemical cycling enhances water quality this will support this service (Gundersen *et al.* 2016 and references therein).	
Control of algal growth	Supports: Harmful algal blooms (HABs) impact upon dive suitability and can prevent diving (Willis *et al.* 2018).	

Food resource	Provision: The presence of preferred target species will attract recreational anglers and divers. Analysis of fish stomach data show that recreationally targeted fish species feed on a wide range of benthic invertebrates (Speybroek *et al.* 2007; Shucksmith *et al.* 2006; Shephard *et al.* 2010; Pinnegar 2014). Sand eel species are ecologically important as prey for breeding seabirds such as puffins, guillemots and kittiwakes (Murray *et al.* 2016; Daunt *et al.* 2002) that will support wildlife watching activities outside of the habitat.
Habitat provision	Supports: Provision of habitat (including nursery habitat) for other species such as fish and target species such as lobsters, may increase the amenity value of a dive site.
Microbial activity	Supports: Microbial activity is likely to indirectly support this service by maintaining habitats and supporting waste remediation.
Nutrient cycling	Supports: No evidence, where biogeochemical cycling enhances water quality this will support this service. Kelps role in controlling eutrophication is noted as supporting this service (Gundersen *et al.* 2016 and references therein). Nutrient cycling will also support bio-assemblages that support this service.
Population control	Supports: Control of harmful algal blooms and invasives could support this service.
Sediment stability	Supports: Reductions in suspended sediment enhance visibility and site amenity and enhance biodiversity.
7. Regional to global ecosystem functions	
Biodiversity enhancement	Supports: The designation and existence of conservation areas may further enhance biodiversity and biomass of certain species. Designation has also been found to be highly valued by recreational divers in the UK (Kenter *et al.* 2013). Results from a survey of Welsh divers found that the level of marine biodiversity at the dive location is one of the most important factors in determining diving location (Ruiz-Frau *et al.* 2013).
Biotope maintenance	See biodiversity above.
Biotope stability	See biodiversity above.
Carbon sequestration	Not relevant
Export of biodiversity	Not relevant to the habitat: May support this service in connected habitats.
Export of organic matter	Not relevant to the habitat: May support this service in connected habitats. Beaches with wave case kelp wrack support higher wading bird abundance (Orr 2013) which may enhance wildlife watching.
Knowledge Gaps	
Very little research is available on the needs and values of SCUBA divers in relation to the marine environment, and hence on the abiotic and biotic components affecting the delivery of this ecosystem service to the diving community (Alexander *et al.* 2016).	