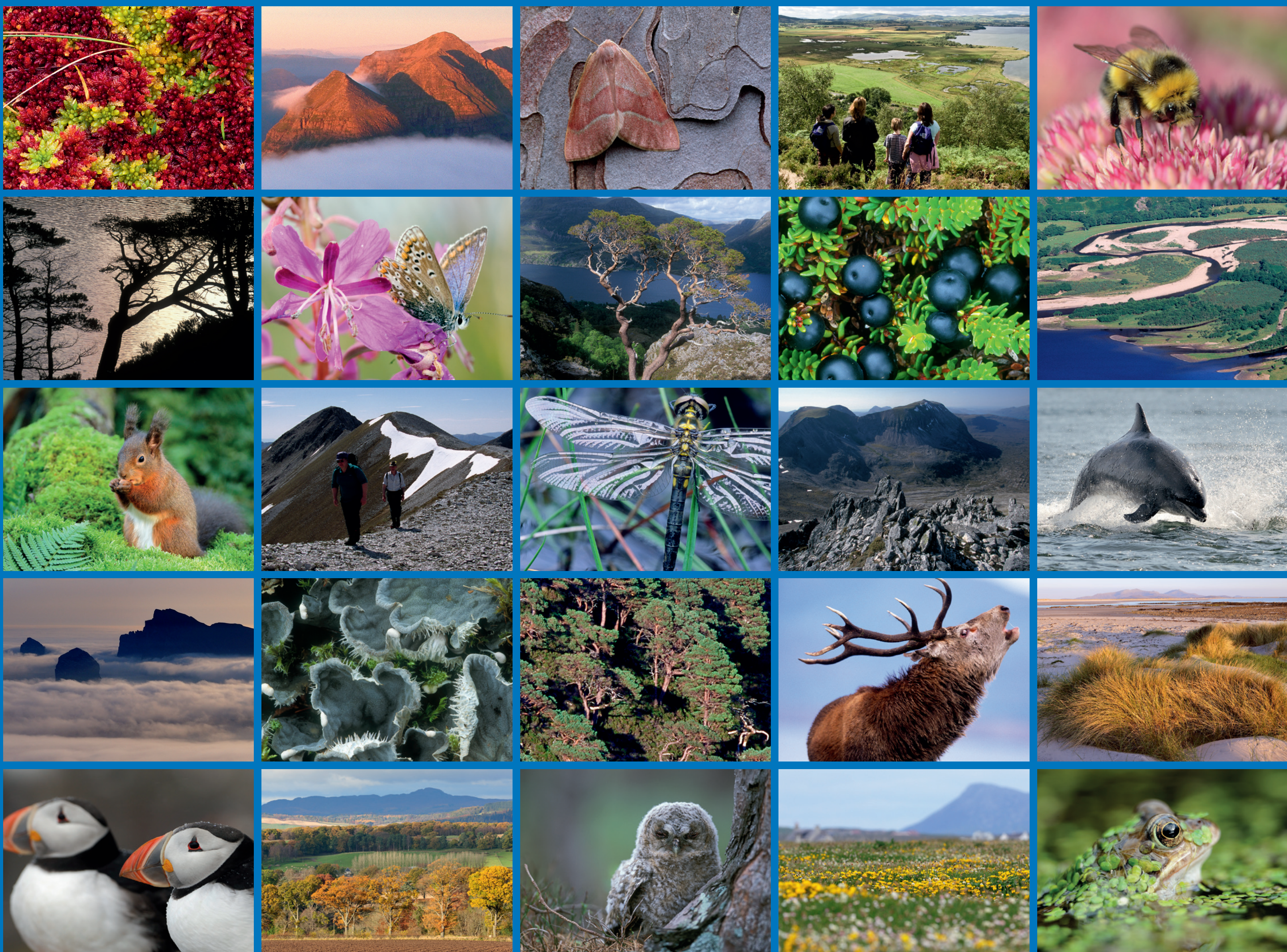
Scottish Natural Heritage
Research Report No. 1071

Feasibility study for a Marine Natural Capital Asset Index for Scotland



RESEARCH REPORT

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RESEARCH REPORT

Summary

Feasibility study for a Marine Natural Capital Asset Index for Scotland

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Keywords

marine; habitats; Natural Capital; Natural Capital Asset Index; ecosystem services; indicators; monitoring

Background

There is increasing recognition of the benefits that humans derive from ecosystems through the provision of food and other goods, including opportunities for recreation. Human well-being is further supported by the processes and functions of ecosystems that regulate and maintain the natural environment, such as the absorption of flood waters by wetlands and carbon capture by woodlands. Degradation and depletion of natural assets, beyond their ability to readily recover, reduces the benefits humans can derive from natural ecosystems. To ensure that uses and benefits are sustained, environmental managers and policy makers are seeking to develop decision support tools that take account of the effects that human pressures have on ecosystem services to inform management. While acknowledging that there are evidence gaps and limitations, work is ongoing nationally and internationally to develop and improve these tools. Typically these tools incorporate information on some or all of the following components:

- Distribution and condition of natural assets;
- Distribution of human activities and pressures and their overlap with natural assets;
- Sensitivity of natural assets to human pressures and activities;
- Systematic categorisation of ecosystem services and links to natural assets; and
- Economic valuation of ecosystem services, goods and benefits.

In 2011, Scotland became the first country in the world to publish a detailed attempt at developing a Natural Capital Asset Index NCAI. The approach tracked annual changes in natural capital stocks, based on an evaluation of ecosystem area (the size of the asset) and condition, measured using a suite of indicators. The original pilot study considered marine assets, but these weren't included in subsequent index development due to the lack of marine data to assess ecosystem condition and develop stock assessments. The NCAI subsequently developed by SNH therefore only includes assessments for terrestrial, freshwater and (some) coastal habitats.

Since the development of this terrestrial NCAI (tNCAI), there has been substantial progress in the development of marine biodiversity indicators, and in the collection and availability of underpinning data. SNH, Marine Scotland and others contracted the Marine Biological Association of the UK (MBA) to produce a desk-based study to examine whether a marine version of the NCAI is now feasible and how it could be delivered.

Assessments of the quantity and quality of ecosystem stocks (natural capital assets) and the ecosystem goods and services that flow from them recognise the fundamental contribution of nature to supporting human well-being. Understanding the importance of natural assets not only helps to improve the sustainable use of natural resources but also makes explicit the consequences of different resource use decisions (e.g. conservation or development).

Main findings

Assessment of feasibility of index development with currently available data/evidence

- This project has reflected on the technical development of the existing tNCAI and has identified similarities and differences that might be expected in developing a marine version (mNCAI).
- It is technically feasible for a mNCAI for Scottish Seas to be developed. Limitations in available data and indicators would mean that a national-scale index is coarse, but likely to be useful in tracking broad trends in the condition of marine natural capital.
- The data and indicator limitations for a mNCAI are similar to the tNCAI but more pronounced for most marine assets, relative to those for land. Indicator data is likely to be uneven in coverage for most ecological components. Outside of protected areas there is very limited monitoring of the condition of habitats; and survey data for species will vary in extent and effort. There are key gaps in indicators relating to future threats (climate change and non-native species). Approaches are suggested to mitigate these limitations.

Preferred methodology for marine index development

- It was considered that the existing tNCAI could be extended to include intertidal habitats, however, these are not systematically mapped and currently a full coverage map is not available (see recommendations, Section 7.4). The option to develop a separate coastal indicator is considered desirable to ensure changes in extent, such as those resulting from climate change are captured.
- Although the structure of the tNCAI could be replicated for a mNCAI, changes in index construction to increase transparency and the capacity to interrogate underlying information could be achieved by combining and weighting indicators at a later stage in index construction. For both the tNCAI and mNCAI this should be explored to potentially allow further disaggregation of stocks/assets, to inform future work on natural capital accounts.
- Adoption of the identified core set of 19 indicators (and potentially, the 8 pilot indicators) that relate to international reporting obligations (WFD/MSFD/OSPAR indicators) would support initial mNCAI development. Consideration should be given to addressing gaps in coverage using proxy (indirect) indicators of condition. Proxy indicators can include species data and human activity (pressure) data.
- The use of proxy indicators based on human activities could provide indirect assessments of condition and could address a wider range of pressures/activities than direct condition indicators. Human activity data for assessments are also likely to be more frequently updated than direct condition assessments. Existing pressure frameworks and sensitivity assessments could be used to link human activities to the condition of ecosystem components. The use of a proxy indicator (abrasion) was tested by this study with condition and ecosystem service delivery adjusted by abrasion intensity and existing sensitivity assessments for subtidal habitats. This proxy would assess the likely effects of activities that cause abrasion such as fishing, dredging and cable laying among others.

- Unlike the tNCAI, the temporal resolution of most marine data means annual reporting is not realistic; longer reporting cycles aligning with other reporting requirements is recommended. Potential indicators should therefore not be excluded from use on the basis of low frequency of updated data. However, some powerful indicators for a mNCAI do update more frequently and could be examined separately for specific management purposes. This may lead in fact to a subset of the index that is regularly updated and a second component that can only be updated sporadically e.g. in line with MSFD reporting.
- More spatially resolved data (particularly for benthic habitats) would allow a more robust index to be developed, capturing more detailed habitat information. The expense of marine survey and monitoring means this is not currently possible at a national scale, However, more robust indices could be developed using available data at smaller scales. This may be relevant to Marine Protected Areas where sampling and monitoring effort is greater and would provide a useful commentary on improvements in natural capital related to Scottish conservation efforts.

Recommendations for a programme of work to improve the potential for a robust mNCAI

- A separate coastal and intertidal index that combines the coastal habitats from the tNCAI with intertidal habitats may provide a pragmatic starting point for mNCAI development. Many marine activities have associated coastal components and there are clear links and shared assets (such as seals) and indicators between marine, intertidal and coastal ecosystems. Similar challenges around habitat mapping, monitoring and indicator availability would need to be resolved. Although early versions of a coastal and intertidal index may not cover the full Scottish coastal and intertidal extent, increasing use of satellite monitoring and other technologies such as unmanned aerial vehicles may address data gaps more readily for coastal and intertidal areas than marine.
- More detailed interrogation of potential indicators is initially required, and a larger programme of work would enable a more robust index to be developed. The link between assets, indicators and ecosystem services should be further considered, building on the case study, to identify key gaps in coverage.
- It is suggested that the national importance weighting used in the tNCAI is revised or a marine relevant version developed, to capture the value of marine ecosystem services and their national significance in the mNCAI.
- Whether and how to include mobile species, as an asset in their own right but also potentially as an indirect indicator of the health of habitats/ecosystems upon which they rely is a key issue to be resolved. Seals and seabirds may be included in both the terrestrial and marine indices.
- Identifying key habitat associations and links with other ecological components would support the use of indicators such as birds, marine mammals and fish, to assess the likely condition of pelagic habitats, feeding grounds, nursery areas and other components such as prey species.
- Further work is recommended to identify and develop other proxy indicators based on pressures. Existing activity and pressure frameworks and work undertaken by Feature Activity Sensitivity Tool (FEAST), hosted by Marine Scotland and the Marine Life Information Network (MarLIN) to assess sensitivity of habitats and species provide an authoritative starting point.
- Other key challenges remain for development of a mNCAI, a key question is how to define and capture temporally variable pelagic habitats as assets.
- Better understanding of condition thresholds for delivery of ecosystem services will improve any index. While there is increasing evidence available for the relationship between pressures and condition e.g. seabed abrasion pressure and habitat condition, little work to date has assessed changes in ecosystem service provision with the breakdown of habitat structure and functioning with degradation; better understanding of

these relationships and key thresholds would greatly inform the assessment of natural capital.

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1. INTRODUCTION

1.1 Background to the project

In 2011, Scotland became the first country in the world to publish a detailed attempt to track annual changes in its natural capital stocks, based on an evaluation of ecosystem service potential (SNH 2012a,b; SNH, 2018). The resulting Natural Capital Asset Index (NCAI), developed by Scottish Natural Heritage (SNH) has developed assessments for terrestrial, freshwater and (some) coastal habitats. The original pilot study (Hambrey & Armstrong, 2010) did consider marine assets, but this was not progressed in subsequent index development due the lack of marine data to assess ecosystem condition and develop stock assessments. Since the development of the terrestrial NCAI (hereafter referred to as tNCAI), there has been substantial progress in the development of marine biodiversity indicators, and in the collection and availability of underpinning data. SNH contracted the Marine Biological Association of the UK (MBA) to produce a desk-based study to examine whether a marine version of the NCAI (hereafter referred to as 'mNCAI') is now feasible and how it could be delivered.

The concept of capital is used to describe anything that can produce goods and services that contribute to human welfare. The Five Capitals model (Figure 1) identifies capital assets as manufactured capital (e.g. roads, buildings and machines), financial capital (money, shares and bonds) human capital (e.g. knowledge, health, skills and motivation), social capital (culture, institutions) and natural capital as the element that underpins all economic activity. Natural capital can be defined as "the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions" (Natural Capital Committee, 2017).

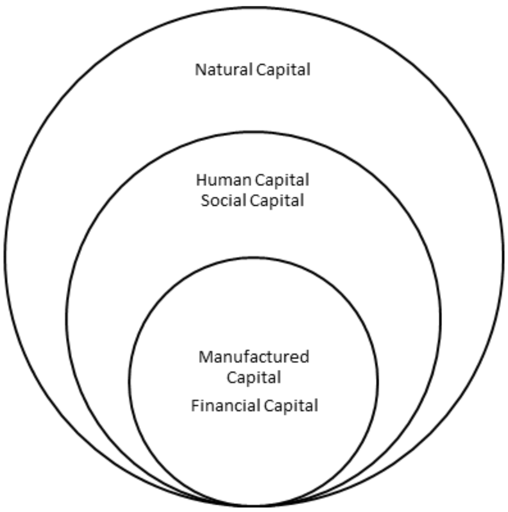


Figure 1. The Five Capitals models (redrawn after the Forum for the Future model)

The Natural Capital Committee (2014) sought to formalise a conceptual framework for defining the different elements of natural capital for assessment (Figure 2), recognising that:

1) There is a set of natural capital stocks (the assets) (e.g. clean air, soil, woodland, species).
2) Each natural capital stock may provide one or more services; these are outputs or features of each stock (e.g. freshwater, crops, trees, wildlife).

3) Services, often combined with 'other capital inputs', can be used to produce goods. Goods are what people receive and use from natural capital stocks (e.g. good health, timber, food, nature appreciation). Goods need not be physical, but can also include e.g. good air quality or recreation. In economic terms, nature (natural capital) can be considered as yielding productive inputs which, when combined with produced and human inputs, generate goods that provide benefits of value to society,
4) 'Goods' are consumed / used and provide *benefits* (to people) which can be *valued* (often in monetary terms). Natural capital stocks provide many potential services with different benefits and values. These relationships may change over time and place.

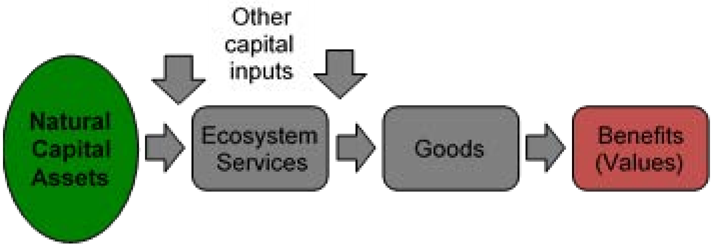


Figure 2. Conceptual framework for natural capital and ecosystem services (adapted from the Natural Capital Committee, 2014).

Natural Capital stock assessments provide a baseline against which the impacts of management and development options can be evaluated within the context of defined objectives for environmental exploitation, protection, maintenance and restoration. Practical difficulties in assessment have been recognised (Natural Capital Committee 2014), and include the fact that stocks of natural capital are unevenly dispersed across landscapes, potentially interconnected and may be dynamic. These characteristics support part of the value of natural capital as a key feature is the potential for natural capital to fulfil different functions and to function differently under changed conditions (the use and value for natural capital may be different in future compared to today). Despite these complexities, it is an increasing priority to develop natural capital assessments and develop robust methodologies to enable comparative measurement.

1.2 Outline of the terrestrial Natural Capital Asset Index (tNCAI)

The terrestrial Natural Capital Asset Index (tNCAI) was developed by SNH as a measure of relative change in the extent and condition (quality) of each of seven natural capital stocks (Broad Habitats). A key feature of the tNCAI is the use of 38 indicators to assess ecosystem quality. The approach recognises that ecosystems need to be in good condition to provide multiple ecosystem services, which, in turn, deliver goods and benefits and increase well-being. Drivers of change can have a positive (e.g. conservation) or negative (pressures) impact on ecosystem condition.

The basic structure for the tNCAI is:

ecosystem area x ecosystem quality

The construction of the tNCAI (see Chapter 2) means that it can be used to:

1) Identify the size of different Natural Capital stocks (Broad Habitats);
2) Identify the ecosystem services associated with Broad Habitats; and
3) To assess the national importance of the stock in producing ecosystem services and how this might be changing over time.

This knowledge allows changes in Scotland's natural assets to be evaluated and communicated and can be used to inform management and policy decisions and communicate the rationale behind these to stakeholders. For example, it could be considered desirable to protect a habitat that produces high-levels of particularly important services, especially if the habitat is limited in extent and sensitive to pressures that will result in reduced delivery of services.

1.3 Policy background and application

Scotland's Economic Strategy,[1] and the Programme for Government,[2] both reference commitments to protecting and enhancing the environment and natural capital. The tNCAI has been adopted as part of the Scottish Government's National Performance Framework. "Increase natural capital" (as measured by the NCAI) is one of 55 National Indicators which document progress towards achieving the Scottish Government's ambition and priority outcomes (Scottish Government, 2018).

A similar approach to the tNCAI for marine assets would support Scotland's National Marine Plan[3] (NMP) that has high level policy drivers with the ambition to "…promote an ecosystem approach, putting the marine environment at the heart of the planning process to promote ecosystem health, resilience to human-induced change and the ability to support sustainable development and use." As strategic objectives, the NMP adopts (a) the Descriptors of Good Environmental Status from the EU Marine Strategy Framework Directive (MSFD) and (b) the High Level Marine Objectives (HLMOs) from the UK Marine Policy Statement. Many details of the MSFD and HLMOs can be clearly associated with the principles of the natural capital concept, as can specific NMP policies which seek to improve ecosystem status and function for the benefit of people.

In addition, the Scottish Biodiversity Strategy's 2020 Challenge[4] identifies the intention to develop a marine Natural Capital Asset Index (mNCAI). This would not only support the tracking of changes in natural capital stocks but also support marine planning through Scotland's National Marine Plan (NMP) and Regional Marine Plans through:

- Identification of species, habitats and functions which are particularly important to maintain to ensure ecosystem health and continue delivery of ecosystem services;
- Better knowledge of the linkages between social and economic activities and the stocks of natural capital which directly and indirectly support them;
- Improved understanding of the consequences of decision making on ecosystems and the services they provide; and
- Identification of key areas to better manage human pressures to safeguard ecosystem services such as natural coastal protection and carbon sinks to mitigate and adapt to climate change.

In addition, international policy drivers such as the European Union's (EU) Biodiversity Strategy to 2020 aims under its Target 2 to maintain and enhance ecosystem services in Europe. To this end, the European Commission is developing a knowledge base on ecosystems including aspects of ecosystem condition, the capacity of ecosystems to provide services, biodiversity and the pressures they are exposed to. The development of a systematic approach to assess the status of ecosystem services which are directly linked to or supported by ongoing MSFD indicators and other related assessments would support coherent mapping and assessment of ecosystem services, as required by the EU

[1] https://beta.gov.scot/publications/scotlands-economic-strategy/pages/2/
[2] https://beta.gov.scot/programme-for-government/
[3] https://www.gov.scot/publications/scotlands-national-marine-plan/
[4] https://www.gov.scot/Publications/2013/06/5538

Biodiversity Strategy 2020 (Maes, *et al*. 2016) and the harmonisation across different legislative drivers.

1.4 Project aims

This initial study has aimed to achieve a clearer understanding of possible and preferred methods for taking forward a mNCAI, including the identification and examination of the merits and challenges of different options. The project has appraised suitable indicators, data and methods and includes an evaluation of whether/which methods from the existing tNCAI are transferable, to allow SNH and partner organisations to:

(a) Assess whether it is feasible to develop a robust index with currently available data/evidence;
(b) Identify a preferred methodology for marine index development;
(c) Develop recommendations for a programme of work to improve the potential for a robust mNCAI.

Following the initial appraisal a case study focusing on a particular region (Clyde), asset group (subtidal benthic habitats) and pressure (abrasion) was used to further interrogate and test some particular aspects of index construction.

1.5 Outline of report sections

The report consists of the following sections in addition to this introductory chapter.

Chapter 2 provides an overview of the tNCAI methodology and outlines the data requirements, weighting and calculation steps and application.

Chapter 3 outlines the main feasibility considerations for development of a mNCAI, highlighting key differences, limitations and alignments between marine and terrestrial ecosystems and what similarities might be expected between the marine and terrestrial NCAIs.

Chapter 4 outlines available habitat and species data and considers the options for categorising key habitats and species as stocks. The chapter identifies a range of sources for assigning ecosystem services to species and habitats.

Chapter 5 a key element of this project was identifying and appraising the suitability of available marine condition indicators. Chapter 5 discusses the methodology and results for indicator collation and appraisal and provides recommendations and options for the final selection of indicators

Chapter 6 assesses in more detail the feasibility of mNCAI development through a case study on abrasion undertaken to investigate key issues around the development of a mNCAI.

Chapter 7 presents the study conclusions and presents an overview of project outcomes, key evidence gaps and key recommendations.

1.6 Outputs

The outputs of this project are this report and two Excel workbooks; the Indicator Directory and Appraisal (see Annex 7) and the worked mNCAI example developed in the abrasion case study (see Annex 8).

2. DEVELOPMENT AND CALCULATION OF THE TERRESTRIAL NCAI

This section provides a brief background and outlines the construction steps for the terrestrial NCAI (tNCAI). The guidance on the tNCAI references two key documents available from SNH[5], the Excel spreadsheet which contains the index calculations and the accompanying technical guidance. A useful document regarding development of the NCAI is the pilot study commissioned by SNH (Hambrey & Armstrong, 2010). The condition (ecosystem quality) indicators used in the tNCAI were systematically evaluated by Albon *et al*. (2014). The Albon *et al*. (2014) report also contains an evaluation of weighting and influences on the tNCAI, a methodological introduction to the NCAI and guidance on score disaggregation that is not presented in other documents.

2.1 Methodological development

The tNCAI uses the European Nature Information System[6] (EUNIS) Level 2 Broad Habitats as units of natural capital that each have the potential to deliver a range of ecosystem services. The stock (habitat) area is weighted by contribution to ecosystem services (potential and importance) and ecosystem condition (measured through a range of pre-existing indicators/measures of ecosystems). This is similar to the approach taken by UK National Ecosystem Assessment (UK NEA, 2011a,b), though the marine ecosystem was not included in the tNCAI.

The tNCAI is structured around a method devised by the Netherland's Environment Agency (ten Brink, 2007), where changes in extent (quantity) of a Broad Habitat are multiplied by changes in the condition (quality) of that Broad Habitat. The tNCAI is updated annually to track changes in the stock of natural capital over time, however, not all data is updated regularly so some trend information is smoothed. The values are standardised to 100 in the year 2000 (see Figure 3). Unless there are methodological updates/ changes the previous year's index values are kept the same and not updated.

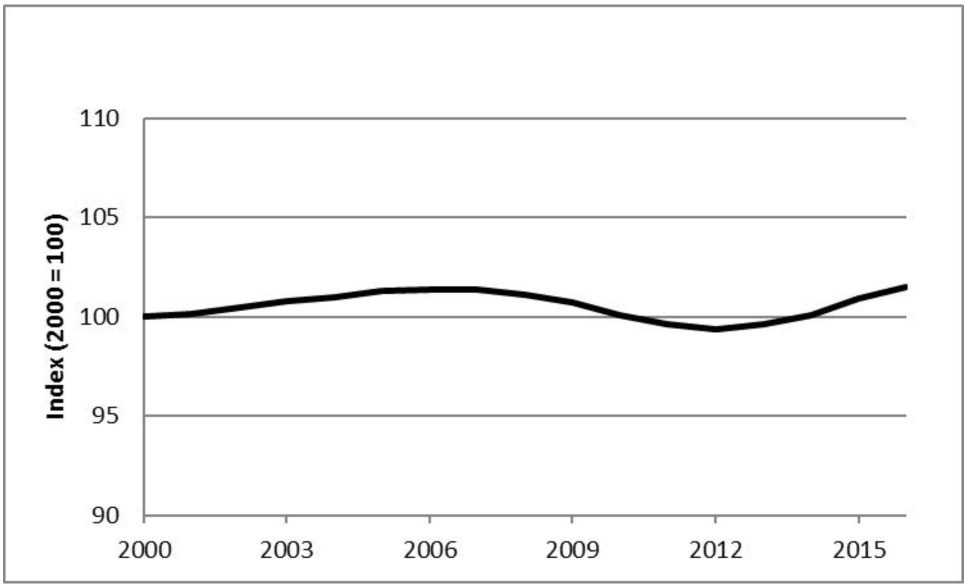


Figure 3. The overall tNCAI trendline from 2000-2016, showing an increase in combined natural stocks across terrestrial ecosystems. The represents a smoothed version of the NCAI index.

[5] Available from https://www.nature.scot/scotlands-natural-capital-asset-index-0
[6] https://eunis.eea.europa.eu/

The methodology to construct the tNCAI has been considered in this report to consist of two main parts. The first part is the creation of a well-being base matrix that weights ecosystem service delivery by Broad Habitat by three factors: potential level of ES delivery, habitat area and national importance of ecosystem service. Part 1 (see Figure 4 below) of the indicator calculation determines the potential delivery of ecosystem services by Broad Habitat. It is weighted by area to assess the % contribution of each habitat to each ecosystem service, to define the well-being base. Part 2 of the index construction (Figure 5) takes into account the condition of the habitat in potential ecosystem service delivery, and weights potential changes resulting from habitat improvement or degradation in ecosystem service delivery by Broad Habitats.

It should be noted that for this project we have made one change in terminology from the tNCAI, renaming the spreadsheet ‘ES Potential (weighting)’ to ‘ES National Importance’, to more clearly differentiate between spreadsheets and contents.

The tNCAI is constructed from the following variables:

- Habitat area;
- Ecosystem service potential delivery by Broad Habitats;
- Ecosystem service importance; and
- Condition indicator values and their relationship to ecosystem service delivery.

2.2 Habitat classification and area

The original tNCAI classified ecosystems in Scotland using the ‘Broad Habitat’ classifications based on those from Countryside Survey 2007 (Norton *et al.*, 2009). Since 2015 a slightly adapted European Nature Information System (EUNIS) classification (Strachan, 2015) has been used as the basis for the assessment. The following Scottish habitats are included in the tNCAI:

- Woodland;
- Inland surface waters;
- Coastal habitats above Mean High Water Springs (MHWS) only (dunes, sandy beaches & rocky shores);
- Grasslands;
- Mires, fens and bogs;
- Heathland; and
- Agriculture and cultivated.

2.3 Ecosystem service framework

The ecosystem service framework, i.e. the identification of services that are delivered by each of the broad habitats types was based on the framework developed by the Common International Classification of Ecosystem Services (CICES) (Version 4.3, Haines-Young & Potschin, 2013). The framework assesses final ecosystem services, classified into three groups, provisioning, regulating and maintenance and cultural (see Section 3.3).

2.4 Calculation of the tNCAI

2.4.1 Part 1: weighting ecosystem service delivery by habitat adjusted by importance and area

SNH adopted a three stage weighting of ecosystem delivery by broad habitats. This weighting discriminates between the different types of habitat and their contribution to natural capital. The three weighting stages (see Figure 4) are used to calculate the well-being base matrix.

Stage 1. Weighting the ecosystem service potential of each habitat (spreadsheet output: ES potential per SPU matrix)

Stage 2. Weighting ecosystem service potential of each habitat by area (spreadsheet output: matrix, ES Potential base)

Stage 3. Weighting each ecosystem service group and component class by its national importance to Scotland (spreadsheet output: ES National importance).

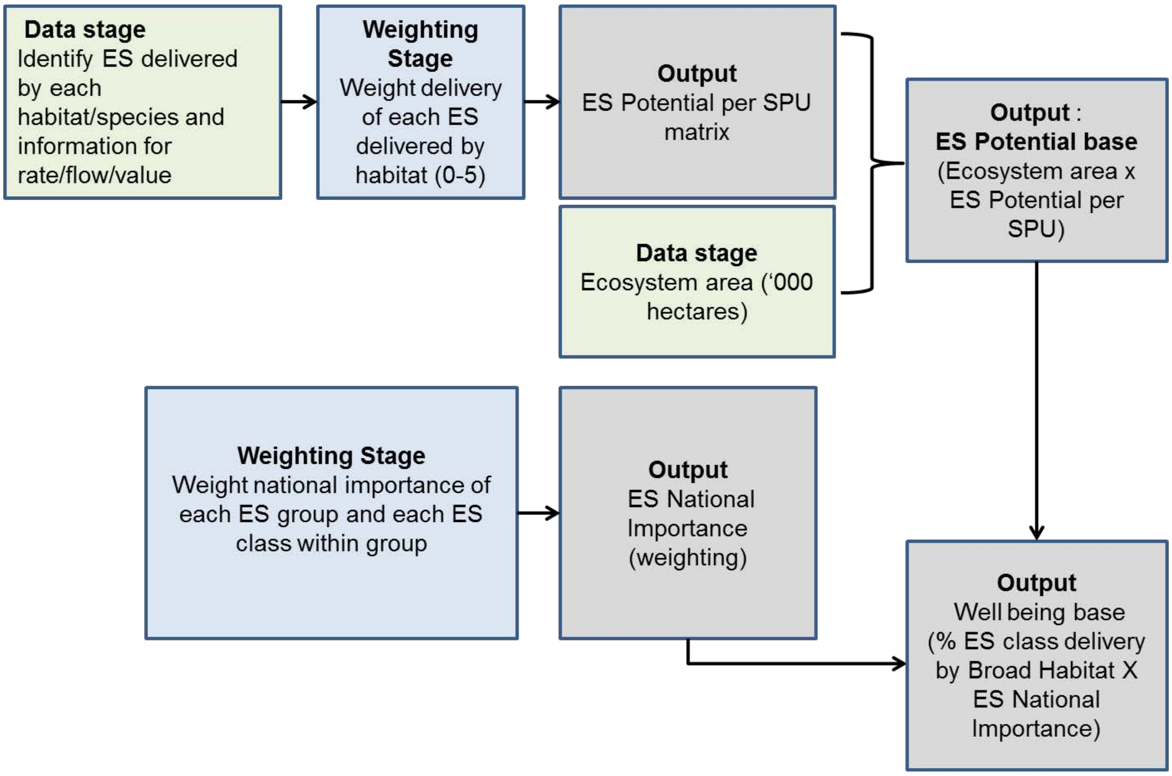


Figure 4. Outline structure of construction of the well-being base to support NCAI, showing data input stages, weighting stages (stages 1 and 2) and outputs.

2.4.2 Stage 1: weighting the ecosystem service potential per habitat (see ES potential per SPU in tNCAI Excel spreadsheet)

A habitat x ecosystem service matrix was developed using professional judgement by experts in SEPA and SNH to indicate the level of potential service that each habitat (or Service Providing Unit-SPU) can deliver. The weighting of delivery potential was developed based upon work by Burkhard *et al*. (2014) with potential level of service delivery scored in the matrix, using a five point scale where:

- 0 = No relevant potential;
- 1 = Low relevant potential;
- 2 = Relevant potential;
- 3 = Medium relevant potential;
- 4 = High relevant potential; and
- 5 = Maximum relevant potential.

For later calculation steps the potential value of each ecosystem service from the ES potential per SPU matrix is converted to a proportional value (ecosystem service potential divided by maximum possible potential).

2.4.3 Stage 2: weighting ecosystem service potential per habitat by area (ES potential base)

The ecosystem area is estimated for each of the habitats in hectares (10,000 m^2). The habitat areas, indexed to the year 2000 baseline, are also used in a later step to adjust the service delivery weight and identify service potential per hectare.

The stage 1 and stage 2 results are multiplied (see Formula 1) for each habitat/ecosystem service. The re-weighting of the potential ecosystem service delivery from 0-1 in this step by dividing by 5 (the maximum potential delivery weighting) prevents the ES potential base value exceeding the extent of the habitat. An ecosystem service that is fully realised, i.e. delivered at full potential, is weighted as the area of habitat (in '000 hectares) for that service.

Formula 1:

$$\text{Area ('000 hectares)} \times \frac{\text{Potential ES delivery}}{\text{Maximum ES Delivery}_{(5)}} = \text{ES Potential base}$$

2.4.4 Stage 3: weighting the national importance of ecosystem service delivery

Each of the three groups of ecosystem services (provisioning, regulation and maintenance and cultural) were assigned a weighting value based on national importance to Scotland. The most important of the three (regulation and maintenance) was assigned a value of 20 and the other two were assigned a value between 0-20 in terms of their relative importance (see Table 1). For example, within provisioning services (see Table 2), the importance to Scotland of cultivated crops and water for drinking purposes were both assigned 20 while animal based mechanical energy was assigned a zero. The weights were then adjusted to indicate contribution (%) based on the importance of the ecosystem service group. The adjusted ecosystem services across the three groups sum to 100.

The relative weights of Broad Habitats were obtained in different ways for each of the service categories:

The weightings for the national ES demand have been informed by their relative contribution to human wellbeing using several pieces of work:

- Phase 1 of the tNCAI work using a market based approach
- Finland's TEEB ecosystem services efforts (Mononen *et al*., 2016);
- The South East Queensland Ecosystem Services Framework (Maynard *et al*., 2010); and
- Theoretical work by Marion Kandziora and colleagues (Kandziora *et al*., 2013).

Cultural services are all weighted equally as they are hardest to differentiate although these may be refined in future as research becomes available. An internal sensitivity testing has found that weighting changes may affect the magnitude of changes but not the trends themselves (Tom Mckenna, pers. comm.).

Table 1. Stage 3: weighted importance of each ecosystem service group to Scotland.

Group	Weighted Importance to Scotland (0-20)	Adjusted Contribution (%)
Provisioning	10	25
Regulation and maintenance	20	50
Cultural	10	25

Table 2. Weighting of each ecosystem service class within the provisioning ecosystem service group by relative importance (from 0-20). The proportional contribution of each class within the group is adjusted relative to the weighted importance of the group (25%) so that the final column sums to 25.

Service class	Weighted importance	Adjusted contribution
Cultivated crops	20	3.85
Reared animals and their outputs	15	2.88
Wild animals, plants and algae (and their outputs)	9	1.73
Animals, plants and algae from in-situ aquaculture	9	1.73
Water for drinking purposes	20	3.85
Materials from animals, plants and algae (for direct use or processing)	13	2.5
Materials from animals, plants and algae (for agricultural use)	13	2.5
Genetic material for all biota	7	1.35
Water for non-drinking purposes	11	2.12
Plant-based energy sources	12	2.31
Animal-based energy sources	1	0.19
Animal-based mechanical energy	0	0
Total	**130**	**25**

2.4.5 Calculation of well-being base (weighting ES potential base by ES national importance)

The well-being base matrix indicates the relative potential contribution to human well-being of each habitat, in terms of its hypothetical ability to supply ecosystem services across the whole of Scotland. The well-being base contribution is calculated (see Formula 2) for each combination of habitat/ecosystem service from the previous matrices:

- ES Potential base matrix (area adjusted ecosystem service delivery potential), and the
- ES National importance weighting (which indicated the importance of each ecosystem service to Scotland)

Formula 2:

$$\left(\frac{Broad\ Habitat\ contribution\ to\ ES\ potential}{Summed\ ES\ potential\ all\ Broad\ Habitats} \times 100\right) \times ES\ National\ importance$$

2.4.6 Part 2: condition indicator weighting of the well-being base

The incorporation of 38 condition indicators into the tNCAI recognises that habitat condition (quality) as well as extent (quantity) influences the delivery of ecosystem services. The indicator weighting stages are outlined below in Figure 5.

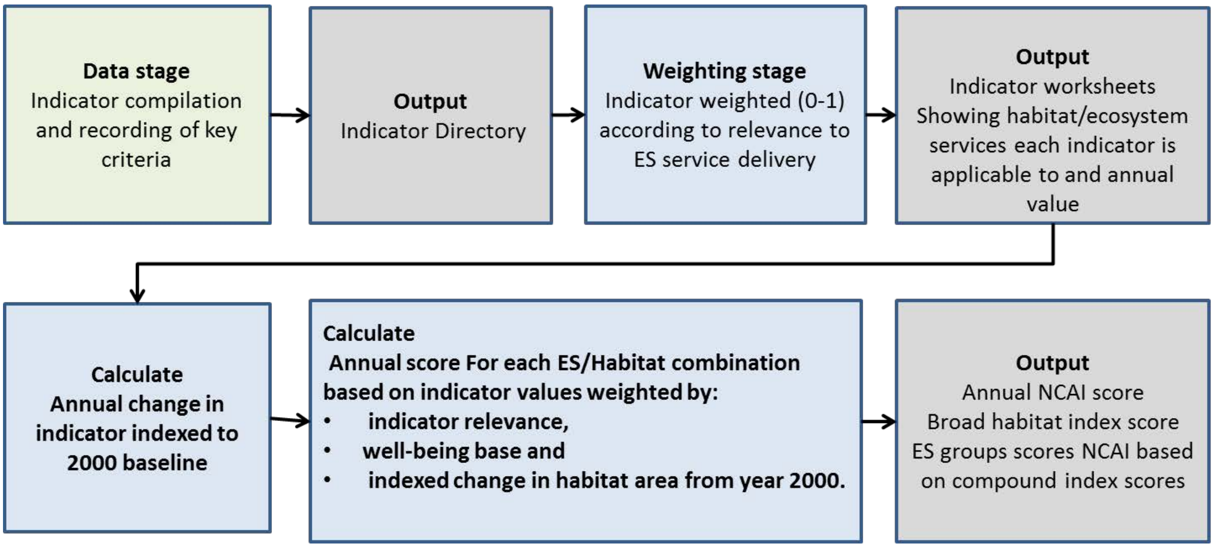


Figure 5. Outline structure of final stage of tNCAI development based on weighted indicators and well-being base, adjusted by indexed change in habitat extent.

2.4.7 Indicator directory

Selected ecosystem condition indicators are compiled into the 'Indicator directory' tab which provides additional data. The indicator list has been appraised and refined as described in Albon *et al*. (2014). Criteria to assess whether indicators are suitable for the NCAI model include among others: the year that data were first available (ideally, since 2000); how frequently data are updated (ideally at least once a year) and spatial coverage (ideally across the entire of Scotland).

Ideally, condition indicators would relate to the capacity of habitats to deliver ecosystem services, so that changes in the indicator reflect changes in service delivery. However, indicator selection is constrained by the availability of pre-existing data and there are gaps within indicators in the tNCAI that mean for some habitats and ecosystem services there may not be an indicator.

Condition indicators vary in the degree to which they represent an ecosystem service group. To reflect this, each indicator is assigned a relative weight of either 0, 0.2, 0.5 or 1 based on its efficacy as a quality measure for each ecosystem service that it represents. The weights are assigned according to the following criteria:

- 0 - No link between indicator and ecosystem service
- 0.2 -Typically used for pressure indicators where the link between indicator and ecosystem service is indirect
- 0.5 - Direct link between indicator and service delivery
- 1 - Near perfect indicator.

Indicators can represent a link between several habitats and/or several ecosystem services. For example, within the tNCAI the 'upland bird index' is judged to be a relevant indicator for regulation & maintenance services for which it scores 0.5 and highly relevant for cultural services, for which it scores 1. It is not considered an indicator of provisioning services for which it scores 0.

A new worksheet is generated for each of the indicators considered suitable for the tNCAI (i.e. included in worksheet 'Indicator Directory' and with a weighting above zero for at least one of the ecosystem service classes). These worksheets show the combination of habitats and ecosystem services that the indicator is relevant to and also contain the raw data for the indicator between 2000 and 2016. As individual quality indicators come in a range of units (e.g. orphosphate levels µg/l, adult grouse density) they must be normalised before they can be compared or aggregated. For each indicator this is achieved by indexing the annual value to the 2000 level which is set at 100. The indicator weighting and the index value (not the raw indicator data) are used to calculate the tNCAI.

2.4.8 tNCAI calculation

For each year the tNCAI is calculated in a separate habitat x ecosystem service worksheet that brings all of the information contained in the previously described worksheets together:

i. Changes in the relevant indicators for each of the combinations of habitat/ecosystem service (using the 38 Indicator worksheets) plus a weighting worksheet 'Indicator 0' (see below);
ii. The well-being value for each of the 868 combinations (using the relevant cell in the well-being Base sheet); and
iii. Changes in area for that particular year (using the Ecosystem Area sheet).

For each cell within the matrix the following calculation steps are applied. The indicator weighting and index value of each indicator are multiplied and summed. The spreadsheets used to calculate the tNCAI include a spreadsheet 'Indicator 0', which contains a value marginally above zero = 1*e^37 to avoid error messages for each cell, this value is used in the calculation of the indicator to ensure that the calculation does not result in a division by zero (which would result in an error). This worksheet has no impact on the final NCAI value.

For each combination of habitat/ecosystem service the contribution to natural capital is calculated as below (Formula 3), with a division by 10,000 to normalise values following repeated multiplication by 100:

Formula 3:

$$\frac{\left(\left(\frac{total\ indicator\ scores}{total\ indicator\ weight}\right) \times wellbeing\ base\right) x\ ecosystem\ area}{10{,}000}$$

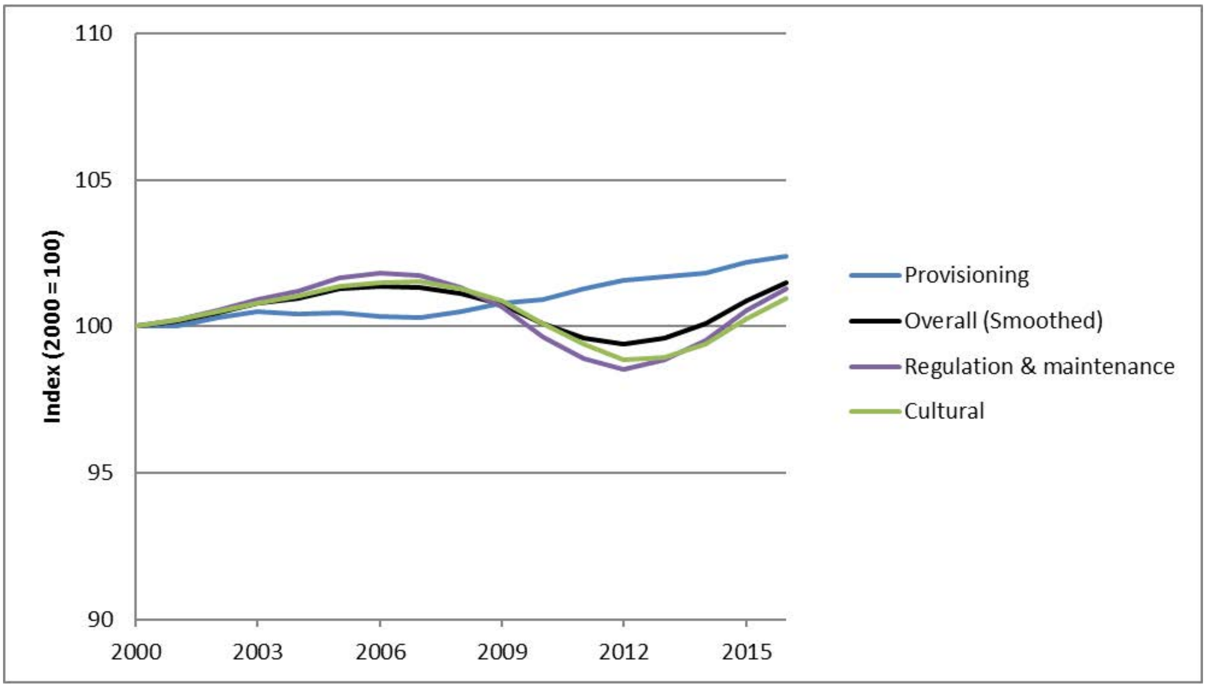
2.5 Application and disaggregation

The final tNCAI values can be used to identify changes between 2000 and 2016 in:

- The overall tNCAI (summed delivery by each habitat across all ecosystem services, see Figure 3);
- Each of the three CICES ecosystem service sections (summed contribution by all habitats to provisioning, regulation & maintenance; cultural) or ecosystem service values within each class (Figure 6A) ; and
- The seven Broad Habitats (Figure 6B) or component habitats (summed delivery by habitat).

The Well-being base spreadsheet can be used to compare contributions between Broad Habitat per hectare in delivering each ES class or aggregated across service groups, such as provisioning.

A)



B)

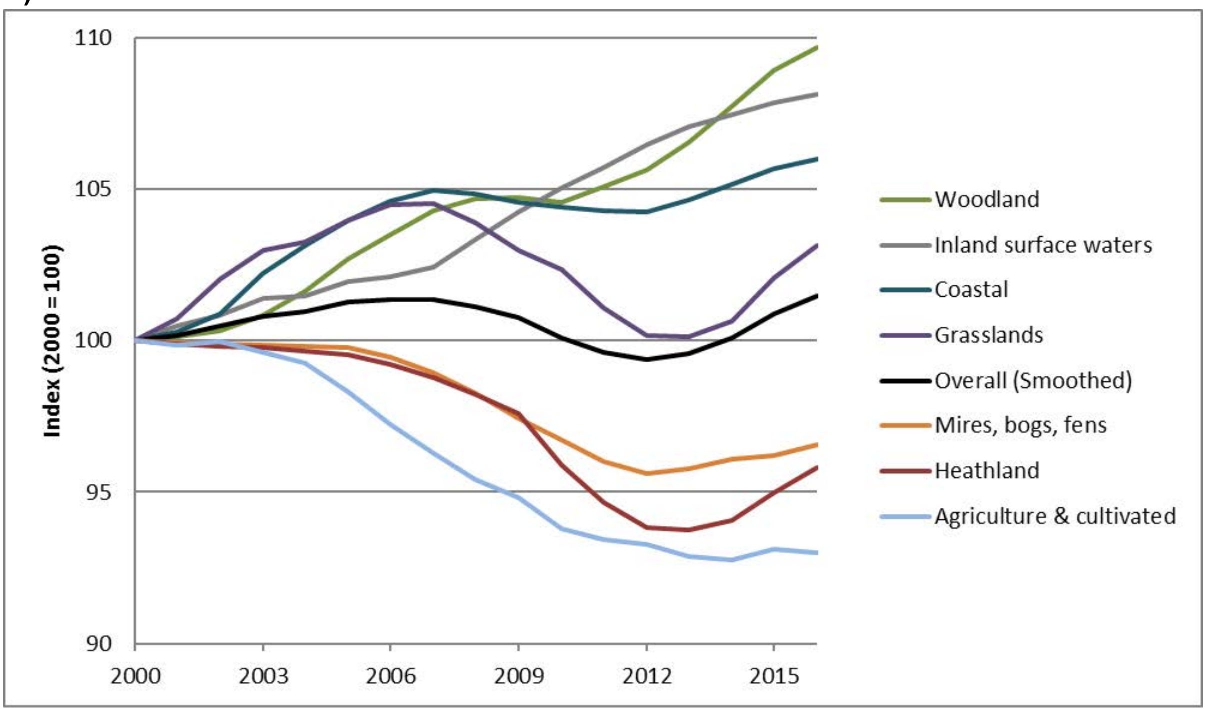


Figure 6. Examples of tNCAI disaggregation to show A) Temporal changes in ecosystem service group levels and B) Changes in the tNCAI by Broad Habitat type. These changes are driven by changes in habitat area and quality.

2.6 Systematic evaluation

SNH commissioned a systematic evaluation of the tNCAI to better understand its strengths and weaknesses. The evaluation focussed on the robustness of the indicators and the weighting system used to combine across ecosystem services, within and between ecosystems (Albon *et al*., 2014). The appraisal resulted in the reduction of indicators used in the tNCAI from approximately 100 to 38, based on fitness for purpose.

The following drawbacks were noted by Albon *et al*. (2014):

- Indicators tend to measure aspects of ecosystem service flows and few are capable of detecting changes in the potential capacity of natural capital assets to deliver ecosystem services.
- The influence of the indicator selection on Broad Habitat scores was assessed, the results were variable but in some Broad Habitats the tNCAI appears to be dependent upon the indicators used. However, further statistical analysis by SNH suggests that individual indicators exert a small influence of the overall index score (Tom McKenna, pers comm.)
- The use of expert judgment to assess the contribution of Broad Habitats to services and to weight the importance of services was considered. Changes in weightings were found to have little effect on the magnitude and trends in the index. However, Albon *et al*. (2014) cautioned that as the changes are measured in percentages, in absolute terms the differences may still be significant, and there is a risk that seemingly small variations could have important implications, particularly if the asset was close to an ecological threshold.

3. ADAPTING THE TNCAI TO A MNCAI: KEY ISSUES

The previous chapter outlined the methodology used to construct the tNCAI. To date, the application of natural capital approaches to marine environments is less developed than terrestrial approaches. As an initial assessment of feasibility, this chapter considers key limitations, differences and alignments between marine and terrestrial ecosystems, and what similarities and differences might be expected between the tNCAI and a mNCAI. Parts of the tNCAI methodology that could be transferred are considered and examples of other marine natural capital assessments provided. More detailed consideration of mNCAI development and recommendations are presented in Chapters 4, 5 and 6.

3.1 Overlap between marine and terrestrial systems: treatment of coastal habitats

Marine and terrestrial habitats share a coastal interface but the boundaries vary depending on the policy driver (e.g. Water Framework Directive 2000/60/EC (WFD), encompasses 3nm offshore in Scotland), planning boundary (relationship between Statutory Land Use Planning System and Marine Planning and Licensing) or mapping initiative (see below). From a functional perspective, the coast is key to the exchange of nutrients, pollutants, sediments through estuaries and their catchments and some species use both terrestrial and marine habitats e.g. seabirds and waterfowl may fly inland to forage. The coastal interface is key for planning and management too, as most developments, activities and uses that take place in the marine environment have an onshore component or implication. For these reasons, there is a strong rationale to ensure that there are no gaps in coverage of natural assets at the coastal interface. This may lead to an area of overlap in spatial coverage if it is not possible to integrate marine and coastal assets in to a single index. Double counting of coastal assets would only be an issue if the terrestrial and marine indices were to be combined.

Coastal habitats and how to classify them in particular has been identified as an issue in the development of accounts (eftec, 2015; ONS, 2016). Established systems exist for the classification of coastal habitats, principally the (EUNIS classification which distinguishes splash zone habitats such as dunes (supralittoral, and classified as coastal) from intertidal (littoral) and fully submerged (infralittoral and below) both of which fall under the marine category. EUNIS also provides classifications for saline water bodies. The UK NEA coastal margin classification (Jones *et al.,* 2011) is a hybrid of four supralittoral and one littoral habitat, as well as coastal lagoons, but its justification for why these were chosen as the "main" coastal habitats is not clear. Classifications such as EUNIS, which have a more robust and systematic basis for categorisation are more useful.

The development of pilot accounts has also raised issues of whether coastal habitats should be considered within marine accounts or together with terrestrial natural capital. The former was proposed by eftec (2015) and ONS (2016), while the latter was broadly the case in the development of the Scotland's tNCAI (although no littoral habitats were included).

The tNCAI follows the same boundary between terrestrial and marine as EUNIS with coastal comprising only the supralittoral (above the spring high tide line and affected by spray or splash but not submerged by seawater). These include:

- coastal dunes and sandy shores (incorporating machair);
- coastal shingle; and
- rock cliffs, ledges and shores.

However, as mentioned earlier, there is an argument for including littoral (intertidal) within coastal. This inclusion of intertidal with terrestrial was advocated by Blaney & Fairley, (2012) who recommended only excluding offshore marine habitats, and included tidal mudflats within the coastal classification. Alternatively, perhaps its unique position at the interface between terrestrial and marine, and with ecological and economic links to both, suggests that the coastal zone does require a separate assessment and accounting process. The coastal margin is small compared to the overall marine area, and changes in its extent will have only fractional effect on overall extent of the marine ecosystem (eftec, 2015). Yet, coastal habitats are under significant pressure, which is likely to increase under climate change at the same time that the services provided in terms of hazard protection become more important. Increased coastal flooding and storm surge events can damage habitats and erode mobile sediments. Sea level rise will alter intertidal extents and lead to inundation of terrestrial environments in low-lying areas. Littoral boundaries are unable to migrate landwards to keep pace with sea level rise where hard rock prevents erosion and coastal realignment. Almost a fifth of Scotland's intertidal zone is formed of resistant hard rock and changes in sea level may lead to the loss of significant areas (modelled predicted changes of up to 27% loss in test areas) of intertidal habitat (Jackson and McIlvenny, 2011). A separate coastal account, supported by surveillance from earth observation satellites, would ensure that changes in the land-sea boundary were captured and not obscured within the more extensive stocks of a wider marine or terrestrial account.

Consideration is also needed on how to assess mobile species such as birds and seals, that use marine, coastal and in some instances terrestrial environments. These comprise a shared asset between accounts and may also act as associated population and condition indicators for an asset index. It may be that each species group needs to be considered and a judgement made, according to their use of marine and terrestrial habitats, as to which NCAI they should fall within. For example, seals depend on the marine ecosystem for food and are a top predator so could reflect the condition of the marine ecosystem, but seal haul outs and nursery areas may contribute to cultural services in the terrestrial / coastal environment (wildlife watching). Ultimately, it may be appropriate to include some species, such as seals in both indices and as both an indicator and a stock.

3.2 Evaluation of key data input transferability to a mNCAI

In considering whether the tNCAI methodology could be applied to develop a mNCAI we first considered whether the three key data inputs to the tNCAI are applicable to the marine environment.

These were:

- Identification of Ecosystem Services
- Habitat classification and mapped geographical coverage
- Indicator availability

3.3 Identification of Ecosystem Services

The CICES framework (v4.3, Haines-Young & Potschin, 2013) was used for the tNCAI and is applicable to the delivery of ecosystem services by coastal and marine assessments. CICES provides a hierarchical classification of final ecosystem services. The highest level of the hierarchy – "Section" – maps on to the three broad ecosystem service categories of Provisioning, Cultural, and Regulation and Maintenance, following international precedents in the Millennium Ecosystem Assessment (MEA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010). The 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.

Since the tNCAI was developed, CICES has been updated (with version 5.1 release in 2018), in a process that involved consideration of the wider literature and a consultation process including a survey to which over 200 users responded (Haines-Young & Potschin, 2018). The process of updating CICES also included more detailed consideration of its applicability to coastal and marine systems. This included consideration of how the previous version (4.3) had been used in the development of an operational framework for the EU policy context. The marine-relevant divisions within the CICES classification are given in Figure 7. A comparison table was created (Annex 1) to compare the terrestrial ecosystem services used in the tNCAI (CICES 4.3) and the updated ecosystem services from CICES version 5.1. For both versions of the CICES framework the ecosystem services are split into the three major groups, Provisioning, Regulation and Maintenance and Cultural.

The tNCAI aggregated 43 ecosystem services into 28 classes across the three groups, whereas the mNCAI could feasibly include over 70 services if the CICES 5.1 framework was rigorously followed. For the case study (Chapter 6) we removed services that weren't relevant to marine and further rationalised the remaining CICES classes into 12 ecosystem services. The rationale and recommendations are discussed in Section 6.1.1 and Annex 1 provides a simple commentary on the suggested changes.

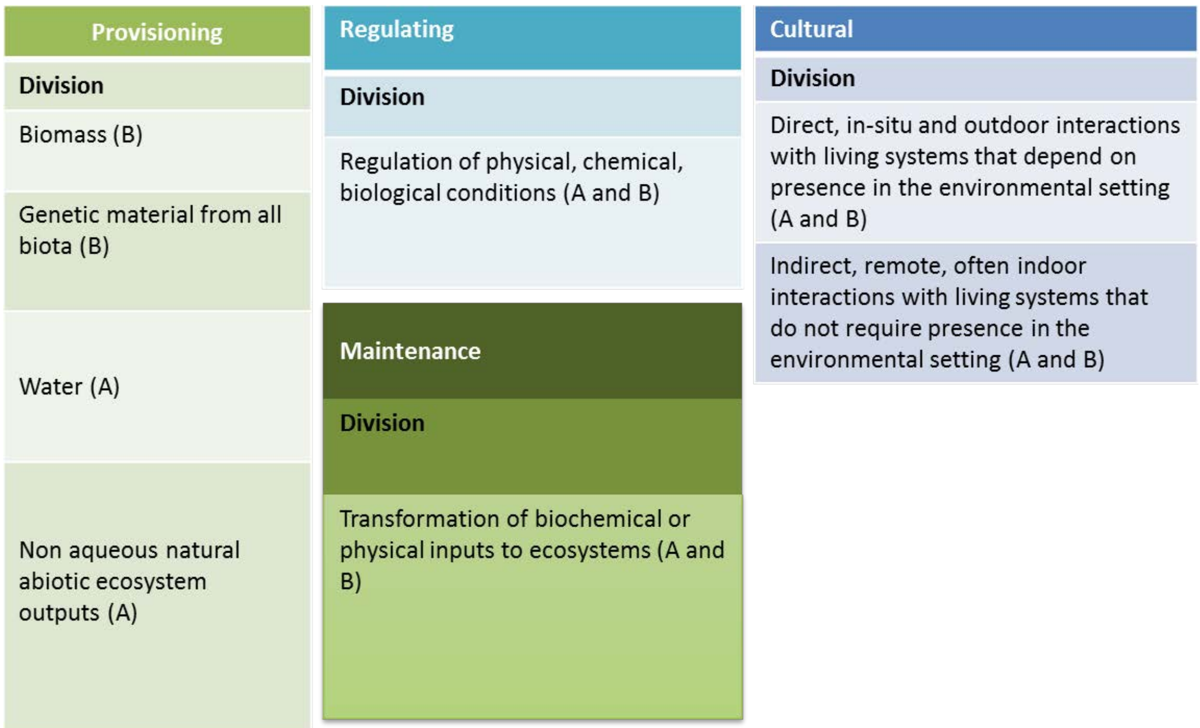


Figure 7. Groupings of ecosystem services and main divisions for Abiotic factors (A); Biotic factors (B); see Annex 1 for more full hierarchy.

3.4 National Importance Classification of ecosystem services

The national importance classification of ecosystem services could be applicable to both terrestrial and marine environments (see Section, 2.4.4). For example the value to Scotland of carbon sequestration or food production was considered to be the same whether this was delivered by terrestrial or marine ecosystems. This issue was further explored in the Case Study (Chapter 6), where it is argued that these values require updating for a marine index.

3.5 Habitat classification and extent

The published tNCAI is based on seven Broad Habitat types as defined by the EUNIS classification (Table 3).

Table 3. The tNCAI classification of ecosystems into Broad Habitats (after Albon et al., 2014)

Broad Habitat	**Ecosystems included in Broad Habitat**
Coast	Dunes, cliffs, beach (above MHWS only)
Cropland	Arable land and improved grazing
Grassland	Rough/semi-natural grasslands
Moorland	Heather moor, montane and peatland/bog
Woodland	Woods/forests, including commercial forestry
Freshwater	Lochs, rivers and fens
Greenspace	Urban parks, gardens etc.

A range of habitat classification schemes for coastal and marine habitats have been developed and are applicable to the UK. These are discussed in more detail in Chapter 4.

An obvious difference between terrestrial and marine ecosystems is the presence of the water column. The air-space and winds above terrestrial ecosystems are, in some ways, analogous to the water column and currents as they transport some materials, disperse propagules and small organisms and provide habitat space and migration pathways for invertebrates, birds and a few mammals (bats in the UK). Like air, the water column can change in character over short and long temporal scales in terms of temperature, or be characterised by spatial and temporal patterns of distinct strata. Pelagic organisms are embedded in a turbulent advective environment; their size, physiology and behaviour, determines how they are affected by the properties of the liquid and their scales of variability (e.g. effect of Reynolds number, advection or migration, etc., Kavanaugh *et al.,* 2016).

The water column may be fundamentally different due to depth, stratification and salinity in transitional waters. This in turn may influence its value as an asset and determine functional characteristics from which ecosystem services originate, such as its importance as habitat for pelagic stocks or charismatic megafauna species. These attributes may also be highly dynamic, seasonal or persistent, adding a temporal dimension which has less equivalence in terrestrial habitats. An additional consideration for the mNCAI was how should pelagic (water column) habitats be incorporated within a mNCAI. This is discussed further in Chapter 4.

3.5.1 Spatial coverage and confidence in habitat data

Compared to terrestrial habitats, marine habitats are less accessible to humans and we therefore have less understanding of their extent and distribution. In the terrestrial environment spatial boundaries between habitats can be readily mapped using aerial photography and satellite images. These methods may be useful for mapping coastal and intertidal habitats, some shallow marine habitats, and pelagic habitat parameters (SST, chlorophyll, turbidity). However, the use of aerial mapping is not possible for many subtidal habitats that are overlain by a deep and/or turbid water layer. Aerial photography can be used to map shallow water marine habitats ranging from 2 metres to 30 metres depending on turbidity conditions (NOAA coastal services centre, 2001). The extent and distribution of the habitat, the qualitative value biomass of the habitat (% of aquatic vegetation) and the fragmentation of the habitat, are characteristics of the benthic habitat which can sometimes be assessed well by aerial photography. However the species composition of the habitats is less well assessed with this method (U.S. NOAA coastal services centre, 2001).

Current marine habitat maps contain large areas where habitat extents and boundaries have been modelled or extrapolated from point data e.g. area between survey locations. Figure 8 presents the most comprehensive subtidal seabed map with Scottish coverage (UKSeaMap 2016[7]) with associated confidence levels shown in Figure 9. The level of habitat resolution between areas is variable but for most areas the habitat maps are assessed as medium confidence. The maps are being updated as new data is submitted but there is no formal updating process whereby annual changes in habitat extent could be systematically assessed for a mNCAI.

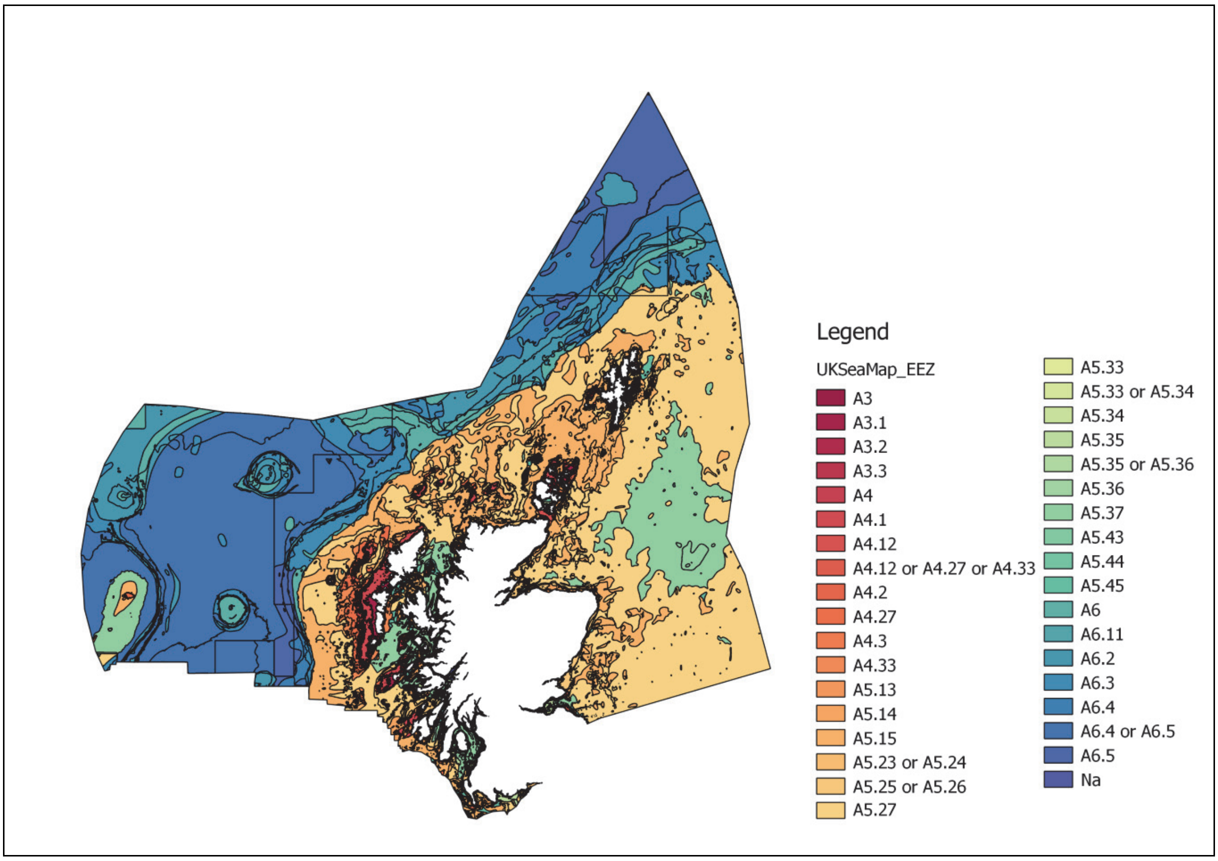


Figure 8. EUNIS classification of Scottish waters (UKSeaMap, 2016)

[7] http://jncc.defra.gov.uk/ukseamap

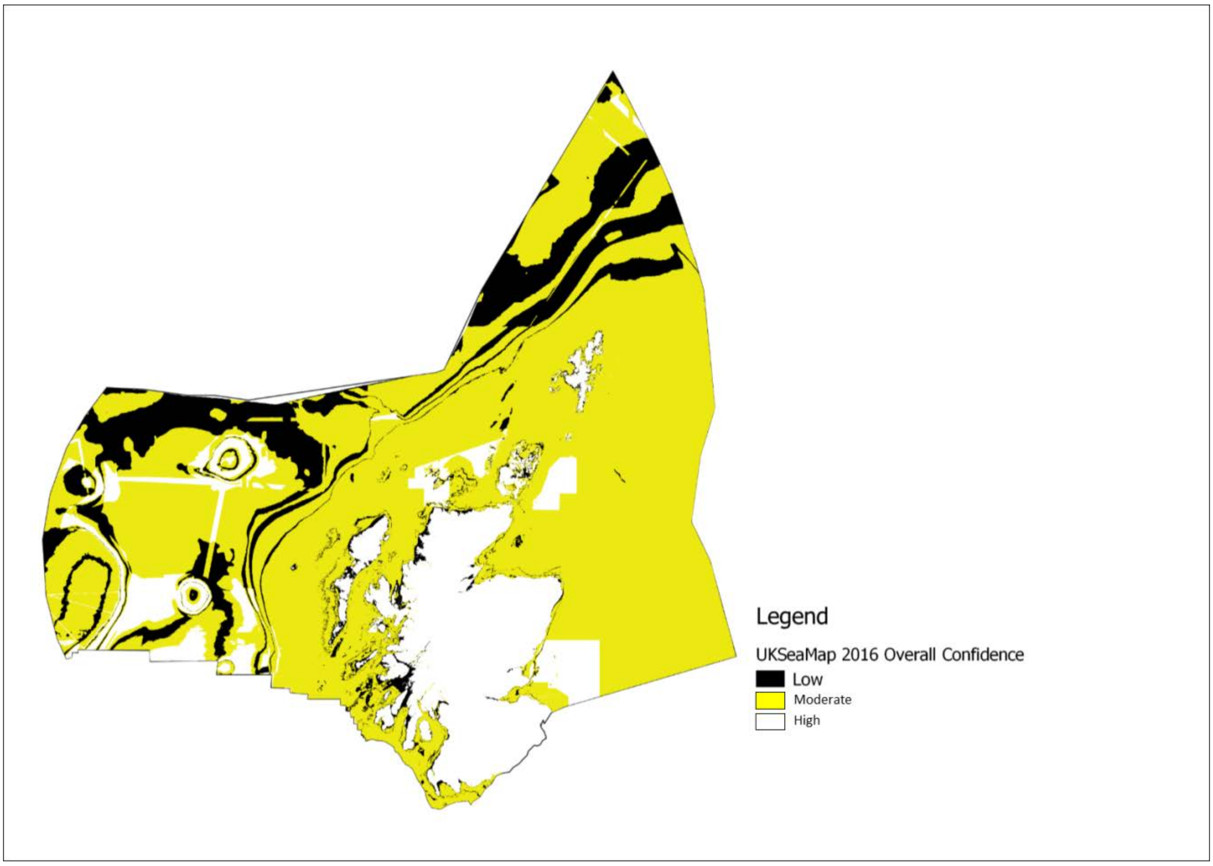


Figure 9. Confidence classification of Scottish waters (UKSeaMap 2016)

3.6 Indicator availability

The tNCAI uses a suite of 38 condition indicators to track change in habitat quality. These include direct indicators of habitat condition as well as indirect measures of ecosystem state using information on pressures (e.g. pesticide use) or flows (e.g. cereal yields). Four indicators from the tNCAI could potentially be applied within the mNCAI, as these are likely to be applicable to intertidal/nearshore habitat condition assessments. They are:

- Coastal site condition (basis of indicator is EU Habitats Directive Article 17 reporting);
- Wintering waterbird index (species such as curlew feed in the intertidal);
- Water Framework Directive (good or better status chosen as basis of indicator for tNCAI); and
- Coastal bathing water quality.

The first two of these indicators relate to the condition of the benthic habitat (wintering waterbirds are used as an indirect measure of the condition of habitats on which they rely). The latter two combine a number of individual indicators into a composite indicator; the WFD status reflects a combination of indicators for both benthic and water column condition, whereas the latter relates solely to water quality.

To assess intertidal and fully marine habitats a full set of indicators needs to be developed and appraised, Chapter 5 describes the indicator review undertaken for this project.

3.7 Inclusion of species assets

The tNCAI does not assess species assets separately from habitats, although it acknowledges the potential for ecosystem services flows from particular species. For example, hunted deer contribute to the provisioning ecosystem service class ‘Wild animals, plants and algae (and their outputs)’. Similarly, the opportunity to birdwatch, or fish recreationally are incorporated within cultural ecosystem service delivery. We have assumed that the assets represented by mobile species such as mammals, fish and birds for the tNCAI have been considered as part of the habitat in which they are found, presumably at the point at which the final service is delivered. This approach is acceptable for species that have a limited spatial range (whether by nature or due to habitat fragmentation) and/or that are strongly connected to a particular habitat (as a food source, for example). The connectivity provided by, and the food sources within, the water column mean this is not the case for many mobile marine species that may span large areas.

Within the tNCAI ten indicators relate either directly to the abundance of species or are indirect measures e.g. numbers removed/caught.

- Woodland Bird Index
- Wintering waterbird index
- Upland bird index
- Adult red grouse density
- Urban birds
- Farmland bird index
- Total number of different bird species counted
- Butterflies- generalists
- Salmon and grilse catches- rod and line fishing
- Domestic animals- (livestock units)

A number of candidate condition indicators for the mNCAI consider species abundance, distribution, breeding success etc. (see Chapter 5, indicator review) could be incorporated into asset or habitat condition assessments. The habitat assigned would depend on the classification typology chosen (see Chapter 5).

3.7.1 Inclusion of species with no or limited mobility within habitat stocks

Many benthic invertebrates are sessile or have low mobility and are closely linked to benthic habitats and frequently have very specific habitat-species associations. Marine benthic invertebrates (like terrestrial invertebrates) are important for ecosystem function and delivery of services. They are therefore considered as an integral part of habitat assets and their contribution to ecosystem service delivery is captured through service classes such as ‘Mediation of wastes or toxic substances of anthropogenic origin by living processes’. Benthic invertebrates can be useful indicators for habitat and, in most instances, will be the component of the habitat that is most sensitive to pressures. The sensitivity of benthic invertebrates could be used as a proxy to assess changes in ecosystem condition and therefore ecosystem service delivery, in response to pressure indicators. As most habitats at EUNIS level 4 and below are characterised by sediment-animal associations, benthic invertebrates are largely considered to be integrated with habitat assets and assessed by changes in condition through some direct condition indicators or pressure (proxy) indicators.

3.7.2 Inclusion of highly mobile species

Populations of mobile animals may represent assets which have significant value, e.g. the value of birds and mammals to wildlife watching and fish for commercial and recreational fisheries. All animals source food, shelter, nursery areas and other essential components of their life history from ecosystems and component habitats. Species-habitat associations can be identified, allowing ecosystem service delivery by species to be linked spatially to habitats (Culhane *et al.,* 2018). Mobile species may be associated with more than one habitat, seals for example use intertidal habitats as resting and nursery areas and feed in pelagic habitats.

In general, improvements in ecosystem condition, through management of pressures, are likely to benefit benthic species that underpin regulation and maintenance services and populations of the large organisms that are valued for cultural benefits (particularly wildlife watching) and provisioning (fish).

3.8 Common limitations between terrestrial and marine NCAIs

3.8.1 Habitat simplification

In both the tNCAI and mNCAI there is a risk of over simplifying habitat complexity. Mace *et al.* (2015) make this point that to date, marine areas are over simplified despite their importance for many benefits. In the case of the UK NEA, because the habitats by definition add up to the total land and sea area of the UK, they were essentially fixed in the assessment, and any transfer of land uses between them would be represented as a trade-off, meaning that the potential for management of habitats for multiple different benefits will be underestimated. Habitat classifications may also overemphasise the differences between habitats (through any system of artificial categorisation), which exist in a continuum on multiple dimensions. For example in marine, benthic habitats are primarily structured by seabed type, exposure, and depth (infralittoral / circalittoral).

There is an optimal point between using finer resolution habitat categories and capturing better the natural capital assets and ecosystem service flows and the lack of robust datasets on extent and condition at finer scales. Thus, there is a need to take a pragmatic approach about what and how often there is the resource to measure extent and condition of natural capital assets. The resolution of habitat classifications may be driven by the availability of monitoring data. Hooper *et al*. (2018) argue that as a minimum there needs to be a differentiation between vegetated habitats and biogenic reefs from other sedimentary habitats and rock due to the differences in ecosystem service provision between these key, habitats and their broadscale parent habitats. Furthermore the authors suggest that a hierarchical 'nested approach' could be articulated, whereby the extent/quality/services is assessed at the highest EUNIS level possible and then condensed to lower categories when reporting across broader spatial scales e.g. national level. This issue is considered further in Chapter 4.

3.8.2 Assumptions: ecosystem service is dependent on condition

The tNCAI and this pilot project assume that an ecosystem's capacity to deliver a service is dependent upon the condition of one or more ecosystem components from which that service is derived, and assumes that the condition of a particular ecosystem component is a good indication of that capacity. This is an assumption because the specific relationships between marine habitats and their condition (structure and functioning) and the ecosystem services that they provide has yet, in most cases, to be empirically assessed. This is an emerging area of research. Relationships between marine features and ecosystem services can be complex; for example, the ecosystem service of wave attenuation and reduction in current velocity (hazard prevention) is a function of seagrass bed density (a condition attribute) (van Keulen & Borowitzka, 2002), the hydrodynamic conditions of the area (Koch & Gust 1999), as well as the depth of the water column compared to the height of the seagrass.

3.9 Examples of Marine Natural Capital Assessments

The natural capital approach continues to evolve, with further refinement of ecosystem service assessment as well as the development of methodologies for other elements such as natural capital accounts. Lessons for mNCAI can potentially be learned from both ecosystem service assessments and natural capital accounting, examples of which are given below. It should be noted that work to assess marine natural capital is largely restricted to conceptual development with some limited pilot accounts developed for some habitat types.

3.9.1 Ecosystem Service assessment: the MAES approach

At the EU level, a framework has been developed by the Mapping and Assessment of Ecosystem Services (MAES) initiative (Erhard *et al.,* 2016), to link together data and maps on habitat, condition, ecosystem services and the drivers and pressures which affected them. A series of pilots, including one for marine ecosystems, have been conducted at the European scale to test the framework, ensure the method can be consistently applied, and consider its relevance to particular policy questions. The programme also considered indicators for pressures and ecosystem condition, and sought to integrate those indicators used within existing monitoring programmes, such as the Habitats and Birds Directives, Birds, Water Framework Directive and MSFD (Erhard *et al.,* 2016; Maes *et al.,* 2018).

3.9.2 Asset registers

Recent work on operationalising the Natural Capital approach has discussed the development of natural capital asset registers and accounts. An asset register has been defined as “an inventory of the natural assets in an area and their condition”, with suggestions that assets could be defined according to their type, area and quality, and represented spatially where possible using maps and GIS layers (Natural Capital Committee, 2017). There is not yet a formal methodology for developing an asset register, although the Natural Capital Committee (2017) does provide some guidance. Also lacking are examples of marine asset registers, although work here is ongoing within the South West Partnership for Environment and Economic Prosperity (SWEEP) programme.[8]

A slightly different approach – a Natural Capital Asset Check (NCAC) – was proposed within the UK National Ecosystem Assessment Follow On (UK NEAFO, Dickie *et al.,* 2014). This included trialling the method for certain marine and coastal habitats to evaluate i) carbon sequestration and storage in seagrass beds; ii) saltmarsh as a nursery ground for commercial fisheries; and iii) the Tees Estuary. The pilots showed that their methodology could be applied, particularly where the natural capital asset was clearly defined and ideally had a fixed spatial boundary and good data availability. Coastal examples were therefore successful, but wider marine ecosystems rarely fit these parameters. Also, the outputs are qualitative, and indeed heavily narrative and thus of limited use in the development of a quantified index such as the NCAI.

3.9.3 Natural Capital accounting

The accounting process (Figure 10) also involves measurement of the extent and condition of natural capital, and so has considerable overlap with an asset register. However, accounts differ in that their defined purpose is to systematically and regularly document changes in natural capital. This may not be the case for an asset register, which may be developed for a single, one-off purpose. Natural capital accounts are also distinct from asset registers in that they also aim “to integrate the value of ecosystem services into accounting and reporting systems” (European Commission & European Environment Agency, 2016).

By these definitions, the tNCAI is more of a non-monetary natural capital account (as its purpose is to document change), although it does not map onto the standard accounting procedure as it is an integrated index of both stocks and flows.

[8] https://sweep.ac.uk/

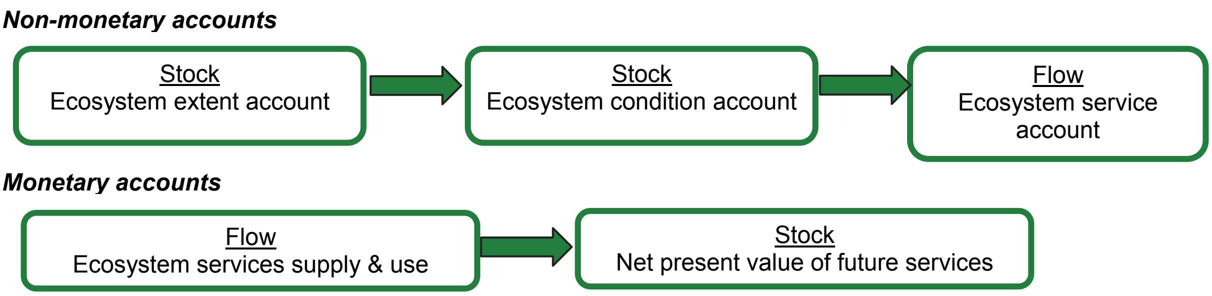


Figure 10. The main elements of natural capital accounts (ONS & Defra, 2017)

3.9.4 UK national accounts

Natural capital accounting is being adopted at the national level in the UK following commitment to it within the 2011 Natural Environment White Paper. The Office for National Statistics (ONS) has published the concepts and methodology (ONS & Defra, 2017), as well as experimental ecosystem service accounts for the period 1997 to 2015 (ONS, 2018), which include wild caught fish and recreation as marine examples. Aquaculture is excluded on the basis that it is a ''produced', as opposed to 'natural', asset. Accounts for coastal habitats including intertidal have been scheduled as a later part of the process, as the conceptual challenges and lack of systematic data were highlighted early on (ONS, 2012). Subsequently, scoping and pilot studies for marine (eftec, 2015) and coastal ONS (2016) accounts have been undertaken, which further discuss the challenges in producing such accounts. Boundaries were a significant issue in both studies, firstly in terms of which elements of coastal areas should be considered in 'marine' accounts. In addition, the issue of where to place the seaward limit of marine accounts was discussed. The limit of the UK's marine waters was proposed, as it reflects governance jurisdiction and property rights, although, from the ecological perspective this boundary needs to be reconciled with the large marine ecosystems of the Celtic and North Seas (eftec, 2015).

Only a limited set of ecosystem services have been considered in these scoping studies, namely carbon sequestration, recreation, fish, sea defence and air quality regulation. A range of habitats were considered for coastal habitats, with sand dunes, machair, saltmarsh, shingle, sea cliffs and coastal lagoons, included. The marine pilot study also considered saltmarsh as well as offshore sediments in two depth ranges, maerl beds and a general marine category.

A marine scoping exercise (eftec, 2015) postulated that a spatial basis for the accounting units (as developed for terrestrial natural capital accounts) may not be entirely appropriate in the marine environment, principally because the marine area is data-poor, more dynamic, and the variables in production functions vary over time and three-dimensional space. The study further explored the potential for an accounting unit based more on the water column, including calculating a value for the role of the North Sea carbon pump (an interaction between the North Sea and deeper North Atlantic waters) in carbon sequestration. Finally, a logic chain approach was proposed to support the development of accounts by explicitly defining all the relevant factors and their role in the delivery of goods and services, including how uses and management measures affect the condition of assets.

3.9.5 European level

Further marine natural capital account scoping work has been undertaken at the European level, primarily through the ongoing Knowledge Implementation Project on the Integrated system for Natural Capital and ecosystem services Accounting (KIP-INCA, European Commission & European Environment Agency, 2016). This programme has further highlighted the particular analytic challenge of accounting for species that move on a daily or seasonal basis (Anon, 2016).

A horizon scanning exercise has been carried out to consider, primarily, how ecological information collected under EU policy obligations can be used within extent and condition accounts (Weatherdon, 2018). The conclusion was reached that 'Good Environmental Status' indicators from the MSFD could be rapidly integrated into accounting frameworks, although the need was identified to i) refine methodological approaches to extent and condition monitoring; and ii) determine the condition thresholds necessary for the continued delivery of services. Using proxies for extent and condition, such as management measures and habitat vulnerability was proposed at least for the short term where data was lacking.

The KIP INCA project has also developed an experimental account for seagrass. The account aligns with existing habitat and ecosystem service classification systems resulting from the close links to the MAES initiative and CICES (Weatherdon *et al.,* 2017). The seagrass study focused on the extent and condition accounts, although also referred to the contribution of seagrass to carbon sequestration, food provisioning, water flow stabilisation, nurseries for commercial fish, and mass stabilisation and erosion control. It was acknowledged that data on ecosystem condition is not always available, and so potential proxies were considered. Metrics such as the area under protection were not considered adequate condition indicators, as the habitat within a protected area could be degraded, recovering or healthy. Measures of the types and levels of pressure on the habitat were suggested as a more suitable proxy for condition.

Independently, marine natural capital accounts have been scoped for the Dutch North Sea area although not trialled (Graveland *et al.,* 2017). As in UK examples, this exercise proposed that the marine area was demarcated in line with the Dutch national economic territory and discussed whether coastal habitats should be included. The typologies proposed by MAES and CICES for, respectively, marine habitats and ecosystem services were further endorsed, and the MSFD monitoring requirements suggested as a starting point for the development of extent and condition indicators. In considering the practicalities of habitat assessment, the authors further suggest that if data is available, distinct habitats (in terms of sensitivity and/or ecosystem services, should be differentiated within broad habitat classes, using a hierarchical structure that can be aggregated for reporting at the national level.

3.10 Conclusions

- There do not appear to be fundamental reasons why a mNCAI could not be developed by adopting the methodology of the tNCAI, with broad similarities in approaches to stocks, ecosystem services and indicators.
- As an alternative to including coastal habitats within the terrestrial or marine accounts an alternative would be to develop a separate coastal index that incorporates intertidal habitats and the coastal habitats from the mNCAI. Ecologically this approach takes into account that coastal and intertidal habitats are closely interlinked and that the same activities and pressures may impact both. Both coastal and intertidal habitats are likely to be impacted by climate change pressures including; range shifts in species, increased exposure to storms and wave action, changes in extent resulting from sea-level rise and altered sediment supply and erosion. A separate index would potentially be more sensitive to changes in habitat extent which could go undetected within the greater habitat areas of the tNCAI or a mNCAI.
- There are some key challenges in developing a mNCAI, particularly around i) understanding the extent and distribution of marine habitats; ii) how to define and capture temporally variable pelagic habitats and iii) the treatment of highly mobile species as an asset in their own right, unconnected to the underlying seabed habitat

and as indicators of condition. These issues are considered further in Chapters 4, 5 and 6.

- For many natural capital assets, particularly those offshore, direct data on asset condition are not available. Pressures arising from human activities may impact on benthic habitats and species which provide ecological functions that deliver ecosystem services. Pressure information may be used as a proxy indicator for seabed condition especially where evidence on types and levels of pressure can be combined with knowledge of the sensitivity of habitats used to assess condition.
- Since the tNCAI was initially designed, there has been considerable progress in better operationalising the natural capital approach. Lessons from this could perhaps be learned for the NCAI in general (both marine and terrestrial) particularly around disaggregating information on stocks (which are usually understood within the natural capital approach to be the assets) and flows (ecosystem services). This would also allow the NCAI to better support natural capital accounts, should these be developed in the future.

4. CATEGORISATION OF KEY HABITAT ASSETS AND CONTRIBUTION TO ECOSYSTEM SERVICES

A fundamental decision for ecosystem service assessments is the number and level of ecosystem components (broad habitats, habitats, species etc.) incorporated in the assessment. Considerations when selecting a classification typology include, inter-habitat/ecosystem component variation in ecosystem service delivery and sensitivity, mapping considerations and reporting obligations. Considerations around indicator applicability and availability are also relevant.

The tNCAI reporting considers seven EUNIS broad habitats, although the index is constructed for nine habitat types, with montane and constructed, industrial and artificial habitats not considered as these are not part of natural capital assets. This chapter examines further the options for categorising habitats and species assets and specifically considers how marine and coastal habitats could be grouped for the purposes of a mNCAI, how pelagic habitats can be categorised and how species assets could be incorporated, either within habitats or as separate indices. Marine ecosystem service frameworks have focussed on benthic habitats and we were able to assess proposed habitat typologies in relation to ecosystem service potential delivery and sensitivity.

This chapter also considers ecosystem service delivery by ecosystem components. The tNCAI is underpinned by the Ecosystem Service potential per Service Providing Unit (SPU) matrix which identifies the potential level of delivery of ecosystem services by each habitat type considered. Options for constructing a similar matrix for marine and coastal habitats based on recent frameworks are explored. A full review of the ecosystem service literature was outside the scope of the project, as was the development of an ecosystem service matrix, however limited ecosystem service matrices were constructed as part of the case study development and are provided as a separate deliverable.

4.1 Habitat classification typologies to support mNCAI development

The foundations for current frameworks for natural capital condition assessment are the underlying ecological components on which the assessment is taking place. To date, the assessment (and hence classification) of these components for marine natural capital assessments follows a habitats-based approach, as developed for terrestrial systems, where habitats are the fundamental 'units' around which asset and risk registers and accounts are developed.

The EUNIS habitat classification is a pan-European, comprehensive and widely accepted classification of all habitat types. The classification is hierarchical, the highest (broadest) level is level 1. The tNCAI reporting is based on seven, level 1 Broad Habitats classified according to EUNIS. The index for each of these level 1 broad habitats is based on the area extent and ecosystem services assigned at EUNIS level 2. A marine habitat classification, based on seabed habitats, would include only one EUNIS broad habitat (A- Marine) with seven Level 2 subdivisions, compared to the 31 level 2 categories within the tNCAI. However, the original focus of EUNIS was terrestrial, and the marine habitat classification was originally oversimplified, so that marine habitats at level 2 are broadly equivalent to terrestrial and freshwater habitats at level 1 (Davies *et al.,* 2004). The mNCAI, if aligned to the tNCAI in use of the EUNIS classification, should therefore consider a subdivision at level 3 (approximately 35 broadscale habitats) to represent a broad habitat that is equivalent to the tNCAI detail.

Marine habitats, as classified by EUNIS, are those that occur below spring high tide limit (or below mean water level in non-tidal waters) and include enclosed coastal saline or brackish waters, without a permanent surface connection to the sea but either with intermittent surface or sub-surface connections (as in lagoons). Marine habitats include those that are fully saline, brackish or almost fresh. Waterlogged littoral saltmarshes and associated saline or brackish pools above the mean water level in non-tidal waters or above the spring high tide limit in tidal waters are included with marine habitats. The classification includes constructed marine saline habitats below water level as defined above (such as in marinas, harbours, etc) which support a semi-natural community of both plants and animals. While these artificial habitats do not represent natural capital stocks, they could be included within the index. There are a number of pros and cons around inclusion of artificial habitats due to different levels of impact and service delivery. For example, work on polluting wrecks would suggest these reduce habitat condition, whereas historic wrecks, where fishing vessels may be restricted, could allow recovery of biodiversity and could cultural services for recreation and education and scientific study. Similarly artificial infrastructures could increase habitat heterogeneity and biodiversity while also providing stepping stones for the spread of non-native species. Ultimately, all marine benthic habitats have high sensitivity to physical loss and physical change pressures that result from placement of artificial structures. Consideration should be given to the message that inclusion of artificial habitats, as a natural capital stock providing services presents, in a framework of national conservation management.

4.2 Water column (Pelagic) habitat classification

Habitat classification typologies for the pelagic (water column) ecosystem are less developed and detailed than benthic habitat classifications. Defining pelagic habitats is complex as these do not have distinct boundaries. In most pelagic systems the prevailing conditions result from bathymetry, location, relative depth and gradients in temperature, salinity, oxygen, circulation, carbon dioxide, light and turbidity (Dickey-Collas *et al.*, 2017).

Some aspects of pelagic habitats are relatively permanent, such as bathymetric and coastal characteristics and hydrographic features such as density and current flows, frontal formation and seasonal stratification. Other characteristics are ephemeral, such as changes in temperature, precipitation, and winds as well as tidal forcing (Hyrenbach *et al*., 2000). Pelagic habitat types, therefore, exhibit a range of stabilities, from ephemeral (e.g. surface frontal systems) to hyper-stable (e.g. deep sea) (Dickey-Collas *et al.*, 2017).

Progress has been made on developing pelagic classification typologies (Table 4) with nine pelagic broad scale (Level 3) habitat classifications developed by EUNIS. However, the EUNIS level 4 component habitats currently lack detailed descriptions and it was not possible within the table to assign EUNIS level 3 pelagic habitats to the MSFD and MAES typology. The EUNIS classification text notes that because of the strong temporal variation in pelagic habitats, the classification of a water column in an area may change throughout the year. There is no mapping of these habitat extents by EMODNET to support index development. It is considered that the EUNIS habitat classification alone for pelagic habitats provides little support to develop a categorisation of Scottish pelagic habitats. The MSFD Commission Staff Working Paper (2017) includes the category ‘water column habitats’ with divisions representing a simplified version of the EUNIS classification of pelagic water column (A7). The MSFD categorises pelagic habitats at four levels; variable salinity, coastal, shelf and oceanic/beyond shelf. These categories align with the MAES habitat typology (Table 4).

MSFD monitoring of Biodiversity Indicators of GES in the water column is based on plankton life-form monitoring (Scherer *et al.*, 2015). Ecohydrodynamic zones (EHDs) have been constructed based on key water column features, which are important to plankton community structure and dynamics and are being used as the spatial basis of OSPAR reporting for plankton (D1 and D4) and oxygen (D5) indicators.[9] There are six predominant EHD types: permanently mixed throughout the year; permanently stratified throughout the year; regions of freshwater influence (ROFIs); seasonally stratified (for about half the year, including summer); intermittently stratified, and; indeterminate regions (inconsistently alternate between the above levels of stratification).

Mobile species linked to pelagic habitats through habitat and trophic links include fish and fish larvae of both pelagic and demersal species that are present in the zooplankton, seabirds and water birds that feed in the water column, cetaceans and seals. Phytoplankton supply and water quality will influence the productivity of commercial shellfish that are suspended in the water column via trestles, longlines etc.

Benthic–pelagic coupling mean that the condition of the water column and plankton also influence benthic habitat condition and the condition of populations of commercial shellfish, demersal fish and the benthos. However, due to the benthos strong links with habitat we suggest that benthic invertebrates including commercial shellfish and crustaceans such as scallops and lobster that are present in seabed habitats should be considered as components and indicators of benthic habitats.

Table 4. EUNIS, MSFD and MAES habitat classification typologies for pelagic ecosystems

EUNIS A7	MSFD	MAES
A7 Pelagic water column	Variable salinity	Marine inlet and transitional
	Coastal	Coastal
	Shelf	Shelf
	Oceanic/beyond shelf	Ocean

Ecosystem service frameworks for pelagic habitats are less developed. Many marine species are dependent on benthic and pelagic habitats such as demersal fish or marine and terrestrial habitats (e.g. seabirds and seals). The assessment of final ecosystem services therefore integrates the condition of both water column and seabed habitats and/or marine and terrestrial habitats.

4.3 Habitats and ecosystem service delivery

In order to link seabed habitats with their relative flow of ecosystem services, it is necessary to understand how different habitats deliver particular components of natural capital flows and thus which are distinct in natural capital terms and where emphasis should be placed. Fletcher *et al.* (2012) conducted a literature review to provide baseline understanding of the marine ecosystem services provided by the broad scale habitats and features of conservation importance that were likely to be protected by Marine Conservation Zones (MCZs). Each feature was reviewed to identify the beneficial ecosystem processes and ecosystem services using a systematic search method. This approach was extended and elaborated by Potts *et al.* (2014) to include features from other marine protected area (MPA) designations. They used a five-point scale to assess contribution and assigned three confidence levels (Table 5).

A similar approach for broader-scale habitats using a slightly different ecosystem services typology was included in the UK NEAFO (Turner *et al*., 2014). These studies produced structured assessment matrices for habitats and species, with scores on the importance of particular features supplying services, goods and benefits which were populated using peer reviewed and grey literature and expert opinion.

[9] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/habitats/plankton-biomass/

Table 5. Potts et al., (2014), ecosystem service delivery categories and confidence levels.

Ecosystem Service Delivery	**Confidence**
Significant contribution	3-UK Peer-reviewed literature
Moderate contribution	2- Grey or overseas literature
Low Contribution	1-Expert opinion
No or negligible potential	Not assessed
Not assessed	

This does not account for situations where an association has high confidence associated with it despite the lack of published information e.g. coastal protection afforded by abiotic structures such as reefs. A more pragmatic approach to resolve this issue could be the application of an approach such as the one used by MCCIP (Figure 11).

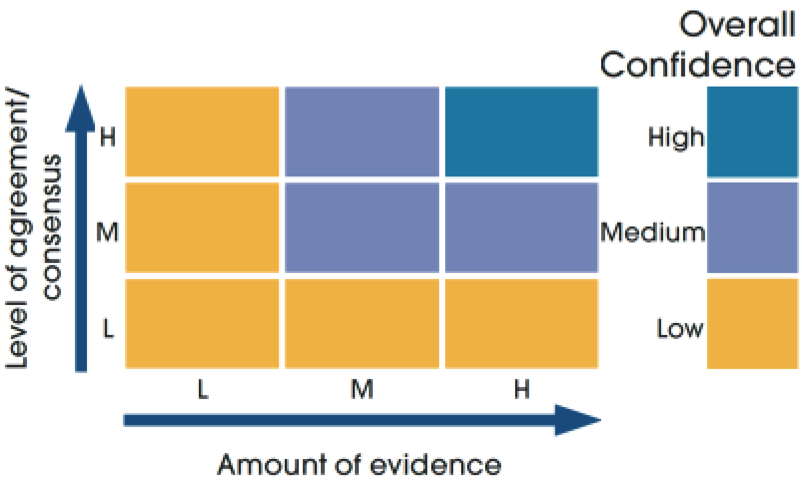


Figure 11. MCCIP approach to confidence assessments (MCCIP, 2013).[10]

4.3.1 Identification of key habitats that disproportionally provide ecosystem services

An assessment was conducted to identify how priority marine feature (PMF) seabed habitats should be treated in terms of their ecosystem services. This was to draw out which PMF habitats could be aggregated with their 'parent' broadscale habitat (EUNIS level 3 habitat) and which should be considered separately due to strong differences in their ecosystem service supply.

The step by step approach used for this analysis was as follows:

1) PMF habitats were nested into their 'parent' broadscale habitats using the JNCC habitat correlation matrix. Some PMFs fell within more than one broadscale habitat e.g. seagrass beds that could form part of A2.6 Intertidal sediments dominated by aquatic angiosperms or A5.5 Subtidal macrophyte-dominated sediment depending on whether the seagrass bed is intertidal or subtidal. In these cases the PMF was included in both broadscale habitats. Annex 3 shows the PMFs nested within their broadscale habitats.
2) Available ecosystem services matrices were used to identify the relative level of provision from both the broadscale habitats and PMFs. Two sources were used: Potts *et al.*, 2014 and matrices constructed by Chris Leakey (SNH) for PMFs. Since the ecosystem service typologies of the two matrices did not align and were different to the

[10] http://www.mccip.org.uk/impacts-report-cards/full-report-cards/2013/confidence-assessments/

categorisation for marine relevant ecosystem services from CICES 5.1 identified for this work, a cross-tabulation exercise was conducted (see Annex 2).

3) Where there were only values from one source for the relative ecosystem service supply for a seabed feature, these were used. Where both matrices contained values for a feature, if the value agreed, this was used, alternatively the values from the SNH matrices were used. In many cases this was given as a range, in which case the midpoint was used if it was a 3 point range, or if it was a 2 point range, if one of the values agreed with Potts *et al*. (2014) then this value was used.
4) The ecosystem service scores for PMFs were subtracted from their broadscale habitats and the direction of change was removed (+/-) to leave just the magnitude of the difference for ecosystem service provided by each seabed PMF. These were averaged across the ecosystem services that were populated to give a score indicating the relative differentiation of the PMF from its parent broadscale habitat (see Table 6 6 for example and Annex 4 for full table). This was colour coded to improve clarity.

The analysis of the differentiation in ecosystem service provision between PMF features and their respective parent broadscale habitats shows a clear pattern. The largest differences in ecosystem service provision are found in the habitats with key ecosystem engineering species that mediate the ecosystem service flow. Examples include algal dominated habitats e.g. Tide-swept algal communities and sea loch egg wrack beds but also biogenic reef communities such as blue mussel beds, horse mussel beds and native oyster beds. In all of these cases, PMF habitats scored higher indicating disproportionately high contributions of ecosystem services. Interestingly low or variable salinity habitats were also differentiated in terms of ecosystem service provision from their respective broadscale habitats mostly due to their relatively high scores for cultural ecosystem services.

Table 6. Example of differentiation of ecosystem service scores of PMFs (subtracted from their parent broadscale habitats). Greyscale indicates broadscale habitat ecosystem service scores by type (values indicate scores), while purple scale indicates the degree of differentiation between the PMF and its parent BSH (values indicate difference in scores). Full table is given in Annex 4.

	Provisioning					Regulating							Cultural				
Feature (Bold type represents Broadscale habitats, normal type represents habitat PMFs)	Farmed seaweeds	Farmed fish and shellfish	Wild harvest of seaweed	Wild capture fisheries	Genetic materials	Waste remediation	Erosion control	Coastal protection	Dispersal (gamete / larvae)	Nursery habitats	Pest and disease control	Carbon sequestration	Tourism, leisure and wildlife watching	Education	Spiritual / cultural	Existence / option use / bequest	Standard deviation
High energy intertidal rock			**0**	**2**		**0**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Tide-swept algal communities			1	1		2	-1	-1	-1	-1	1	0	0	-1	0		1.04
Moderate energy intertidal rock			**2**	**2**		**0**	**2**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Low energy intertidal rock			**3**	**2**		**0**	**1**	**2**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Sea loch egg wrack beds			0	1		3	1	0	-1	0	1	1	0	-1	0		1.08

4.4 Importance of Ecosystem Services

Although assessing the value of ecosystem services is outwith the scope of this pilot project, the authors have noted from a report currently in publication (Hooper *et al.*, 2018), that there are also several databases of published values for goods and services, although, again, these often have only limited entries relevant to UK marine and coastal assets (Table 7). The Environment Agency's Benefits Inventory provides additional useful information including a matrix showing the services provided by the different broadscale habitats listed in NEA, and has a further direct link to the decision-making process as it includes a template for an Appraisal Summary Table (as required in regulatory Impact Assessment).

Table 7. Databases that include published values for UK marine and coastal goods and services (from Hooper et al., 2018).

Database	**Link**	**Number of UK marine or coastal studies (individual values)**
DEFRA/Eftec Environmental Value Look-up Tool	http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19514	6
The Economics of Ecosystems and Biodiversity	http://www.teebweb.org/publication/tthe-economics-of-ecosystems-and-biodiversity-valuation-database-manual/	7 (41)
Marine Ecosystem Services Partnership	http://map.marineecosystemservices.org/	42 (44)
National Ocean Economics Program	http://www.oceaneconomics.org/	33
Environmental Valuation Reference Inventory	http://www.evri.ca/	48
ICES Marine and Coastal Cultural Ecosystem Services Knowledge Repository	http://www.ices.dk/community/groups/Pages/WGRMES-knowledge-repository-2.aspx	5
Environment Agency Benefits Inventory		9 (15)

4.5 Conclusions

- The feasibility of considering more detailed habitat based indices, rests on data and evidence availability on habitat extents and condition, while the desirability of the approach will depend on cost-benefit trade-offs around resources expended in constructing the matrix, relevance to delivery of ecosystem services and sensitivity reporting requirements and applicability to policy and management. There is a limit to the number of distinct habitats that can feasibly and cost-effectively be considered within natural capital assessments and reporting, although this will vary with the scale and purpose of the activity. It is recommended that the index is constructed using EUNIS Level 3 habitats as a basis.
- The mNCAI could potentially include pelagic habitats, with mobile species as a condition indicator (Chapter 5). Further exploration of the use of ecohydrodynamic zones is recommended to inform this approach. A key limitation of this approach is that, to our knowledge, links with trophic levels higher than plankton have not been evaluated and it may be that there are no linkages between ecohydrodynamic regions and fish, marine mammals and birds that form part of the pelagic asset as both stock and condition indicators. If included a pelagic habitat category may not be meaningfully subdivided based on ecohydrodynamic regions.

- Ecosystem services are one of the most studied components of the natural capital approach, but reviews have concluded that here again the evidence base supporting linkages between marine features and ecosystem services is highly inconsistent; with some features offering the potential for relatively strong conclusions whereas others offered little or no evidence (Fletcher *et al*., 2012). Substantially more evidence was related to:

    - Habitats than species (the evidence base for individual species for both processes and ecosystem services was very limited with no evidence at all for most species);
    - Beneficial ecosystem processes than ecosystem services;
    - Certain processes such as primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat and species diversification; and
    - Commercial fisheries (food provisioning) than other ecosystem services.

- An analysis was conducted to identify which EUNIS Level 3 component habitats, may have disproportionate importance in terms of ecosystem service supply and should be differentiated from the broad habitat, if possible. Examples where PMF habitats provide disproportionately high contributions of ecosystem services include algal dominated habitats e.g. tide-swept algal communities and sea loch egg wrack beds and also biogenic reef communities such as blue mussel beds. Low or variable salinity habitats were also differentiated in terms of ecosystem service provision from their respective broadscale habitats mostly due to their relatively high scores for cultural ecosystem services. The feasibility of separating component habitats within a mNCAI will depend on habitat data availability.

5. INDICATOR AVAILABILITY, APPRAISAL AND GAP ANALYSIS

The feasibility of constructing a mNCAI that incorporates an assessment of both extent and condition is highly dependent on the data available to support assessments of ecosystem condition. Indicators provide measures of natural capital assets (extent and condition), ecosystem processes and ecosystem service benefits, allowing for study of the linkages between ecological, social and economic systems and changes in relationships over time (Böhnke-Henrickes *et al*., 2013; Hattam *et al*., 2015). In terms of data that are linked to species (extent and condition) and habitats (condition) there are a range of indicators that are collected at a national level linked to reporting processes of key national and international policy drivers e.g. in relation to MSFD, WFD and National Marine Plans).

This chapter outlines the creation of the Indicator Directory, collation of relevant marine indicators, the indicator appraisal methodology and presents the results and gap analysis. Selection of indicators and the degree to which these represent ecosystem condition and ecosystem services are considered and limitations around indicator characterisation and availability are discussed.

The indicator review focussed on monitoring indicators for ecosystem condition. Although some potential indicators of extent were reviewed, none have been recommended for use in the mNCAI. No centralised, up-to-date catalogue of indicators is available for Scotland and the UK; and collating and appraising indicators was a time-consuming process. Although some indicators of chemical status and pressures were appraised, (notably WFD water body classifications that integrate a number of chemical parameters), this list is not exhaustive. Further limitations in the assessments and available indicators are described in this chapter. The Indicator Directory and indicator appraisal results are supplied as separate deliverables (Excel spreadsheets).

5.1 Outline indicator review methodology and results

An initial list of Scottish indicators was provided by SNH and supplemented by discussion with experts. Additional on-line, systematic searches for current indicators were undertaken. These focussed primarily on Scottish Government regulators, statutory agencies, non-governmental organisations and other key organisations. The main sources of indicators were:

- NMPi (National Marine Plan interactive),[11]
- Convention on Biological Diversity- UK Biodiversity Indicators List,[12]
- Scottish Biodiversity Strategy Indicators List,[13]
- OSPAR Oslo/Paris convention (for the Protection of the Marine Environment of the North-East Atlantic),[14]
- MSFD,[15]
- WFD (Water Framework Directive),[16]
- NPF (National Performance Framework).[17]

The indicator list was then cross-checked against indicator reviews by HBDSEG (Healthy and Biologically Diverse Seas Evidence Group), EU FP7 DEVOTES (Development of

[11] http://www.gov.scot/Topics/marine/seamanagement/nmpihome
[12] https://www.gov.uk/government/statistics/biodiversity-indicators-for-the-uk
[13] https://www.nature.scot/scotlands-biodiversity-strategy-indicators
[14] https://www.ospar.org/convention
[15] http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm
[16] http://ec.europa.eu/environment/water/water-framework/index_en.html
[17] http://www.gov.scot/About/Performance/purposestratobjs

innovative tools for understanding marine biodiversity and assessing good environmental status) project indicator directory, and the North Devon Marine Pioneer project (associated with SWEEP). In some cases headline indicators may be based on a number of component indicators but this was not always apparent. In the project timescale it was not possible to resolve component indicators within headline indicators.

5.2 Indicator directory, information and coding

The Indicator Directory was created as an Excel spreadsheet that aligns with the Indicator Directory supplied with the terrestrial NCAI. The spreadsheet records key information about the character of the indicator and additional information to allow the suitability of each indicator for application in a mNCAI to be appraised (see section 5.4). The final indicator directory spreadsheet contains 146 indicators. A further 29 datasets/datalayers held by the NMPi were also identified through the indicator review. The NMPi layers are presented in a separate Excel spreadsheet to the indicator directory but were included in the indicator appraisal spreadsheet (see below). Although initially included in the indicator directory, Protected Marine Features (PMFs) were removed as current levels of survey and monitoring do not support the use of these as extent or condition indicators (Chris Leakey, pers. comm.).

The list of indicators was checked against the list maintained by HBDSEG. Deciding on a 'definitive' up-to-date register of indicators is challenging as indicators constantly evolve and are all in different stages of development (Matt Frost, HBDSEG chair, pers comm). Management and policy indicators are, on the whole, subject to a process of continuous updating, refinement and evolution to respond to changing management and policy requirements. Due to the project time-scale, some assumptions have been made about the data used for indicators - these have been flagged in the appraisal directory for further checking.

Indicators were assigned to ecosystem components. Benthic habitats were subdivided into six categories: 1) biogenic; 2) coastal; 3) intertidal; 4) subtidal; 5) intertidal and subtidal and 6) coastal and intertidal and subtidal. Additional components: Marine Protected Areas (MPAs) and Anthropogenic, were added. Anthropogenic indicators include indicators of human attitudes towards the environment, and pressure indicators such as marine pollution and litter. A category 'multiple' was used to identify two indicators that encompassed a range of species. Further key information about each indicator was compiled in the Indicatory Directory. The information columns are detailed in Table 8 below.

Table 8. Indicator Directory information columns

Column Title	Description
Code	Identifier to allow cross-checking between the Indicator Directory and the Indicator Appraisal spreadsheets
Ecosystem Component	Basic ecosystem component covered by the indicator
Indicator title	Indicator title
List/Obligation	The obligation or list from which the indicator was sourced
Double badging	Identifies re-use of indicator for other reporting obligations
Type of indicator	Driver, Pressure, State, Impact or Response (in accordance to the DPSIR Anthropogenic, benthic habitats, coastal habitats, pelagic, birds, marine mammals, fish. model (Rogers and Greenaway, (2005))
Extent/Condition/Flow	Identifies whether indicator measures extent, condition or flow of ecosystem services,
Indicator status	Identifies whether indicator is in use, (current, under development or candidate/pilot)
Indicator description	Brief description of indicator

Areas of spatial coverage	Description of spatial coverage
Regional gap analysis	The indicator coverage of Scotland- any regional gaps were highlighted where identified.
Date first available	Start date (year) of the indicator survey or monitoring data.
Frequency of updates	The frequency of indicator surveys or monitoring or reporting
Most recent assessment	Year of most recent survey conducted.
Next reporting requirement	Proposed future reporting date.
Publications Link	Any links to relevant publications.
Reporting Lead for Scotland	Scotland lead.
Dataset Available on NMPi	Useful for sourcing indicator datasets using data portals.
Raw Data Source	Additional data sources if not available on NMPi

5.3 Indicator appraisal methodology

Once collated into the directory, the indicators were assessed for suitability for inclusion in a mNCAI. The indicator appraisal spreadsheet provides an audit and record of this process. Additional checking ensured, as far as possible in the timescale, that indicators that were used for more than one reporting obligation were not presented separately in the indicator appraisal spreadsheet. This checking and combination means there are more indicators in the indicator directory than the indicator appraisal spreadsheet. The unique identifier codes used in the directory and appraisal, allows identification of indicators that are used for multiple monitoring and reporting purposes.

Indicator coverage of marine ecosystem components is not even (Table 9). Ecosystem components with high numbers of indicators subject to indicator appraisal include: anthropogenic (26), commercial fish, shellfish and fish community (23) benthic habitats (20) and pelagic habitats (12).

Table 9. Ecosystem components and number of associated, appraised indicators.

Ecosystem Component	Number of Indicators
Benthic Habitats:	
Biogenic	3
*Coastal;	1
Intertidal;	2
Subtidal	4
Intertidal and subtidal	9
Coastal and intertidal and subtidal	1
Pelagic habitats	12
Seabirds	6
Seabirds and Water birds (waders and wildfowl)	3
Cetacean	5
Seals (grey and harbour)	6
Cetaceans and Seals (grey & harbour)	3
Commercial fish, shellfish and fish community (including Sharks and rays)	23
Non-native invasive species	1
Marine Protected Areas	10
Multiple species	2
Anthropogenic	26

* Includes saltmarsh- other habitats within this indicator are covered by the tNCAI

The first stage appraisal of indicator suitability used three Albon *et al*. (2014) appraisal criteria originally used for indicator appraisal for the tNCAI. The criteria used are; whether the indicator was current (in use), its spatial coverage, and frequency of updates.

A further appraisal criteria added to the Indicator Directory was whether the indicator is likely to be recommended for inclusion, regardless of status, coverage and update frequency. Recommended indicators were those that were considered to be useful indicators of the stock of the component (either extent or condition) and could be linked to the delivery of ecosystem services. Adding recommendations to all indicators allowed identification of potentially suitable pilot indicators and indicators with gaps in information that should be the focus of further investigation. Recommendations should be considered to be preliminary rather than a final decision on suitability and inclusion.

To aid the appraisal process, the criteria were categorised into classes (0-3), and colour coded in the spreadsheet, based on a traffic light system (green, amber (light/dark) and red) (See Table 10).

Table 10. Scoring and traffic light shading of the three categories of each indicator

Criteria	**Criteria Categories**			
	3 (green)	**2 (light amber)**	**1 (dark amber)**	**0 (white)**
Indicator Status	Current (in use)	Candidate/Pilot studies	Under development	Unknown
Spatial Coverage	Full Scotland coverage (including offshore)	Full coverage but uneven (e.g. differing survey or monitoring effort)	Not full Scottish Marine Area, some regions not covered	Unknown
Frequency of Updates	Annual/Biennial	3-5 years	Over 5 years	unknown

5.4 Results of appraisal

Finding up to date, authoritative sources on indicator status and application was time consuming. Compiling indicators and all information required in the project timescale was challenging and inevitably there are gaps in information. Further targeted checking was undertaken to reduce any uncertainty regarding indicator status, spatial coverage and reporting cycle for indicators proposed for the mNCAI, but study limitations meant that a number of indicator criteria were recorded as unknowns (Table 11). Frequency of updates and the spatial coverage were the key information gaps.

Table 11. Number of indicators for each ecosystem component for which key criteria were recorded as unknowns. Note this is not a sequential sift, the figures represent the full number of unknowns for each component.

Component	**Number of indicators for which criteria are 'unknown'**		
	Indicator Status	**Spatial Coverage**	**Frequency of Updates**
Benthic Habitats (all)	1	4	9
Pelagic habitats	0	5	3
Seabirds	0	2	2
Seabirds and Water birds (waders & wildfowl)	0	0	0
Cetaceans	0	0	1
Seals (grey and harbour)	0	0	3
Cetaceans and Seals (grey & harbour)	1	1	1
Commercial fish and shellfish & Fish Community (including Sharks and rays)	1	13	14
Non-native invasive species	0	0	0
Marine Protected Areas	0	4	6
Multiple species	0	2	1
Anthropogenic	0	17	15
Total	**3**	**48**	**55**

Following the initial sift of all 115 indicators, 73 were identified as current and in use across all ecosystem components. Thirty-six of these current indicators had full spatial coverage across the Scottish marine area including offshore. Five of these indicators were updated biennially or more frequently.

5.5 Recommended indicators

Relaxing the criteria on annual data collection/updating to incorporate all reporting cycles, was recommended, as it is not currently possible to develop a mNCAI with the restricted list of indicators that are frequently updated. Reporting and updating frequencies are unlikely to change given the high costs of data collection in the marine environment. The tNCAI includes indicators updated less regularly, e.g. condition reporting for EU Habitats Directive under Article 17, demonstrating this limitation can be overcome.

A sift that included all indicators that were in use and had full coverage identified 73 indicators of which 18 were recommended as potential mNCAI indicators. As there was some uncertainty around spatial coverage a final sift of recommended indicators was undertaken that included current indicators and those where spatial coverage was either full or full but uneven, as these may be useable and the indicator was recommended. The results and identity of the 19 recommended indicators are shown in Table 12. No current indicators met the appraisal criteria for biogenic habitats, intertidal habitats and anthropogenic factors.

Relevant legislation with legally binding descriptors of the quality of specific ecosystems (or of their specific habitat types) are the Birds and Habitats Directives, the WFD and the MSFD. Each of these directives determines when the conditions of habitats, species or ecosystems under their target are good: 'favourable conservation status' for habitats and species listed in the Habitats Directive, 'good ecological status' for surface waters under the WFD, and 'good environmental status' for marine water under the MSFD. Usually quality descriptors (each describing a specific aspect of the environmental and ecosystem quality considered by these directives) are combined into a composite indicator such as ecological status or conservation status which is characterized by different, qualitative condition levels (e.g. good, medium, poor). Taken together across the different ecosystem types, these indicators form a core set which, in combination with information about ecosystem extent and ecosystem services, could serve as an essential input for the mNCAI. It is recommended that further work on indicators to address gaps focusses on indicators associated with these directives. A key advantage is that a mNCAI developed using this approach can be used for European monitoring commitments and could be adopted by other European countries to unify reporting, as these are common indicators across states.

Table 12. Results of the final indicator appraisal using three criteria; indicator status (current), spatial coverage (full, full but uneven or unknown) and whether the indicator is recommended. Frequency of updates was not included in the sift criteria. Indicator title contains only the first title entered in the Indicator Directory cell to reduce overall table length.

Ecosystem Component	**Indicators meeting appraisal criteria:**	
	List/Body	**Indicator Title**
Benthic Habitats:		
*Coastal	SCCAP	Extent of key semi-natural habitats: coastal habitats (coastal sand dunes, **saltmarsh**, vegetated shingle. Maritime cliff and slopes, machair)
Subtidal	MSFD/OSPAR:	Extent of physical damage to predominant seafloor habitats (MSFD: D6C1, D6C2,

Ecosystem Component	Indicators meeting appraisal criteria:	
	List/Body	Indicator Title
		D1C6; OSPAR: BH3)
Intertidal and subtidal and coastal	EU Habitats Directive/ CBD/Aichi - UK Biodiversity Indicators/SBS - Scottish Biodiversity Indicators (S11)/SCCAP; National Performance Framework	EU Habitats Directive Article 17 reporting /Condition of notified habitats;
Pelagic habitats	OSPAR/MSFD WFD	Changes in plankton communities (MSFD: D1C4, D1C6, D4C3; OSPAR: PH1) Coastal and Estuarial (Transitional) Waters ((WFD)
Seabirds	OSPAR/MSFD/SBS - Scottish Biodiversity Indicators/SCCAP/CBD/Aichi - UK Biodiversity Indicators	Marine bird abundance (MSFD: D1C2, D4C3; OSPAR: B1)
Seabirds and Water birds (waders and wildfowl)	EU Birds Directive SBS - Scottish Biodiversity Indicators	Status and condition S04 Abundance of wintering waterbirds
	OSPAR/MSFD/Scottish Biodiversity Indicators/NMPi?/SCCAP/CBD/Aichi - UK Biodiversity Indicators	Marine bird breeding success / failure (MSFD: D1C3, D4C1; OSPAR: B3);
Cetaceans	OSPAR/MSFD EU Habitats Directive/	Abundance and distribution of cetaceans other than coastal bottlenose dolphins (MSFD: D1C1, D1C2, D4C3) EU Habitats Directive Species-cetaceans
Seals (grey and harbour)	OSPAR/MSFD OSPAR/MSFD EU Habitats Directive	Grey seal pup production (MSFD: D1C3, D4C1; OSPAR: M5) Changes in abundance and distribution of seals (MSFD: D1C1, D1C2, D4C3; OSPAR: M3) EU Habitats Directive Species-seals
Commercial fish and shellfish & Fish Community	Scottish Biodiversity Indicators/CBD/Aichi - UK Biodiversity Indicators/National Performance Framework/ SDG OSPAR/MSFD/CBD/Aichi/National performance framework OSPAR/MSFD OSPAR/MSFD EU Habitats Directive	B2 Sustainable fisheries (MSY & SSB); Large Fish Index (MSFD: D1C7; OSPAR: FC2) Recovery in the population abundance of sensitive fish species (MSFD: D1C2; OSPAR: FC1) Size composition in fish communities (MSFD: D4C2; OSPAR: FW3) EU Habitats Directive Species-fish

Eight pilot indicators that were considered potentially useful for a mNCAI were identified. These all relate to WFD/MSFD/OSPAR indicators, if they are developed they are likely to have application across Europe for reporting (Table 13).

Table 13. Pilot indicators identified as potentially suitable for a mNCAI if developed and implemented.

Component	List/Obligation	Indicator title
Benthic habitats:biogenic	MSFD	Change to predicted area of subtidal biogenic habitats caused by physical loss (MSFD: D1C5)
Cetaceans	OSPAR	Abundance and distribution of killer whales
Seabirds	OSPAR/MSFD	Breeding success of kittiwakes (MSFD: D1C3)
Seabirds	OSPAR/MSFD	Invasive mammal presence on island seabird colonies (MSFD: D1C3)
Benthic habitats:subtidal	MSFD/WFD	Spatial aggregation of WFD tools for MSFD: Infaunal Quality Index (MSFD: D1C6, D6C2)
Benthic habitats:intertidal	MSFD/WFD	Spatial aggregation of WFD tools for MSFD: Rocky shore macroalgal index (MSFD: D1C6, D6C2)
Benthic habitats:biogenic	MSFD/WFD	Spatial aggregation of WFD tools for MSFD: Seagrass (MSFD: D1C6, D6C2)
Benthic habitats:biogenic	MSFD/WFD	Spatial aggregation of WFD tools for MSFD: Saltmarsh (MSFD: D1C6, D6C2)

5.5.1 Gap analysis

Undertaking a gap analysis is problematic without examining the underlying data and assessing links between recommended indicators and other ecological components (e.g. the condition of fish stocks to reflect pelagic habitats or lower trophic species consumed as prey). What is clear from an examination of the recommended indicators is that there are significant gaps in coverage. Current indicators do not assess the condition or extent of biogenic habitats, intertidal or coastal habitats outside of protected areas. A single indicator assesses the condition of subtidal benthic habitats and, as this layer relates to abrasion from bottom-fishing gears, it is unlikely to be relevant to rocky habitats that are avoided by mobile fishing gear. Implementation of the pilot indicators around seagrass, saltmarsh and macroalgae would assess important biogenic habitats but sedimentary shores are likely to remain a key information gap unless proxy indicators, such as the presence of feeding birds, can be used to address assessment of condition.

The health of mobile species populations is not directly assessed but proxy indicators of abundance and distribution provide an indicator of the stock. However, fish indicators largely relate to commercial fish stocks and do not encompass rare species or the health of smaller, non-commercial fish species. The quality of indicator data for seals, cetaceans and seabirds is not clear and the extent to which these indicators are satisfactorily addressed is uncertain.

Climate change is a significant pressure likely to cause widespread effects in the future to coastal, intertidal and fully marine habitats. However, no associated direct indicators were identified for this pressure. Climate change may result in range shifts of species, and it is likely that changes in bird, seal and cetacean communities may be identified but not causally linked to climate change. Natural England are currently working with experts to develop climate change indicators for intertidal species (Nova Mieszkowsksa, MBA, pers. comm.) and it is possible that in future this pressure may be addressed.

A further pressure that could have widespread effects that are potentially permanent, is the introduction of non-native species. Non-natives can compete with native species and can directly or indirectly alter the character of habitats and biological assemblages. Examples of impacts include the domination of intertidal pools by the wire weed *Sargassum muticum*. Economic impacts may also result from fouling by non-natives such as the carpet squirt, *Didemnum vexillum* and the Japanese skeleton shrimp *Caprella muticum* (Baxter et al., 2011).

5.5.2 Using proxy indicators, pressures, flows and species

Given the strong causal relation between some pressures, condition and ecosystem services (European Environment Agency, 2015a); selected pressures can be used as alternative indicators to approximate condition in cases where indicators for ecosystem condition are not available. A number of pressure indicators including human activity datalayers, were included in the indicator appraisal but not recommended, as either the link to ecosystem condition and ecosystem services was weak or the pressure indicator related to the flow of ecosystem services. The exception was the MSFD/OSPAR indicator, 'extent of damage to predominant seafloor habitats' (BS1 in directory), as this is considered to be suitable as a pressure indicator due to the strong link to condition and ecosystem services. The case study (Chapter 6) tests the use of this proxy indicator of condition (abrasion) to assess condition and ecosystem service delivery. However, it should be noted that we did not use data that had been reported under the MSFD or OSPAR obligations and tested instead an annual data set.

Further work to identify suitable proxy pressure indicators could be rapidly progressed using existing pressure assessment frameworks and sensitivity assessments such as the Feature Activity Sensitivity Tool (FEAST)[18] and the Marine Evidence based Sensitivity Assessment (MarESA) approach (Tyler-Walters *et al*., 2018a and b). The use of sensitivity assessments to make a pressure based proxy indicator operational is demonstrated in Chapter 6 which presents a worked example of how this could be done, using abrasion. Only pressures that can be linked to asset condition and ecosystem service delivery are valid candidates for this approach. Pressures (from the OSPAR 2014 framework) that are linked to benthic species and ecosystem processes and service delivery, that are likely candidates, include the pressures; physical loss, physical change, removal of substratum, siltation rate changes, organic enrichment, subsurface penetration and/or disturbance of the substratum and removal of target and non-target species. For highly mobile species, the following pressures are likely to affect the stock and delivery of ecosystem services: removal of target and non-target species, underwater noise changes, visual disturbance and death or injury by collision and barriers to species movements.

No proxy flow indicators were recommended from the indicator appraisal. Flow indicators are those that use the flow of ecosystem services as a proxy for condition. Flow indicators are potentially problematic indicators for condition where they relate to provisioning services that rely on extraction of resources, for example, wild harvesting. An increase in flow may be underpinned by unsustainable exploitation of a resource that may become depleted. Maximisation of ecosystem service delivery for one service class may prevent other flows being realised. For example, the presence of a mooring area that enhances recreation (cultural service) may prevent fishing, reducing the flow of provisioning service. This complexity is not captured in the tNCAI but has been explored by Kandziora *et al*. (2013).

Mobile species such as marine mammals and seabirds can be considered as both a stock of natural capital (particularly for delivery of cultural services) and a potential proxy indicator of ecosystem condition. The extent and distribution of seabirds and mammals provide a metric that integrates the condition of a range of factors, including the stock of prey species, the availability of suitable habitats and the absence of key pressures, such as noise and, for seabirds the presence of invasive rats on islands (a recommended pilot indicator). The presence and abundance of seabirds and waterbirds may provide a proxy indicator for the condition of key habitats that are not currently associated with indicators such as the extent and condition of sediment shores where these feed. They could therefore be considered headline indicators. A disadvantage is of course, that declines and increases may not be attributable to single factors or manageable activities. Migratory species may face key

[18] https://www.marine.scotland.gov.uk/feast/Help.aspx

pressures in other parts of the range that do not reflect local conditions, however, their use as an indicator does capture local stock of cultural ecosystem services.

5.6 Key limitations

A key limitation for this project was the lack of central, up to date information on status, data collection and reporting for individual indicators. Finding 'definitive' up-to-date indicator information is challenging. Management and policy indicators are, on the whole, subject to a process of continuous updating, refinement and evolution to respond to changing management and policy requirements.

Collating an exhaustive list of pressure indicators and indicators of chemical status was outside the scope of this project.

Spatial coverage of indicators was difficult to determine, as the raw data for most datasets was not easily accessible and sourcing data was outside the project scope. Without access to datasets it was difficult to assess regional coverage unless this was specified in metadata.

5.7 Key recommendations

The indicator appraisal identified only a restricted set of indicators (19) that were considered suitable for a mNCAI with further possible supplementation by eight pilot indicators (if these were further developed/Implemented).

Within the project timescale we were able to add information to the supplied indicator list, to source more indicators and to conduct a preliminary appraisal of suitability with further checking to reduce uncertainties around status, coverage and update frequency. However, there are still information gaps and further work to address these is recommended to increase the number of indicators considered suitable for a mNCAI. We suggest that this could be done efficiently through batching queries and contacting those responsible. HBDSEG may be interested in co-operating with a working group to update the indicator registers and datasheets that they hold and to make these accessible. This would add further value to the mNCAI to support marine management in Scotland.

If development of a mNCAI was reliant on pressure indicators as a proxy for condition, datalayers could be constructed which indicate the levels of human activities in the marine environment. Existing pressure frameworks such as those developed by OSPAR (2014) and existing sensitivity assessments such as FEAST[19] and MarESA (Tyler-Walters *et al.*, 2018a;b) could be used to link these to the condition of ecosystem components. Such an approach would, potentially, be less robust that using condition indicators. However, this would offer a pragmatic solution and some pressures and likely impacts, such as abrasion from fishing, are well understood and can be linked to condition (see case study, chapter 6).

Although efforts were made to identify whether indicators could be assigned to regions to develop a national index that could also be disaggregated, the project timescale and the difficulties with checking indicator data meant that this has not been resolved and should form part of further work to develop a mNCAI.

The project did not assess how the indicators map on to ecosystem services and it is likely that there are gaps in ecosystem service provision assessments. A scoping exercise would support targeted efforts to address these gaps. Cultural services are an apparent gap and further efforts to assess relevant datalayers such as the NMPI bird and wildlife watching data as well as recreational activity data would support assessment is recommended.

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

5.8 Conclusions

- A core set of 19 indicators were identified that could serve as indicators for a mNCAI. Eight pilot indicators were also identified associated with European commitments, if they are developed they are likely to have application across Europe for reporting. A key advantage is that a mNCAI developed using these indicators can be used in conjunction with European monitoring commitments and could be adopted by other European countries to unify reporting, as these are common indicators across states.
- Key indicator gaps were identified around pressures (climate change and non-native species) for all ecological components. Other significant gaps include indicators for biogenic habitats and intertidal and coastal habitats (outside of protected areas subject to Habitats Directive reporting). The health of species populations are not reported but abundance may serve as a proxy. In general evidence is lacking for invertebrates and small fish species.
- Further work to develop a robust index should address key gaps (the unknowns) within the indicator appraisal and to assess further those indicators identified as potentially suitable. It is recommended that HBDSEG and other bodies are involved in this work as monitoring and indicator reporting is a key issue for marine management. We understand work is on-going by JNCC and others to rationalise indicator data collection and reporting.
- Relaxing the criteria on annual data collection/updating to incorporate all reporting cycles, was recommended, as it is not currently possible to develop a mNCAI relying on indicators that are updated annually or biennially. This is unlikely to change given the high costs of data collection in the marine environment. This does not, however, preclude development of a useful, robust mNCAI. Further work on selected indicators is recommended to identify whether the mNCAI can be updated annually using extrapolated data or whether it is more robust to limit index updates to a longer time-scale such as 6 years to align with WFD, MSFD and Habitats Directive reporting.
- Data that can be used as direct indicators of 'condition' of marine habitats is limited in the marine environment to site condition assessments undertaken by the statutory agencies. For many benthic habitats there may be data on extent, possibly a baseline survey for an MPA but annual data on condition are rare. Condition monitoring of many MPAs is on cycle of 6 years or more and is moving to a site-specific risk-based approach. An alternative to direct monitoring of condition of habitat assets is to use proxy measures linked to the key pressures. Given the strong causal relation between some pressures and ecosystem condition, pressures can be used as indicators to approximate condition in cases where indicators for ecosystem condition are not available. Pressure data may be updated more regularly. An obvious candidate for the marine ecosystem is demersal fisheries activity and seabed abrasion pressure given the annual reporting, widespread nature of this activity and the contribution of many other sectors to this pressure. The case study presented in chapter 6 explores the use of abrasion as a condition indicator (Chapter 6). Further work to develop other pressure data and associated indicators is recommended as likely to enable a more robust index.

6. MNCAI FEASIBILITY TESTING: ABRASION CASE STUDY

A key aspect of the feasibility of using marine data in the NCAI was tested using a seabed abrasion layer as a proxy for condition of seabed habitats, given that seabed condition is not widely monitored outside of MPAs. The abrasion layer has been constructed from the frequency and intensity of towed demersal fisheries activity. As the intention was to test a method, a subregion was selected to elaborate the approach; the Clyde Scottish Marine Region, in order to reduce processing time for the spatial analysis.

6.1 Approach and methodology

6.1.1 Ecosystem service rationalisation

Currently there are over 70 marine relevant ecosystem service classes in CICES V5.1 (see Annex 1 and Haines-Young & Potschin, 2018). It was considered that a sub-set of these would suffice to capture delivery of the key ecosystem services. A suggested rationale for service inclusion and exclusion is outlined below. Annex 1 provides a simple commentary on ecosystem services that should be included in a mNCAI and indicates where, in our opinion, service classes could be aggregated, included or reasons for exclusion.

Ecosystem service rationalisation:

Step 1. Exclude CICES marine relevant ecosystem services that are considered to be marine relevant but not utilised in Scotland e.g. abstraction of sea water for drinking water.
Step 2. Removal of services delivered by the abiotic habitat, e.g. noise attenuation (see below for further detail)
Step 3. Aggregate ecosystem services, where appropriate within a group, (see examples below)
Step 4. Merge ecosystem services between classes where appropriate (see below).
Step 5. Remove ecosystem services for which there is limited information

Services that were delivered entirely by the abiotic environment, without biotic components, were removed (step 2) on the basis that these were independent of condition or human pressures and would therefore be unchanged. This decision aligns with the tNCAI which largely excludes abiotic components (exceptions are the supply of freshwater). Services excluded on this basis were:

- All the abiotic provision services,
- Abiotic regulation and maintenance services, but see below for the group regulation of baseline flows and extreme events

The tNCAI aggregated some CICES 4.3 classes, e.g. heritage, scientific and educational interactions into one class, this is a pragmatic approach and one that we adopted for the case study (step 3). It is suggested that multiple CICES classes of ecosystem service could be aggregated at the CICES v5.1 group level. In some cases the ecosystem service group level was preferred because some services classes in the group were evidence poor or were not considered to be significant ecosystem service classes. Ecosystem services that we suggest could be usefully assessed at the group level for a mNCAI are:

- Cultivated aquatic plants for nutrition, materials or energy (aggregates 3 classes)
- Reared aquatic animals for nutrition, materials or energy (aggregates 3 classes)
- Wild plants (terrestrial and aquatic) for nutrition, materials or energy (aggregates 3 classes)
- Wild animals (terrestrial and aquatic) for nutrition, materials or energy' (aggregates 3 classes)

- Mediation of wastes or toxic substances of anthropogenic origin by living processes' (aggregates 2 classes)
- Gamete and seed dispersal (aggregates 2 classes)
- Pest and disease control (aggregates 2 classes)
- Physical and experiential interactions with natural environment (aggregates 2 classes)
- Intellectual and representative interactions with natural environment (aggregates 4 classes)
- Spiritual, symbolic and other interactions with natural environment (aggregates 3 classes)
- Other biotic characteristics that have a non-use value (aggregates 2 classes)

A single division level category was included, 'Genetic material from all biota (including seed, spore or gamete production)' (aggregates 5 ecosystem service classes)

The CICES framework separates service delivery by abiotic and biotic features. We consider that for a mNCAI, both biotic and abiotic components for some relevant services could be considered together and the service merged (step 4). For example, the ecosystem service group, 'regulation of baseline flows and extreme events', is delivered by abiotic and biotic components together. This group includes two classes that were considered relevant, control of erosion rates and hydrological cycle and water flow regulation (including flood control, and coastal protection). Similarly 'mediation of nuisances of anthropogenic origin' and 'regulation of the chemical condition of salt waters by living processes' were considered to be difficult to separate from the service 'mediation of wastes or toxic substances of anthropogenic origin by living processes'. It was also considered that in many instances biotic and abiotic components would deliver cultural services such as recreation opportunities, heritage and education opportunities and could not be sensibly separated. The cultural services therefore include biotic and abiotic components.

Ecosystem services that were considered to have little importance, or for which data and/or links to final ecosystem services were very poor, were also excluded (step 5). The services 'micro and regional climate regulation and ventilation and transpiration' and gaseous flows were excluded as they were considered difficult to link to final ecosystem services.

Existing studies linking marine features to ecosystem services were also considered as part of the rationalisation process in order to enable existing information to be used to develop a mNCAI. The table in Annex 2 identifies the links between the rationalised ecosystem service list and existing frameworks that have assessed ecosystem services.

For the case study we used a subset of 12 ecosystem services that could be linked to habitats using existing frameworks as outlined in Annex 2:

- Wild harvest of seaweed
- Wild capture fisheries
- Waste remediation
- Erosion control
- Coastal protection
- Dispersal (gametes / larvae)
- Nursery habitats
- Pest and disease control
- Carbon sequestration
- Tourism, leisure & wildlife watching
- Education
- Spiritual / cultural

6.1.2 *Construction of geospatial database, data collation and processing*

EUNIS habitat shapefiles from UKSeaMap[20] and EUSeaMap[21] were imported into QGIS 3.2.3 mapping software. UKSeaMap had higher resolution (100m) than EUSeaMap in Scottish waters, thus was used for the analysis, with recommendation from JNCC. The associated raster Overall Confidence layer was also imported; this confidence layer classifies confidence into High, Moderate and Low classes.

A shapefile displaying the Scottish Marine Regions (Figure 12) was downloaded from data.gov.uk, and as an offshore boundary, the UK Exclusive Economic Zone (EEZ), approximately 200nm offshore, was downloaded from the UKHO Inspire Portal,[22] as recommended by Marine Scotland.

Figure 12. Scottish Marine Regions.

The UKSeaMap (2016) seabed habitats layer was clipped to the Clyde Scottish Marine Region boundary as was the associated seabed habitats confidence layer (Figure 11 and Figure 12).

[20] http://jncc.defra.gov.uk/UKSeaMap/
[21] https://www.emodnet-seabedhabitats.eu/access-data/launch-map-viewer/
[22] https://www.gov.uk/guidance/inspire-portal-and-medin-bathymetry-data-archive-centre

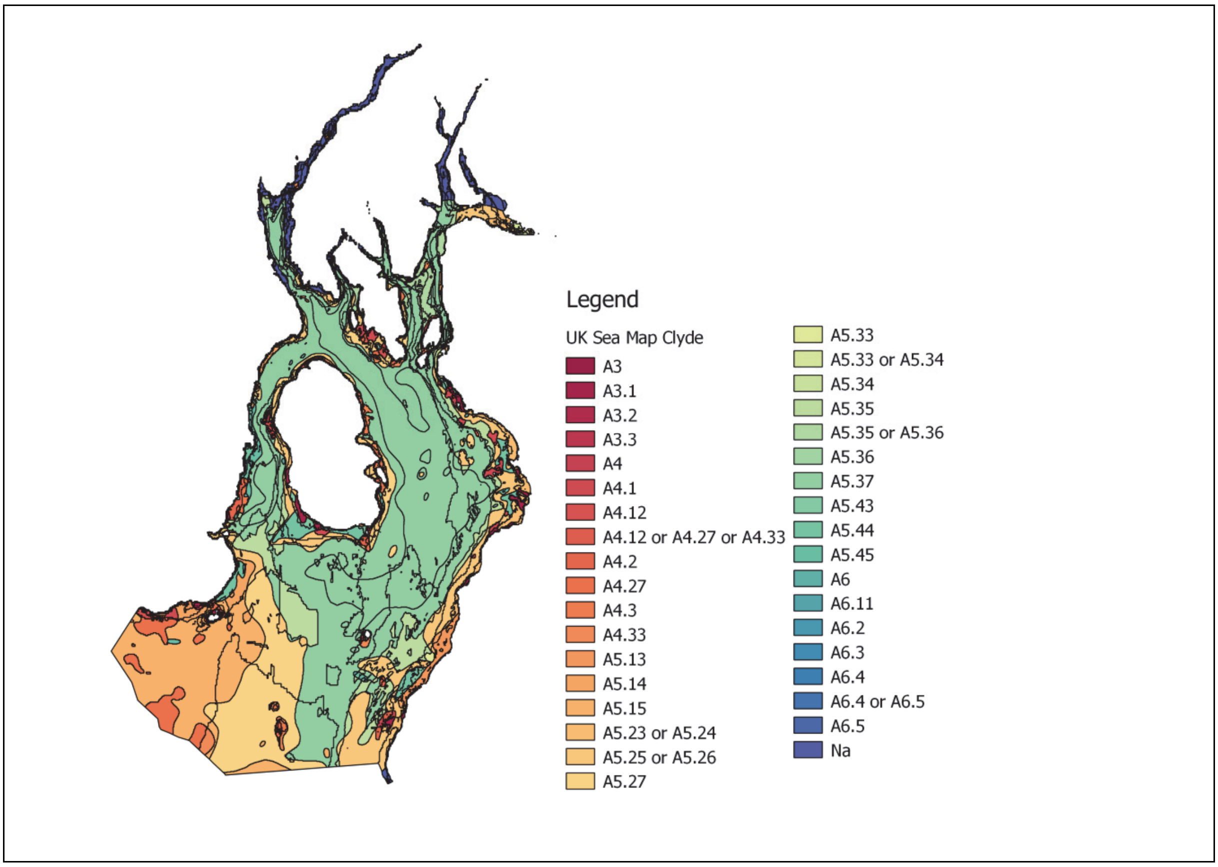


Figure 13. UKSeaMap (2016) seabed habitats layer clipped to the Clyde Scottish Marine Region.

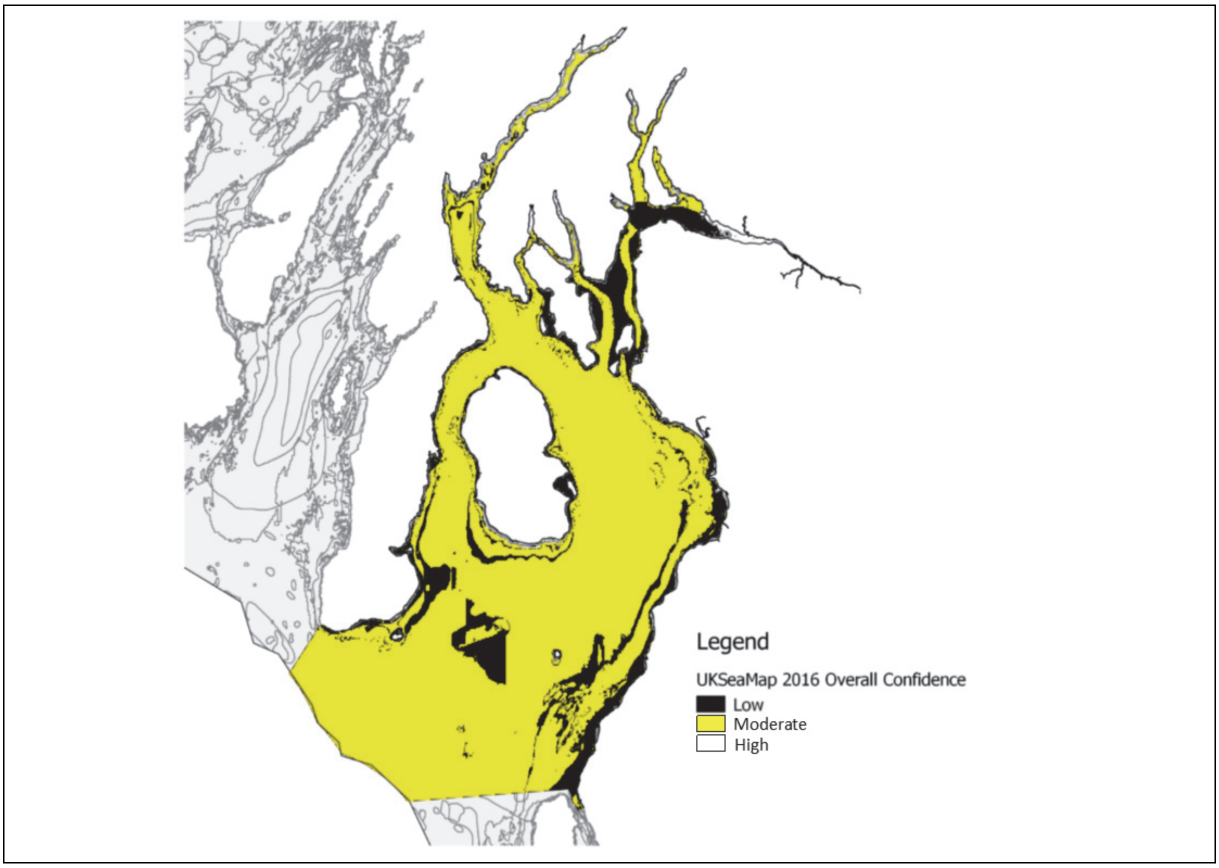


Figure 14. UKSeaMap (2016) Confidence for seabed habitats layer clipped to the Clyde Scottish Marine Region.

The full list of habitat types was reduced and aggregated at EUNIS level 3 (broadscale habitats) aside from a few EUNIS level 4 habitats that were kept separate. These include:

- A4.12 Sponge communities on deep circalittoral rock – which was kept separate due to its higher sensitivity to abrasion pressure;
- A5.36 Circalittoral fine mud – which was kept separate on the basis that it contains many PMFs of conservation interest;
- A5.43 Infralittoral mixed sediments – which was kept separate due to its higher sensitivity to abrasion pressure.

This reduced the list of habitats from 25 to a more tractable 13 (Table 14). Unfortunately since the habitat data was not resolved to higher EUNIS levels it was not possible to pull out the key habitats that disproportionately contribute ecosystem services (see section 6.2).

Table 14. Aggregation of seabed habitats

Code	Seabed habitat	Code	Aggregated habitats name
A3.1	Atlantic and Mediterranean high energy infralittoral rock	A3.1	Atlantic and Mediterranean high energy infralittoral rock
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock
A3.3	Atlantic and Mediterranean low energy infralittoral rock	A3.3	Atlantic and Mediterranean low energy infralittoral rock
A4.1	Atlantic and Mediterranean high energy circalittoral rock	A4.1	Atlantic and Mediterranean high energy circalittoral rock
A4.12	Sponge communities on deep circalittoral rock	A4.12	Sponge communities on deep circalittoral rock
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock
A4.27	Faunal communities on deep moderate energy circalittoral rock		
A4.3	Atlantic and Mediterranean low energy circalittoral rock	A4.3	Atlantic and Mediterranean low energy circalittoral rock
A4.33	Not in JNCC Correlation table		
A5.13	Infralittoral coarse sediment	A5.1	Sublittoral Coarse sediment
A5.14	Circalittoral coarse sediment		
A5.15	Deep circalittoral coarse sediment		
A5.23 / A5.24	Infralittoral fine sand/Infralittoral muddy sand	A5.2	Sublittoral Sand
A5.25 / A5.26	Circalittoral fine sand/Circalittoral muddy sand		
A5.27	Deep circalittoral sand		
A5.33	Infralittoral sandy mud	A5.3	Sublittoral mud
A5.33 / A5.34	Infralittoral sandy mud/Infralittoral fine mud		
A5.34	Infralittoral fine mud		
A5.35	Circalittoral sandy mud		
A5.35 / A5.36	Circalittoral sandy mud/Circalittoral fine mud		
A5.37	Deep circalittoral mud		
A5.36	Circalittoral fine mud	A5.36	Circalittoral fine mud
A5.43	Infralittoral mixed sediments	A5.43	Infralittoral mixed sediments
A5.44	Circalittoral mixed sediments	A5.4	Circalittoral/deep mixed sediments
A5.45	Deep circalittoral mixed sediments		

The areas of each seabed habitat type in the UKSeaMap (2016) habitats layer within the Clyde Scottish Marine Region of Clyde was calculated (full detail on the GIS processing method is given in Annex 6). The total area (Table 15) deviates somewhat from other area totals for the Clyde Region since there were some habitats that were not classified and have been excluded from the analysis.

Table 15. Area (km^2) for each of the aggregated seabed habitat types in the Clyde Scottish Marine Region.

Code	Aggregated seabed habitat type	Area (km^2)
A3.1	Atlantic and Mediterranean high energy infralittoral rock	36.78
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	7.19
A3.3	Atlantic and Mediterranean low energy infralittoral rock	9.45
A4.1	Atlantic and Mediterranean high energy circalittoral rock	41.27
A4.12	Sponge communities on deep circalittoral rock	9.27
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	111.58
A4.3	Atlantic and Mediterranean low energy circalittoral rock	60.79
A5.1	Sublittoral Coarse sediment	506.51
A5.2	Sublittoral Sand	863.49
A5.3	Sublittoral mud	324.32
A5.36	Circalittoral fine mud	7.24
A5.43	Sublittoral mud	1807.06
A5.4	Infralittoral mixed sediments	21.76
A3.1	Circalittoral/deep mixed sediments	100.86
A3.2	Circalittoral/deep mixed sediments	20.61
Total (habitat polygons – not including unclassified habitats)		**3928.18**

Vector shapefiles of fishing intensity within regions II and III of the OSPAR maritime area, derived from VMS and logbook data were obtained from ICES. This data product captures vessels >12m that carry VMS, smaller vessels are not included. The Total Surface Swept Area Ratio (SurfSAR) at a resolution of c-squares (0.05° × 0.05°) was used to show the fishing intensity across all gear types (demersal seine netting, otter trawls, beam trawl, dredge) with a <2 cm penetration depth of the gear components. Fishing intensity was calculated by dividing the swept area by the surface area of the grid cell (ICES Technical Service, 2018).

The abrasion grid was clipped to the Clyde Scottish Marine Region, and classified into intensity classes by the value of the swept area ratio (Table 16). The intensity was very high in some cases, the maximum swept area ratio was 19.8, which indicates that all of that grid cell was swept >19 times during one year. Since nearly three quarters of the Clyde Scottish Marine Region was swept at least once a year (71%), this high pressure class was further subdivided to account for the frequency which can influence the condition based on the resistance of the seabed features. This was mapped for the Clyde Scottish Marine Region (16).

Table 16. Classification of the fishing abrasion data – total surface swept area ratio (all gear types) into classes for used in the analysis.

Code	Abrasion Classes	Total surface swept area ratio (SurfSSAR)	Area (km^2)
1	Very Low	0-0.05	874.51
2	Low	0.05-0.25	864.37
3	Moderate	0.25-0.5	358.88
4	High	0.5-0.75	438.15
5	Complete	0.75-1	107.02
6	Complete- Low frequency	1.0-2.0	594.48
7	Complete-Mid frequency	2.0-4.0	1520.18
8	Complete High frequency	4.0+	4671.31

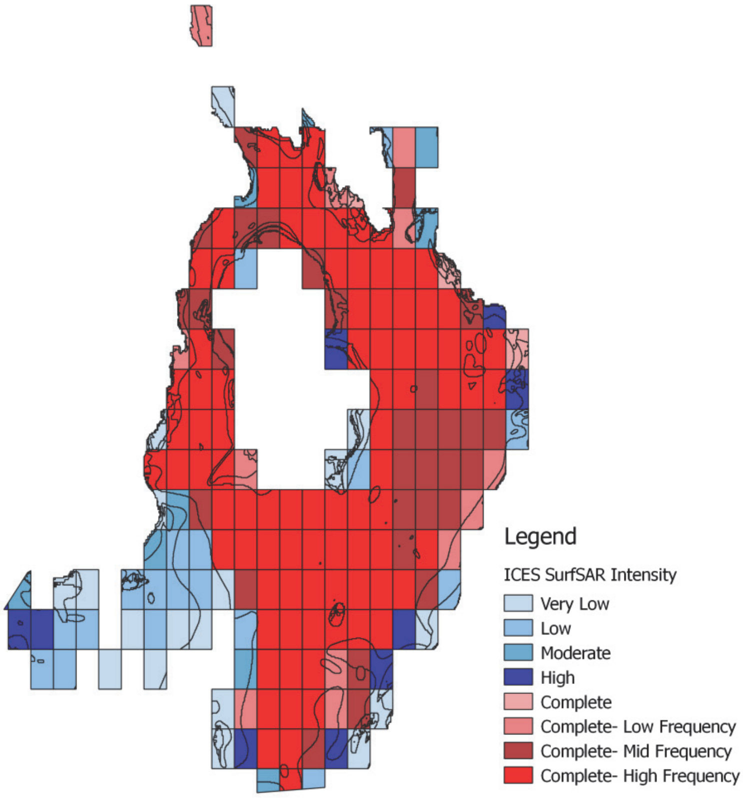


Figure 15. Total surface swept area ratio (all gear types combined) for the Clyde Scottish Marine Region (Source: ICES).

6.1.3 Relating abrasion pressure intensity to habitat condition using existing feature sensitivity

In order to use abrasion pressure as a proxy for condition of seabed habitats, there needs to be an understanding of how different levels of pressure affect the condition of seabed habitats. Key to this understanding is the different sensitivities of seabed habitats to abrasion pressure, and in particular their resistance (how much disturbance or stress can be absorbed by a habitat before it degrades). Table 17 outlines the five classes that constitute levels of influence of abrasion pressure on seabed habitats and the combinations of abrasion pressure and feature resistance they arise from. Also given, in parentheses, is the factor representing the supply of ecosystem services based on the deterioration in condition.

Table 17. Influence of abrasion pressure on seabed habitat condition (adapted from eftec 2015).

Habitat resistance	Abrasion category							
	Complete - high freq	Complete - mid freq	Complete - low freq	Complete	High	Moderate	Low	V low
None	**E (0)**	**E (0)**	**E (0)**	**E (0)**	**D (0.25)**	**C (0.5)**	B (0.75)	A (1)
Low	**E (0)**	**E (0)**	**D (0.25)**	**D (0.25)**	**C (0.5)**	B (0.75)	B (0.75)	A (1)
Medium	**E (0)**	**D (0.25)**	**C (0.5)**	B (0.75)	B (0.75	B (0.75)	B (0.75)	A (1)
High	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)

Table 18 shows the influence of different intensities of abrasion pressure on the condition of seabed habitat types from the Clyde Scottish Marine Region that was derived from the categories outlined in Table 17.

Table 18. Classification of the influence of abrasion pressure intensity on the condition of seabed habitat types in the Clyde Scottish Marine Region

Code	Habitat	Resistance	Abrasion pressure category (swept area ratio) Very Low (0-0.05)	Low (0.05-0.25)	Moderate (0.25-0.5)	High (0.5-0.75)	Complete (0.75-1)	Complete- Low freq. (1.0-2.0)	Complete-Mid freq. (2.0-4.0)	Complete High freq. (4.0+)
A3.1	Atlantic and Mediterranean high energy infralittoral rock	Low	A	B	B	C	D	D	E	E
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	Low	A	B	B	C	D	D	E	E
A3.3	Atlantic and Mediterranean low energy infralittoral rock	Low	A	B	B	C	D	D	E	E
A4.1	Atlantic and Mediterranean high energy circalittoral rock	Low	A	B	B	C	D	D	E	E
A4.12	Sponge communities on deep circalittoral rock	Low	A	B	B	C	D	D	E	E
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	Low	A	B	B	C	D	D	E	E
A4.3	Atlantic and Mediterranean low energy circalittoral rock	Low	A	B	B	C	D	D	E	E
A5.1	Sublittoral Coarse sediment	Med	A	B	B	B	B	C	D	E
A5.2	Sublittoral Sand	Med	A	B	B	B	B	C	D	E
A5.3	Sublittoral mud	Med	A	B	B	B	B	C	D	E
A5.36	Circalittoral fine mud	Med	A	B	B	B	B	C	D	E
A5.4	Circalittoral/deep mixed sediments	Low	A	B	B	C	D	D	E	E
A5.43	Infralittoral mixed sediments	None	A	B	C	D	E	E	E	E

6.1.4 Geospatial analysis

The process of geospatial analysis was twofold. The first part involved clipping the aggregated habitats layer to the seabed abrasion pressure layer in order to identify the level of abrasion overlying each habitat (or habitat fragments, in the case of habitat polygons that had multiple abrasion grid cells overlying them). The area of each habitat type in each abrasion category was then summed, and the percentage calculated (Table 19).

Table 19. Percentage area of each aggregated habitat type in each of the abrasion pressure categories in the Clyde Scottish Marine Region.

		% habitat area in each abrasion pressure category (swept area ratio)							
Code	**Habitat**	**Very Low (0-0.05)**	**Low (0.05-0.25)**	**Moderate (0.25-0.5)**	**High (0.5-0.75)**	**Complete (0.75-1)**	**Complete- Low freq. (1.0-2.0)**	**Complete-Mid freq. (2.0-4.0)**	**Complete High freq. (4.0+)**
A3.1	Atlantic and Mediterranean high energy infralittoral rock	18.9	3.0	1.5	5.2	18.2	21.7	14.1	17.4
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	37.6	21.2	2.7	0.0	0.0	5.3	3.8	29.4
A3.3	Atlantic and Mediterranean low energy infralittoral rock	20.2	15.2	5.4	3.8	0.0	2.8	26.5	26.1
A4.1	Atlantic and Mediterranean high energy circalittoral rock	19.7	0.8	1.0	12.5	23.1	15.2	15.4	12.3
A4.12	Sponge communities on deep circalittoral rock	3.3	2.2	12.5	0.0	0.0	6.0	33.8	42.3
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	45.1	12.0	7.0	9.3	0.0	4.1	10.2	12.3
A4.3	Atlantic and Mediterranean low energy circalittoral rock	23.0	5.1	1.8	2.7	0.0	1.8	21.7	43.9
A5.1	Sublittoral Coarse sediment	34.2	45.2	7.7	10.1	0.1	0.0	1.6	1.2
A5.2	Sublittoral Sand	18.5	20.6	6.6	9.1	2.0	10.9	12.8	19.5
A5.3	Sublittoral mud	1.3	1.4	2.2	2.5	0.4	5.1	19.6	67.6
A5.36	Circalittoral fine mud	0.0	0.0	13.0	0.0	0.0	0.9	13.1	73.0
A5.4	Circalittoral/deep mixed sediments	12.0	5.5	10.4	7.0	7.0	24.0	9.1	25.1
A5.43	Infralittoral mixed sediments	29.3	2.3	7.1	4.3	16.8	23.8	8.0	8.5

The second step was to then use the influence of abrasion pressure on the condition of habitats (Table 17) to work out the overall area and proportion of seabed area in each condition class (Table 20).

Table 20. Percentage of each seabed habitat in each condition class, based on the influence of abrasion pressure on the condition of seabed habitats

Code	Habitat	% habitat in each condition class				
		A	B	C	D	E
A3.1	Atlantic and Mediterranean high energy infralittoral rock	19	5	5	40	31
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	38	24	0	5	33
A3.3	Atlantic and Mediterranean low energy infralittoral rock	20	21	4	3	53
A4.1	Atlantic and Mediterranean high energy circalittoral rock	20	2	13	38	28
A4.12	Sponge communities on deep circalittoral rock	3	15	0	6	76
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	45	19	9	4	22
A4.3	Atlantic and Mediterranean low energy circalittoral rock	23	7	3	2	66
A5.1	Sublittoral Coarse sediment	34	63	0	2	1
A5.2	Sublittoral Sand	19	38	11	13	19
A5.3	Sublittoral mud	1	6	5	20	68
A5.36	Circalittoral fine mud	0	13	1	13	73
A5.4	Circalittoral/deep mixed sediments	12	9	7	31	34
A5.43	Infralittoral mixed sediments	29	2	7	4	57

From this two indicators were tested in the NCAI model:

1. % seabed habitat in "good" condition – this was the mean % of the sum of condition classes A and B across all habitat types; and
2. % seabed habitat in "poor" condition – this was the mean % of the sum of condition classes D and E across all habitat types.

These are provisionally assigned on a pragmatic basis for this exercise to test the index construction. Class C is not included in either category, since the extreme conditions are more responsive to change. The inclusion of this indicator into a mNCAI would require clear policy and science rationale to underpin the categorisation of seabed conditions.

In this case study using the 2017 abrasion data, % seabed habitat in "good" condition for the Clyde Scottish Marine Region was 37.46% of the seabed area, and % seabed habitat in "poor" condition was 57.09%.

6.1.5 Populating the NCAI model

The NCAI model was populated using the collated data from the Clyde Scottish Marine Region that had been imported into the project geospatial database.

Ecosystem services potential per service providing unit (SPU) sheet was populated using the ecosystem service scores that were derived from combining ecosystem service matrices from Potts *et al*. (2014) and SNH with marine relevant ecosystem service categories defined for this project, but following the CICES 5.1 classification system. Annex 5 shows the full table of ecosystem services per SPU.

Ecosystem potential weightings were taken directly from the terrestrial NCAI, but not all ecosystem service types were represented in marine so the proportional weightings were recalculated to ensure that the contributions by broad type (provisioning, regulation and maintenance and cultural services) added up (Table 21).

Table 21. Ecosystem service potential weighting. Greyed out ecosystem services indicate those that it was not possible to find associations with marine habitats from the literature, thus were not taken forward in the case study.

Ecosystem service	**Score for Scotland**	**Proportion**
Provisioning	10	25
Regulation & maintenance	20	50
Cultural	10	25
Total	**40**	**100**
Provisioning services		
1.1 Cultivated aquatic plants for nutrition, materials or energy		
1.2 Reared aquatic animals for nutrition, materials or energy		
1.3 Wild plants (terrestrial and aquatic) for nutrition, materials or energy	9	12.50
1.4 Wild animals (terrestrial and aquatic) for nutrition, materials or energy	9	12.50
1.5 Genetic material from all biota (including seed, spore or gamete production)		
Total	**18**	**25**
Regulation and maintenance services		
2.1 Mediation of wastes or toxic substances of anthropogenic origin by living processes	10	6.17
2.2 Control of erosion rates	12	7.41
2.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	7	4.32
2.4 Gamete and seed dispersal	10	6.17
2.5 Maintaining nursery populations and habitats (Including gene pool protection)	10	6.17
2.6 Pest and disease control	12	7.41
2.7 Regulation of chemical composition of atmosphere and oceans	20	12.35
Total	**81**	**50**
Cultural services		
3.1 Physical and experiential interactions with natural environment	20	8.3
3.2 Intellectual and representative interactions with natural environment	20	8.3
3.3 Spiritual, symbolic and other interactions with natural environment'	20	8.3
3.4 Characteristics or features of living systems that have an existence, option, or bequest value		
Total	**60**	**25**

Ecosystem area for each of the aggregated habitat types was extracted directly from the geospatial database. All years were set to 100 as there were no data to indicate changes in habitat area.

Ecosystem Service Potential Base was calculated using the following function for seabed habitats by ecosystem service type:

Ecosystem Service Potential Base = Ecosystem area / (ES Potential per SPU *3)

Wellbeing Base was calculated by working out the proportion of the overall ecosystem service by type represented by a habitat type and then multiplying this by 100 and weighting this using the weightings in Table 21.

6.1.6 Assessing the strength in the relationship between the indicator and the provision of ecosystem services

In the terrestrial NCAI, the relationship between a condition indicator and how well it represents an ecosystem service type is variable. An assigned relative weight of either 0, 0.2, 0.5 or 1 is based on its efficacy as a quality measure for each ecosystem service that it represents. Weights were assigned according to the following criteria:

- 0 - No link between indicator and ecosystem service
- 0.2 -Typically used for pressure indicators where the link between indicator and ecosystem service is weak
- 0.5 - Good link between indicator and service delivery
- 1 - Near perfect indicator.

In this example, all weightings were set at either 0 (no link) or 0.2 (since abrasion is a pressure indicator).

6.1.7 Creating artificial time-series for testing sensitivity of proxy indicator data

The area (km^2) of each habitat type in each abrasion category formed the basis for the artificial time-series to test the data. This approach was taken for two reasons:

1) It took longer than anticipated to develop the method to assign condition; and
2) It was not known if the abrasion datasets had a trend. If considerable time had been taken to compute condition and it was found that there was no differentiation across years, it would not have helped understand model sensitivity to changes in indicators.

The rationale was that there was an improvement in habitat condition from the base year of 2010 to 2017. This was operationalised by simulating a reduction of 5% of the total habitat area for any particular habitat from the least impacted habitat class into all of the others. This was iterated for the years 2016 backwards through to 2010. Then from the habitat areas, the % habitat in each abrasion class was calculated and from this, the percentage of habitat in each condition was calculated. The overall amount of habitat by type in “good” (condition categories A and B) was calculated as was the amount in “poor” condition (condition categories D and E) and the average % across all habitat types was calculated to constitute the indicator.

These artificial time-series were run through the model to examine model sensitivity to:

1) change in indicators; and
2) whether “good” condition or “poor” condition were more responsive.

6.2 Results

The results of running the artificial abrasion time series through the MNCAI show that the model is responsive to changes in the condition of benthic habitats. A 5% negative change was generated and propagated backwards from 2016 to 2010 to test the model.

Interestingly, the % habitat in good condition was much more responsive to this artificial change in habitat condition: there is a 220% increase in NCAI score over the time-series from the base year of 2010, while % habitat in poor condition declined by about 25% of the base year score (100).

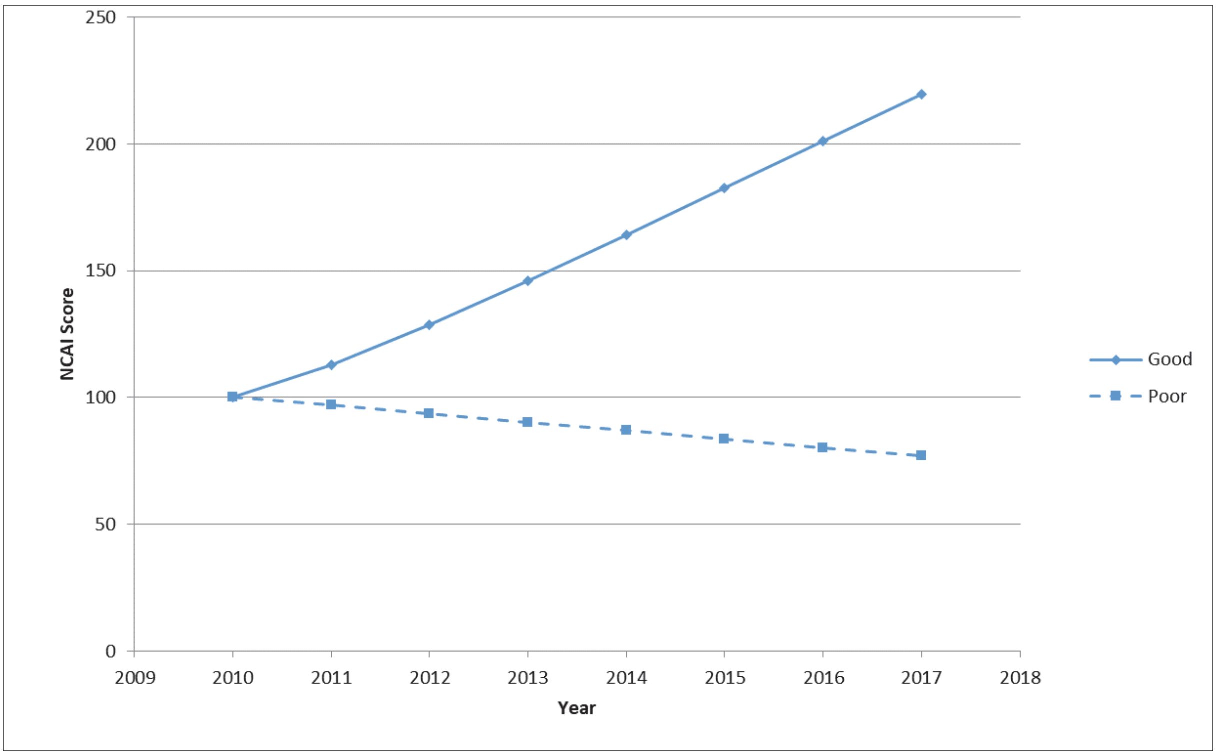


Figure 16. Testing of abrasion proxy data in the NCAI. Change was indexed to the base year, 2010. The time series was artificially constructed for the purpose of model data (abrasion data from 2017 are real data, other data have been calculated based on a decrease in habitat condition by 5% of habitat area year on year). "Good" indicates the overall amount of habitat by type in "good" condition (condition categories A and B), and "Poor" indicates the overall amount of habitat by type in "poor" condition (condition categories D and E).

6.3 Conclusions

- This case study shows that it is possible to use pressure data (swept area ratio of the seabed in this case) as an indicator for habitat condition. There are however some issues both related to using pressure data as a proxy, but also more generally in adapting this terrestrial based model to marine systems.
- The model is complicated and the output is not easily comprehensible without supporting explanation informed by interrogation of underlying data. It is useful for comparing relative change from the base year, but further analysis would be necessary to then inform management considerations.
- Weightings based on value judgements are incorporated into the model at a very early stage. By contrast the natural capital accounts e.g. ONS & Defra (2017) consider two components of stock accounts (extent and condition) and then separately consider ecosystem service flow accounts (e.g. Figure 10). The advantage of not combining and weighting indicators at an early stage is that changes in the individual components are clear, and thus their influence on the final index score is a lot more transparent and meaningful.
- The relevance of the ecosystem service weightings that were developed for the terrestrial NCAI to the marine ecosystem is a consideration. In this case study the national importance of ecosystem services to Scotland were used directly, but it could be argued that they need adapting for marine – one example is that the highest weighting for provisioning services (20) is assigned to 'cultivated crops', while 'wild animals, plants and algae' score 9, as do 'animals, plants and algae from aquaculture'. This is contrary to their sectoral importance in Scotland, where wild capture fisheries

and aquaculture outweigh seaweed farming. A second issue is related to how transferable these national level importance scorings are at a regional level. In the Clyde, the importance of ecosystem services may be considerably different to the rest of Scotland, driven by their supply and demand and how this is distributed across the marine landscape.

- The NCAI is weighted at several stages, and indicators are standardised to a base year. For some indicators it would be possible to obtain annual datasets e.g. abrasion, but for others that are not collected at regular intervals, it would be better to move to a longer reporting interval rather than annual updating. This may lead in fact to a subset of the index that is regularly updated and a second component that can only be updated sporadically e.g. in line with MSFD reporting.
- An alternative system to weight the relevance of the indicator could be developed, e.g. a risk based approach (Hooper *et al*. 2017). This study combined scores for habitat sensitivity and capacity to provide ecosystem services to identify the sensitivity of ecosystem services to pressures. A similar system would provide a more robust basis to score indicator relevance and potentially increase model sensitivity.
- In this case study the habitat data were of low resolution (e.g. mostly EUNIS level 3); if this layer had been resolved to higher EUNIS levels it would have been possible to pull out the key habitats that disproportionately contribute ecosystem services. If this type of assessment was to be conducted at smaller scales e.g. MPA or better survey data were available, key PMF habitats such as algal dominated, seagrass and biogenic habitats would be better considered separately due to their disproportionate contribution to ecosystem service flows.
- The weighting applied to indicate the strength of the association between the indicator and ecosystem services did not influence the overall result, which was surprising. However, the method devised to identify the strongest associations through the sensitivity of ecosystem services to pressures has a great deal of potential application in other types of natural capital assessments. This is an advance on considering all pressure indicators weak in terms of their linkage with ecosystem services, especially for seabed abrasion where there is an increasing evidence base on the relationship between intensity, gear type, habitat condition and changes in structure and functioning (Eno *et al*., 2013, Tillin & Tyler-Walters, 2014).

7. CONCLUSIONS AND RECOMMENDATIONS

This initial study has aimed to achieve a clearer understanding of possible and preferred methods for taking forward a mNCAI, including the identification and examination of the merits and challenges of different options. Following the initial appraisal a case study focusing on a particular region (Clyde), asset group (subtidal benthic habitats) and pressure (abrasion) was used to further interrogate and test some particular aspects of index construction.

There do not appear to be fundamental reasons why a mNCAI could not be developed. There are nonetheless some key challenges to resolve in developing a mNCAI, specifically around resolving indicator limitations, classification of pelagic habitats and treatment of highly-mobile species and the incorporation of proxy (pressure) indicators. The development of the tNCAI has overcome similar challenges and the treatment of indicators around infrequent updates, gaps and overlap have been accommodated or mitigated. Unlike the tNCAI, a full mNCAI is unlikely to be updated annually due to limitations in habitat and condition monitoring and the frequency of indicator reporting.

Development of a mNCAI could proceed in stages. Resolution of the key technical challenges would allow the development of a basic index which can be improved over time, with further components assessed or regional datasets developed or reported on separately as the suite of indicators grows and data is improved. Some regions may, for example, develop better habitat and pressure data layers that are updated more frequently allowing the development of more robust sub-indices focussed on specific regions, ecosystem services or stocks. As long as data can be disaggregated to remain consistent with a national index this would not create national reporting issues.

The following sections outline key evidence gaps and limitations identified and then conclusions and recommendations for development of a mNCAI focussed on the project aims.

7.1 Key evidence gaps and limitations

- Compared to terrestrial habitats, marine habitats are less accessible to humans and more costly to survey and monitor, thus there is less understanding of the extent of habitats and species populations and their condition. This issue relating to the availability and quality of marine data was reflected in the resolution of the data used in the abrasion case study, for which no intertidal data were available, and the majority of subtidal data were at EUNIS level 3, which meant that the separation of key features that may disproportionally contribute ecosystem services was not possible.
- Some linkages between features and ecosystem services are highly uncertain or variable depending on the specific conditions, so are hard to elaborate across larger scales with any confidence. While there is increasing evidence available about the relationship between pressures and condition e.g. seabed abrasion pressure and habitat condition (e.g. Eno *et al*., 2013, Tillin & Tyler-Walters, 2015), little work to date has assessed changes in ecosystem service provision with the breakdown of habitat structure and functioning with degradation; better understanding of these relationships and key thresholds would greatly inform the assessment of natural capital.
- There are key gaps in indicators relating to future threats (climate change and non-native species) and to the condition of ecological components such as intertidal and subtidal habitats and invertebrates. Only commercial fish stocks are associated with indicators and the condition of small fish, rare fish and non-commercial migratory fish species was not captured in indicators.

- Research effort on pressure impacts is typically focussed on widespread activities that are likely to be of concern and that are commercially important. Hence, fishing and associated physical damage pressures are better understood than other activities that are more limited in extent and intensity. The impacts of physical damage are also more predictable. It is clear that fragile features that rise above the seabed are more likely to be removed by physical abrasion than deeply buried features and that a complex habitat created by living organisms will be more sensitive to abrasion than bare rock. The pathways by which other pressures impact species and habitats are less predictable and thus it is harder to identify what the impacts may be. Although other pressures are typically on a smaller scale, it would be preferable to consider them cumulatively alongside abrasion from towed fishing gear.

7.2 Is it feasible to develop a robust index with currently available data/evidence?

- The feasibility of considering more detailed habitat based indices rests on data and evidence availability on habitat extent and condition, while the desirability of the approach will depend on cost-benefit trade-offs around resources expended in constructing the matrix, relevance to delivery of ecosystem services and sensitivity reporting requirements and applicability to policy and management. There is a limit to the number of distinct habitats that can feasibly and cost-effectively be considered within natural capital assessments and reporting, although this will vary with the scale and purpose of the activity.
- Identifying key habitat associations and links with other ecological components would support the use of indicators such as birds, marine mammals and fish to assess the likely condition of pelagic habitats, feeding grounds, nursery area and other components such as prey species. Whether and how to include mobile species, as an asset in their own right but also potentially as an indirect indicator of the health of habitats/ecosystems upon which they rely is a key challenge for development on a mNCAI.

7.3 Preferred methodology for marine index development

- The current tNCAI model is complicated and the output is not easily comprehensible without supporting explanation informed by interrogation of underlying data. It is useful for comparing relative change from the base year, but further analysis would be necessary to then inform management considerations. Since the tNCAI was initially designed, there has been considerable progress in better operationalising the natural capital approach. Lessons from this could perhaps be learned for the NCAI in general (both marine and terrestrial) particularly around disaggregating information on stocks (which are usually understood within the natural capital approach to be the assets) and flows (ecosystem services). This would also allow the NCAI to better support natural capital accounts, should these be developed in the future.
- The mNCAI, if aligned to the tNCAI in use of the EUNIS classification, should consider a subdivision at Level 3 (approximately 35 broadscale habitats) to represent a broad habitat that is equivalent to the tNCAI detail. While it would be desirable to separate component habitats, such as PMFs that are considered to support different levels of ecosystem service delivery, current extent data does not support this.
- Weightings based on value judgements are incorporated into the model at a very early stage. By contrast the natural capital accounts (ONS & Defra, 2017) consider two components of stock accounts (extent and condition) and then separately consider ecosystem service flow accounts (e.g. Figure 10). The advantage of not combining and weighting indicators at an early stage is that changes in the individual components are clear, and thus it is a lot more transparent and meaningful how they influence the end result index score.

- Adoption of the core set of 19 indicators and, potentially, the 8 pilot indicators that relate to WFD/MSFD/OSPAR indicators would support initial mNCAI development. These are likely to have application for European monitoring commitments and could be adopted by other European countries to unify reporting, as these are common indicators across states.

7.4 Recommendations for a programme of work to improve the potential for a robust mNCAI

- It is suggested that the national importance (to Scotland) weighting of ecosystem services used in the tNCAI is revised or a marine relevant version developed, to capture the value of marine ecosystem services and their national significance in the mNCAI.
- Further work to address uncertainties around ecosystem service delivery by assets is required. Existing scientific evidence and expert judgement could identify the specific components of assets that contribute to ecosystem services and final goods and benefits.
- Further work to develop a robust index should address key gaps (the unknowns) within the indicator appraisal and further assess those indicators identified as potentially suitable. This would likely increase the number and spread of useful indicators across ecosystem components. Indicators that are likely to be supported and developed in the long-term and that relate to international obligations such as WFD and OSPAR should be assessed further. Of particular interest to fulfil gaps are indicators relevant to cultural ecosystem services, such as bird and wildlife watching, and identifying where species such as birds, seals and fish can be used as proxy indicators to assess pressures and condition.
- Relaxing the criteria on annual data collection/updating to incorporate all reporting cycles, was recommended, as it is not currently possible to develop a mNCAI relying on indicators that are updated annually or biennially. This is unlikely to change given the high costs of data collection in the marine environment. This does not, however, preclude development of a useful, robust mNCAI. Further work on selected indicators is recommended to identify whether the mNCAI can be updated annually using extrapolated data or whether it is more robust to limit index updates to a longer time-scale such as 6 years to align with WFD, MSFD and Habitats Directive reporting.
- In most cases the extent of marine habitats is unlikely to change greatly as this is linked to seabed type (e.g. rocky reef, sedimentary habitat). However, some biogenic or vegetated habitats may change in extent with changes in the extent of the ecosystem engineering species e.g. saltmarsh and seagrass beds. It is recommended that for these habitats the application of WFD pilot indicators of saltmarsh and seagrass condition could be explored further (although saltmarsh and seagrass could be included in a separate coastal asset index).
- For many natural capital assets, particularly those offshore, direct data on asset condition are not available. Selected pressure indicators are recognised as the only way to get broader information on seabed condition (e.g. MSFD benthic habitats indicators and ICES fishing intensity/pressure spatial layers). Further work is recommended to usefully identify and develop other proxy indicators. Human activity data for assessments are also are more likely to be more frequently updated than direct condition assessments. Existing pressure frameworks and sensitivity assessments could be used to link human activities to the condition of ecosystem components. The use of a proxy indicator (abrasion) was tested by this study with condition and ecosystem service delivery adjusted by abrasion intensity and existing sensitivity assessments for subtidal habitats.
- Pressures (from the OSPAR 2014 framework) that are linked to benthic species and ecosystem processes and service delivery, that are likely candidates for the development of proxy indicators, include the pressures; physical loss, physical change,

removal of substratum, siltation rate changes, organic enrichment, subsurface penetration and/or disturbance of the substratum and removal of target and non-target species. For highly mobile species, the following pressures are likely to affect the stock and delivery of ecosystem services: removal of target and non-target species, underwater noise changes, visual disturbance and death or injury by collision and barriers to species movement.

- It is recommended that HBDSEG and other bodies are involved in indicator work as monitoring and indicator reporting are cross-cutting issues for marine management. We understand work is on-going by JNCC and others to rationalise indicator data collection and reporting.
- While service provision of benthic taxa can be usefully assessed within broadscale habitats as natural capital stocks, the treatment of pelagic habitats and mobile species requires further consideration by experts and should take into consideration the spatial resolution of population and monitoring data, habitat associations and habitat connectivity. Within the mNCAI there is the opportunity to define and incorporate highly mobile species (fish, marine mammals and birds) that form part of the pelagic asset as both stock and condition indicators. Recent work by Culhane *et al*. (2018) demonstrates how mobile assets can be incorporated into service providing units. Given different habitat requirements, it would be possible to separate cetaceans, fish, plankton and seals into different pelagic habitat stocks. For index purposes it is, however, likely to be more pragmatic to treat pelagic habitats as a single stock, with contribution to natural capital assessed using mobile species and plankton as indicators.
- Rising sea levels resulting from climate change will reduce the extent of intertidal habitats from coastal squeeze where the shoreward boundaries cannot migrate landwards (e.g. where cliffs prevent erosion). A separate coastal index would potentially be more sensitive to changes in habitat extent which could go undetected within the greater habitat areas of the tNCAI or mNCAI. A key recommendation to support creation of a coastal index would be improved mapping of intertidal and coastal habitats. Surveillance through satellite earth observation, notably through Sentinel 1 and 2 satellite analysis ready data, and the use of aerial surveys using unmanned aerial vehicles could support this aspiration.

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ANNEX 1: CICES ECOSYSTEM SERVICES COMPARISON

Comparison table between the updated CICES v5.1[23] and the former version, 4.3[24] that underpins the tNCAI framework. The table compares the terrestrial ecosystem services from CICES v4.3 used in the tNCAI (shaded in green). Ecosystem services from CICES 5.1 framework relating to the marine environment were identified; any services which did not directly relate were greyed out. Services that we have merged **between** classes e.g. abiotic and biotic cultural services are identified with blue shading. The suggestions column outlines the conclusions of the rationalisation exercise that identified recommended ecosystem services for inclusion in a mNCAI. The abbreviated names shows the ecosystem service name used in the case study (Chapter 6).

	CICES Version 5.1		**CICES Version 4.3**		**Suggestions**	**Abbreviated names**
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Provisioning (Biotic)	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	1.1.1.1	*Cultivated crops*	*1.1.1.1*	*Not marine (see aquaculture instead)*	*Not relevant*
Provisioning (Biotic)	Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	1.1.1.2	*Fibres and other materials from plants, algae and animals for direct use or processing*	*1.2.1.1*		
Provisioning (Biotic)	Cultivated plants (including fungi, algae) grown as a source of energy	1.1.1.3	*Plant-based resources*	*1.3.1.1*		
Provisioning (Biotic)	Plants cultivated by *in situ* aquaculture grown for nutritional purposes	1.1.2.1	*Plants and algae from in-situ aquaculture*	*1.1.1.5*	*Plants and algae from in-situ aquaculture: the suggested merged classes equate to the CICES Group 'Cultivated aquatic plants for nutrition, materials or energy'*	**Farmed seaweed**
Provisioning (Biotic)	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Plants and algae from in-situ aquaculture*	*1.1.1.5*		
Provisioning (Biotic)	Plants cultivated by in- situ aquaculture grown as an energy source	1.1.2.3	*Plants and algae from in-situ aquaculture*	*1.1.1.5*		
Provisioning (Biotic)	Animals reared for nutritional purposes	1.1.3.1	*Reared animals and their outputs*	*1.1.1.2*	*Not marine (see aquaculture instead)*	*Not relevant*
Provisioning (Biotic)	Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	1.1.3.2	*Materials from plants, algae and animals for agricultural use*	*1.2.1.2*		
Provisioning (Biotic)	Animals reared to provide energy (including mechanical)	1.1.3.3	*Animal-based resources & Animal-based mechanical energy*	*1.3.1.2 & 1.3.2.1*		
Provisioning (Biotic)	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Animals from in-situ aquaculture*	*1.1.1.6*	*Animals from in-situ aquaculture: the suggested*	**Farmed fish and shellfish**

[23] https://cices.eu/
[24] https://cices.eu/resources/

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Provisioning (Biotic)	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	*Animals from in-situ aquaculture*	*1.1.1.6*	*merged classes equate to the CICES group 'Reared aquatic animals for nutrition, materials or energy'.*	
Provisioning (Biotic)	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Animals from in-situ aquaculture*	*1.1.1.6*		
Provisioning (Biotic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Wild plants, algae and their outputs*	*1.1.1.3*	*The suggested merged classes equate to the CICES group 'Wild plants (terrestrial and aquatic) for nutrition, materials or energy'*	**Wild harvest of seaweed**
Provisioning (Biotic)	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Wild plants, algae and their outputs*	*1.1.1.3*		
Provisioning (Biotic)	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Not recognised in V4.3*	*N/A*		
Provisioning (Biotic)	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	*Wild animals and their outputs*	*1.1.1.4*	*The suggested merged classes equate to the CICES group 'Wild animals (terrestrial and aquatic) for nutrition, materials or energy'*	**Wild capture fisheries**
Provisioning (Biotic)	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	*Not recognised in V4.3*	*N/A*		
Provisioning (Biotic)	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	*Not recognised in V4.3*	*N/A*		
Provisioning (Biotic)	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*Not recognised in V4.3*	*N/A*	*Suggested merged classes correspond to the CICES Division 'Genetic material from all biota (including seed, spore or gamete production)'*	
Provisioning (Biotic)	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*Genetic materials from all biota*	*1.2.1.3*		**Genetic materials**
Provisioning (Biotic)	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Genetic materials from all biota*	*1.2.1.3*		
Provisioning (Biotic)	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*Not recognised in V4.3*	*N/A*		
Provisioning (Biotic)	Wild animals (whole organisms) used for breeding new strains or varieties	1.2.2.2	*Genetic materials from all biota*	*1.2.1.3*		
Provisioning (Biotic)	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Genetic materials from all biota*	*1.2.1.3*		
Provisioning (Biotic)	Other	1.3.X.X	*Not recognised in V4.3*	*N/A*		
Provisioning (Abiotic)	Surface water for drinking	4.2.1.1	*Surface water for drinking*	*1.1.2.1*	*Exclude, abstraction for drinking water not relevant to Scotland*	*Excluded*

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Provisioning (Abiotic)	Surface water used as a material (non-drinking purposes)	4.2.1.2	*Surface water for non-drinking purposes*	*1.2.2.1*	*Could include surface water abstracted for cooling- but potentially this is a pressure indicator due to entrainment of fish and other biota and production of heated effluents if returned, rather than an ecosystem service.*	*Excluded*
Provisioning (Abiotic)	Freshwater surface water used as an energy source	4.2.1.3	*Not recognised in V4.3*	*N/A*	*Not marine*	*Excluded*
Provisioning (Abiotic)	Coastal and marine water used as energy source	4.2.1.4	*Not recognised in V4.3*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Ground (and subsurface) water for drinking	4.2.2.1	*Ground water for drinking*	*1.1.2.2*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Ground water (and subsurface) used as a material (non-drinking purposes)	4.2.2.2	*Ground water as source of energy*	*1.2.2.2*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Ground water (and subsurface) used as an energy source	4.2.2.3	*Ground water for non-drinking purposes*	*N/A*	*Not relevant marine in Scotland*	
Provisioning (Abiotic)	Other	4.2.X.X	*Not recognised in V4.3*	*N/A*		
Provisioning (Abiotic)	Mineral substances used for material purposes	4.3.1.2	*Solid*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Mineral substances used for as an energy source	4.3.1.3	*N/A*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Non-mineral substances or ecosystem properties used for nutritional purposes	4.3.2.1	*Non-mineral*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Non-mineral substances used for materials	4.3.2.2	*Gas*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Wind energy	4.3.2.3	*Wind*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Solar energy	4.3.2.4	*Solar*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Geothermal	4.3.2.5	*Geo-thermal*	*N/A*	*Excluded: abiotic*	*Excluded*
Provisioning (Abiotic)	Other	4.3.2.6	*Not recognised in V4.3*	*N/A*	*Unclear*	

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Regulation & Maintenance (Biotic)	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	*Bio-remediation by micro-organisms, algae, plants, and animals*	*2.1.1.1*	*Suggested merged classes correspond to CICES group 'Mediation of wastes or toxic substances of anthropogenic origin by living processes'.*	**Waste remediation**
Regulation & Maintenance (Biotic)	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals And Filtration/sequestration/storage/accumulation by ecosystems*	*2.1.1.2 & 2.1.2.1*		
Regulation & Maintenance (Biotic)	Smell reduction	2.1.2.1	*Mediation of smell/noise/visual impacts*	*2.1.2.3*	*Merge with visual: suggested merged classes correspond with CICES group 'Mediation of nuisances of anthropogenic origin'. However evidence or basis for assessment are not clear and we consider this would be assessed through mediation of wastes or toxic substances of anthropogenic origin by living processes'.*	*Waste remediation*
Regulation & Maintenance (Biotic)	Noise attenuation	2.1.2.2	*Mediation of smell/noise/visual impacts*	*2.1.2.3*	*Not relevant in context benthic habitats and species*	*Not relevant*
Regulation & Maintenance (Biotic)	Visual screening	2.1.2.3	*Mediation of smell/noise/visual impacts*	*2.1.2.3*	*See above 'smell reduction'*	*Waste remediation*
Regulation & Maintenance (Biotic)	Control of erosion rates	2.2.1.1	*Stabilisation and control of erosion rates*	*2.2.1.1*	*Include at class level- service provision would consider biota and abiotic habitat, for example sediment stabilisation by saltmarsh.*	**Erosion control**
Regulation & Maintenance (Biotic)	Buffering and attenuation of mass movement	2.2.1.2	*Buffering and attenuation of mass flows*	*2.2.1.2*		**Erosion control**
Regulation & Maintenance (Biotic)	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*Hydrological cycle and water flow maintenance And Flood protection*	2.2.2.1 2.2.2.2	*Include at class level- service provision would consider biota and abiotic habitat, e.g. water flow management by saltmarsh*	**Coastal protection**
Regulation & Maintenance (Biotic)	Wind protection	2.2.1.4	*Storm protection*	*2.2.3.1*	*Not relevant in context benthic habitats and species*	*Not relevant*

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Regulation & Maintenance (Biotic)	Fire protection	2.2.1.5	*Not recognised in V4.3*	*N/A*	*Not relevant in context benthic habitats and species*	*Not relevant*
Regulation & Maintenance (Biotic)	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*Pollination and seed dispersal*	*2.3.1.1*	*Suggest merge classes and refer to according to version 4.3, 'Gamete and seed dispersal' seed dispersal refers to seagrass.*	**Dispersal (gamete/larvae)**
Regulation & Maintenance (Biotic)	Seed dispersal	2.2.2.2	*Pollination and seed dispersal*	*2.3.1.1*		
Regulation & Maintenance (Biotic)	Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	*Maintaining nursery populations and habitats*	*2.3.1.2*	*Advise to not merge with gamete dispersal and to include at class level, specifically consider nursery/spawning areas and complex habitats that provide shelter and refugia for juveniles, e.g. seagrass beds for cuttlefish,*	**Nursery habitats**
Regulation & Maintenance (Biotic)	Pest control (including invasive species)	2.2.3.1	*Pest control*	*2.3.2.1*	*Suggested merged classes correspond to CICES group 'Pest and disease control'.*	**Pest and disease control**
Regulation & Maintenance (Biotic)	Disease control	2.2.3.2	*Disease control*	*2.3.2.2*		
Regulation & Maintenance (Biotic)	Weathering processes and their effect on soil quality	2.2.4.1	*Weathering processes*	*2.3.3.1*	*Not relevant in context benthic habitats and species*	*Not relevant*
Regulation & Maintenance (Biotic)	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	*Decomposition and fixing processes*	*2.3.3.2*	*Nutrient cycling is covered in provisioning service: Mediation of wastes or toxic substances of anthropogenic origin by living processes'*	***Waste remediatio**n*
Regulation & Maintenance (Biotic)	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	*Chemical condition of freshwaters*	*2.3.4.1*	*Not relevant to marine.*	*Not relevant*
Regulation & Maintenance (Biotic)	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	*Chemical condition of salt waters*	*2.3.4.2*	*Chemical condition of seawater, not clear that this is a significant ecosystem service not covered by nutrient cycling or detoxification by biota.*	***Waste remediation***

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Regulation & Maintenance (Biotic)	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*Global climate regulation by reduction of greenhouse gas concentrations*	*2.3.5.1*	*Include carbon sequestration but large-scale geological processes such as the North Sea carbon pump won't be included as a stock- may be possible to include offshore sediments >50m deep- see ABPmer report. Will also refer to production of DMS etc.*	**Carbon sequestration**
Regulation & Maintenance (Biotic)	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*Micro and regional climate regulation &Ventilation and transpiration*	*2.3.5.2 & 2.2.3.2*		
Regulation & Maintenance (Biotic)	Other	2.3.X.X	*Not recognised in V4.3*	*N/A*		
Regulation & Maintenance (Abiotic)	Dilution by freshwater and marine ecosystems	5.1.1.1	*Dilution by atmosphere, freshwater and marine ecosystems*	*2.1.2.2*	*Abiotic. Exclude*	
Regulation & Maintenance (Abiotic)	Dilution by atmosphere	5.1.1.2	*Dilution by atmosphere, freshwater and marine ecosystems*	*2.1.2.2*	*Abiotic. Exclude*	
Regulation & Maintenance (Abiotic)	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	5.1.1.3	*Mediation of waste, toxics and other nuisances, by natural chemical and physical processes*	*N/A*	*Mediation of waste, toxics and other nuisances, by natural chemical and physical processes. Remediation by biological processes is included.*	*Waste remediation*
Regulation & Maintenance (Abiotic)	Mediation of nuisances by abiotic structures or processes	5.1.2.1	*Not recognised in V4.3*	*N/A*	*Excluded: Abiotic. Unclear this pressure is linked to intertidal and marine habitats and biologically mediated processes are captured by other services*	*Excluded*
Regulation & Maintenance (Abiotic)	Mass flows	5.2.1.1	*Mediation of flows by natural abiotic structures*	*N/A*	*Merge with biotic service*	*Erosion control*
Regulation & Maintenance (Abiotic)	Liquid flows	5.2.1.2	*Not recognised in V4.3*	*N/A*	*Merge with biotic service*	*Coastal protection*

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Regulation & Maintenance (Abiotic)	Gaseous flows	5.2.1.3	*Not recognised in V4.3*	*N/A*	*Physical barriers to air movements- some friction with the sea surface would reduce wind flow as would intertidal habitats and other topographical barriers such as cliffs (but these would be excluded as above MHWS). This service is difficult to quantify and would not be affected by human pressures. Suggested: exclude.*	*Excluded*
Regulation & Maintenance (Abiotic)	Maintenance and regulation by inorganic natural chemical and physical processes	5.2.2.1	*Maintenance of physical, chemical, abiotic conditions*	*N/A*	*Exclude Abiotic*	*Excluded*
Regulation & Maintenance (Abiotic)	Other	5.3.X.X	*Not recognised in V4.3*	*N/A*		
Cultural (Biotic)	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	3.1.1.1	*Experiential use of plants, animals and land-/seascapes in different environmental settings*	*3.1.1.1*	*Suggest merge-this would alignn with the tNCAI - the suggested merged classes equate to the CICES Group 'Physical and experiential interactions with natural environment',*	**Tourism, leisure & wildlife watching**
Cultural (Biotic)	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3.1.1.2	*Physical use of land-/seascapes in different environmental settings*	*3.1.1.2*		
Cultural (Biotic)	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*Scientific*	*3.1.2.1*	*Heritage, scientific and education merged in tNCAI - if culture and aesthetic are included the suggested merged classes equate to the CICES Group 'Intellectual and representative interactions with natural environment' The difference from the group below is that this group is based on direct interactions,*	**Education**
Cultural (Biotic)	Characteristics of living systems that enable education and training	3.1.2.2	*Educational*	*3.1.2.2*		
Cultural (Biotic)	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*Heritage, cultural*	*3.1.2.3*		
Cultural (Biotic)	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*Aesthetic*	*3.1.2.5*		
Cultural (Biotic)	Elements of living systems that have symbolic meaning	3.2.1.1	*Symbolic*	*3.2.1.1*	*Suggest merge-symbolic and sacred/religious to align with the tNCAI - but also include education – the suggested*	**Spiritual/cultural**
Cultural (Biotic)	Elements of living systems that have sacred or religious meaning	3.2.1.2	*Sacred and/or religious*	*3.2.1.2*		

	CICES Version 5.1		CICES Version 4.3		Suggestions	Abbreviated names
Section	**Class**	**Code (5.1)**	**V4.3 Equivalent**	**Code (4.3)**		
Cultural (Biotic)	Elements of living systems used for entertainment or representation	3.2.1.3	*Entertainment*	*3.1.2.4*	*merged classes equate to the CICES Group level 'Spiritual, symbolic and other interactions with natural environment'. This group refers to indirect or remote interactions rather than the direct interactions of the group above.*	
Cultural (Biotic)	Characteristics or features of living systems that have an existence value	3.2.2.1	*Existence*	*3.2.2.1*	*Suggest merge, existence and bequest- alignment tNCAI - 'Characteristics or features of living systems that have an existence, option, or bequest value' this aligns with the CICES group level 'Other biotic characteristics that have a non-use value' for clarity we **suggest the tNCAI definition is adopted***	**Existence/ option use/ bequest**
Cultural (Biotic)	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*Bequest*	*3.2.2.2*		
Cultural (Abiotic)	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	6.1.1.1	*Not recognised in V4.3*	*N/A*	*We consider this can be covered as a single abiotic & biotic class.*	**Spiritual/cultural**
Cultural (Abiotic)	Natural, abiotic characteristics of nature that enable intellectual interactions	6.1.2.1	*Not recognised in V4.3*	*N/A*	*We consider this can be covered as a single abiotic & biotic class.*	
Cultural (Abiotic)	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	6.2.1.1	*Not recognised in V4.3*	*N/A*	*We consider this can be covered as a single abiotic & biotic class.*	
Cultural (Abiotic)	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value	6.2.2.1	*Not recognised in V4.3*	*N/A*	*We consider this can be covered as a single abiotic & biotic class.*	**Existence/ option use/bequest**

ANNEX 2: RATIONALISATION OF DIFFERENT ECOSYSTEM SERVICE TYPOLOGIES USED TO CLASSIFY ECOSYSTEM SERVICE MATRICES FOR MARINE FEATURES

Abiotic is not included in this table as it has yet to be included in matrices linking features with ecosystem services.

Marine relevant ES categories from CICES v5.1	This study	SNH draft PMF matrices	Potts *et al*. 2014 MPA features ES matrices		Culhane *et al.* 2018
			Intermediate	**Goods/Benefits**	**Marine Ecosystem Services**
1. Provisioning					
1.1 Biomass		Biomass production			
1.1.2 Cultivated aquatic plants for nutrition, materials or energy					
1.1.2.1 Plants cultivated by in- situ aquaculture grown for nutritional purposes	**Farmed seaweed**			Food (wild and farmed)	Plant and algal seafood from aquaculture
1.1.2.2 Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)				Fish feed (wild, farmed, bait)/ Fertiliser and biofuels/Medicines and blue biotechnology	Raw materials
1.1.2.3 Plants cultivated by in- situ aquaculture grown as an energy source				Fertiliser and biofuels	Plant and algal based biofuels
1.1.4 Reared aquatic animals for nutrition, materials or energy					
1.1.4.1 Animals reared by in-situ aquaculture for nutritional purposes	**Farmed fish and shellfish**			Food (wild and farmed)	Animal seafood from aquaculture
1.1.4.2 Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)				Fish feed (wild, farmed, bait)/Medicines and blue biotechnology	Raw materials
1.1.4.3 Animals reared by in-situ aquaculture as an energy source					Animal based biofuels
1.1.5 Wild plants (terrestrial and aquatic) for nutrition, materials or energy					
1.1.5.1 Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	**Harvestable seaweed**	Harvestable seaweed		Food (wild and farmed)	Seafood from wild plants and algae
1.1.5.2 Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)				Fish feed (wild, farmed, bait)/ Fertiliser and biofuels/Medicines and blue biotechnology	Raw materials
1.1.5.3 Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy				Fertiliser and biofuels	Plant and algal based biofuels

Marine relevant ES categories from CICES v5.1	**This study**	**SNH draft PMF matrices**	**Potts *et al*. 2014 MPA features ES matrices**		**Culhane *et al*. 2018**
			Intermediate	**Goods/Benefits**	**Marine Ecosystem Services**
1.1.6 Wild animals (terrestrial and aquatic) for nutrition, materials or energy					
1.1.6.1 Wild animals (terrestrial and aquatic) used for nutritional purposes	**Wild capture fisheries**	Fish and shellfish stocks		Food (wild and farmed)	Seafood from wild animals
1.1.6.2 Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)		Ornamental materials (commercial and personal)		Fish feed (wild, farmed, bait)/Ornaments and aquaria/Medicines and blue biotechnology	Raw materials
1.1.6.3 Wild animals (terrestrial and aquatic) used as a source of energy					Animal based biofuels
1.2 Genetic material from all biota (including seed, spore or gamete production)					
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	**Genetic resources**	Genetic resources			Genetic materials
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					
1.2.2 Genetic material from animals					
1.2.2.1 Animal material collected for the purposes of maintaining or establishing a population	**Genetic resources**				
1.2.2.2 Wild animals (whole organisms) used to breed new strains or varieties					
1.2.2.3 Individual genes extracted from organisms for the design and construction of new biological entities					
2. Regulation & Maintenance					
2.1 Transformation of biochemical or physical inputs to ecosystems					
2.1.1 Mediation of wastes or toxic substances of anthropogenic origin by living processes					
2.1.1.1 Bio-remediation by micro-organisms, algae, plants, and animals	**Waste remediation**	nutrient cycling/ waste breakdown & detoxification of water and sediments	Nutrient cycling/ waste breakdown & detoxification	Waste burial/ removal/ neutralisation	Waste and toxicant treatment via biota
2.1.1.2 Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals					Waste and toxicant removal and storage

Marine relevant ES categories from CICES v5.1	This study	SNH draft PMF matrices	Potts *et al*. 2014 MPA features ES matrices		Culhane *et al*. 2018
			Intermediate	**Goods/Benefits**	**Marine Ecosystem Services**
2.1.2 Mediation of nuisances of anthropogenic origin					
2.1.2.1 Smell reduction					Mediation of smell/ visual impacts
2.1.2.3 Visual screening					Mediation of smell/ visual impacts
2.2 Regulation of physical, chemical, biological conditions					
2.2.1 Regulation of baseline flows and extreme events		Formation of physical barrier/ Natural coastal protection	Formation of physical barriers/ Natural hazard regulation	Prevention of coastal erosion/ sea defence	
2.2.1.1 Control of erosion rates	**Erosion control**	Sediment stabilisation			Erosion prevention and sediment retention
2.2.1.2 Buffering and attenuation of mass movement					Erosion prevention and sediment retention
2.2.1.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	**Coastal protection**	Water cycling	water cycling		Flood protection
2.2.2 Lifecycle maintenance, habitat and gene pool protection					
2.2.2.1 Pollination (or 'gamete' dispersal in a marine context)	**Dispersal (gamete/larvae)**	Larval/gamete supply (supporting connectivity)	Larval and gamete supply		Seed and gamete dispersal
2.2.2.2 Seed dispersal					Seed and gamete dispersal
2.2.2.3 Maintaining nursery populations and habitats (Including gene pool protection)	**Nursery habitats**	habitat for other species (supporting biodiversity)	Formation of species habitat		Maintaining nursery populations and habitats/ Gene pool protection
2.2.3 Pest and disease control					
2.2.3.1 Pest control (including invasive species)	**Pest and disease control**	Natural resilience to INNS & disease	Biological control		Pest control
2.2.3.2 Disease control					Disease control
2.2.4 Regulation of soil quality					
2.2.4.2 Decomposition and fixing processes and their effect on soil quality					Sediment nutrient cycling
2.2.5 Water conditions					

Marine relevant ES categories from CICES v5.1	This study	SNH draft PMF matrices	Potts *et al*. 2014 MPA features ES matrices		Culhane *et al*. 2018
			Intermediate	**Goods/Benefits**	**Marine Ecosystem Services**
2.2.5.2 Regulation of the chemical condition of salt waters by living processes		nutrient cycling			Chemical condition of seawater
2.2.6 Atmospheric composition and conditions					
2.2.6.1 Regulation of chemical composition of atmosphere and oceans	**Carbon sequestration**	Carbon storage and climate regulation	Carbon sequestration	Healthy climate	Global climate regulation
2.2.6.2 Regulation of temperature and humidity, including ventilation and transpiration					Global climate regulation
3. Cultural					
3.1 Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	**Tourism, leisure & wildlife watching**	Socially valued places/ seascapes	Formation of the seascape	Tourism and nature watching	
3.1.1 Physical and experiential interactions with natural environment					
3.1.1.1 Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions					Recreation and leisure
3.1.1.2 Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions					Recreation and leisure
3.1.2 Intellectual and representative interactions with natural environment					
3.1.2.1 Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge					Scientific
3.1.2.2 Characteristics of living systems that enable education and training	Education			Education	Educational
3.1.2.3 Characteristics of living systems that are resonant in terms of culture or heritage					Heritage
3.1.2.4 Characteristics of living systems that enable aesthetic experiences				Aesthetic benefits	Aesthetic
3.2 Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting					
3.2.1 Spiritual, symbolic and other interactions with natural environment	**Spiritual/cultural**			Spiritual and cultural wellbeing	
3.2.1.1 Elements of living systems that have symbolic meaning					Symbolic

Marine relevant ES categories from CICES v5.1	**This study**	**SNH draft PMF matrices**	**Potts *et al*. 2014 MPA features ES matrices**		**Culhane *et al*. 2018**
			Intermediate	**Goods/Benefits**	**Marine Ecosystem Services**
3.2.1.2 Elements of living systems that have sacred or religious meaning					Sacred and/or religious
3.2.1.3 Elements of living systems used for entertainment or representation					Entertainment
3.2.2 Other biotic characteristics that have a non-use value					
3.2.2.1 Characteristics or features of living systems that have an existence value	**Existence/option use/bequest**				Existence
3.2.2.2 Characteristics or features of living systems that have an option or bequest value					Bequest

ANNEX 3: NESTING OF PMFS WITHIN THEIR BROADSCALE HABITATS

Bold indicates broadscale habitats (Eunis level 3) and normal type seabed PMF features.

Feature Type (PMF - Priority marine feature, BSH - Broadscale habitat)	**EUNIS code** Note: Eunis codes were identified using the JNCC EUNIS translation matrix. Some habitats do not have a direct relationship to the EUNIS code and this column should only be used as a guide.	**Feature** (Bold type represents Broadscale habitats, normal type represents habitat PMFs)
BSH	**A1.1**	**High energy intertidal rock**
PMF	A1.151, A1.152, A1.153	Tide-swept algal communities
BSH	**A1.2**	**Moderate energy intertidal rock**
BSH	**A1.3**	**Low energy intertidal rock**
PMF	A1.325	Sea loch egg wrack beds
BSH	**A2.1**	**Intertidal coarse sediment**
BSH	**A2.2**	**Intertidal sand and muddy sand**
PMF	A2.212	Blue Mussel beds
BSH/PMF	**A2.3**	**Intertidal mudflats**
BSH	**A2.4**	**Intertidal mixed sediments**
BSH	**A2.5**	**Coastal saltmarshes and saline reedbeds**
BSH	**A2.6**	**Intertidal sediments dominated by aquatic angiosperms**
PMF	A2.61	Seagrass beds
BSH	**A2.7**	**Intertidal biogenic reefs**
PMF	A2.72, A2.721	Blue Mussel beds
BSH	**A3.1**	**High energy infralittoral rock**
PMF	A3.126	Tide-swept algal communities
PMF	A3.113, A3.115	Kelp beds
BSH	**A3.2**	**Moderate energy infralittoral rock**
PMF	A3.213, A3.221, A3.222, A3.223	Tide-swept algal communities
PMF	A3.212, A3.213, A3214	Kelp beds
BSH	**A3.3**	**Low energy infralittoral rock**
PMF	A3.361	Blue mussel beds
	A3.32, A3.321, A3.322, A3.323, A3.34, A3.341, A3.342, A3.343, A3.344, A3.36, A3.361, A3.362, A3.363	Low or variable salinity habitats

BSH	**A4.1**	**High energy circalittoral rock**
PMF	A4.12, A4.121, A4.133	Northern sea fan and sponge communities
BSH	**A4.2**	**Moderate energy circalittoral rock**
PMF	A4.211	Northern sea fan and sponge communities
BSH	**A4.3**	**Low energy circalittoral rock**
BSH	**A5.1**	**Subtidal coarse sediment**
PMF	A5.133	Shallow tide-swept coarse sands with burrowing bivalves
PMF	A5.144	Maerl or coarse shell gravel with burrowing sea cucumbers
PMF	A5.15, A5.151, A5.152	Offshore subtidal sands and gravels
BSH	**A5.2**	**Subtidal sand**
PMF	A5.25, A5.251, A5.252, A5.27, A5.271, A5.272	Offshore subtidal sands and gravels
BSH	**A5.3**	**Subtidal mud**
PMF	A5.35, A5.351, A5.352, A5.353, A5.354, A5.355, A5.36, A5.361, A5.362, A5.363, A5.371, A5.372, A5.375, A5.376, A5.377	Low or variable salinity habitats
PMF	A5.361	Burrowed mud - Sea-pen and burrowing megafauna communities
PMF	A5.362	Burrowed mud - Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud
PMF	A5.371	Inshore deep mud with burrowing heart urchins
PMF	A5.31	Offshore deep sea muds
BSH	**A5.4**	**Subtidal mixed sediments**
PMF	A5.434	Flame/ File shell beds
PMF	A5.435	Native Oyster *Ostrea edulis* beds
BSH	**A5.5**	**Subtidal macrophyte-dominated sediment**
PMF	A5.51, A5.511, A5.512, A5.513, A5.514	Maerl beds
PMF	A5.52	Kelp and seaweed communities on sublittoral sediment
PMF	A5.53	Seagrass beds
S	A3.126, A3.213, A1.15, A3.22, A4.11, A4.25, A5.52	Tide-swept algal communities
BSH	**A5.6**	**Subtidal biogenic reefs**
PMF	A5.613	Serpulid aggregations
PMF	A5.625	Blue Mussel beds
PMF	A5.621, A5.622, A5.623, A5.624	Horse mussel (*Modiolus modiolus*) beds

PMF	A5.63	Cold-water coral reefs
BSH	**A5.7**	**Features of sublittoral sediments**
PMF	A5.71, A5.711, A5.712	Submarine structures made by leaking gases
BSH	**A6.6**	**Deep-sea bioherms**
PMF	A6.1, A6.2, A6.3, A6.4, A6.5, A6.7, A6.8, A6.9	Coral Gardens
PMF	A6.62	Deep-sea sponge aggregations
BSH	**A6.7**	**Raised features of the deep-sea bed**
PMF	A6.75	Carbonate mound communities
PMF	A6.72, A6.721, A6.722, A6.723, A6.724, A6.725	Seamount communities

ANNEX 4: DIFFERENTIATION OF ECOSYSTEM SERVICE SCORES OF PMFS (SUBTRACTED FROM THEIR PARENT BROADSCALE HABITATS)

Greyscale indicates broadscale habitat ecosystem service scores by type (values indicate scores), while purple scale indicates the degree of differentiation between the PMF and its parent BSH (values indicate difference in scores).

	Provisioning					Regulating							Cultural				
Feature (Bold type represents Broadscale habitats, normal type represents habitat PMFs)	Farmed seaweeds	Farmed fish and shellfish	Wild harvest of seaweed	Wild capture fisheries	Genetic materials	Waste remediation	Erosion control	Coastal protection	Dispersal (gamete / larvae)	Nursery habitats	Pest and disease control	Carbon sequestration	Tourism, leisure and wildlife watching	Education	Spiritual / cultural	Existence / option use / bequest	Standard deviation
High energy intertidal rock			**0**	**2**		**0**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Tide-swept algal communities			1	1		2	-1	-1	-1	-1	1	0	0	-1	0		1.04
Moderate energy intertidal rock			**2**	**2**		**0**	**2**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Low energy intertidal rock			**3**	**2**		**0**	**1**	**2**	**3**	**3**	**2**	**2**	**2**	**1**	**2**		
Sea loch egg wrack beds			0	1		3	1	0	-1	0	1	1	0	-1	0		1.08
Intertidal coarse sediment			**1**	**1**		**1**	**2**	**2**	**2**	**2**			**3**	**1**	**1**		
Intertidal sand and muddy sand			**1**	**2**		**2**	**3**	**2**	**2**	**3**	**2**	**3**	**3**	**1**	**3**		
Blue Mussel beds			0			0	-1	0	0	-1	1	-1	-1	0	-1		0.67
Intertidal mudflats			**1**	**2**		**3**	**3**	**2**	**3**	**2**	**2**	**3**	**3**	**1**	**3**		
Intertidal mixed sediments			**1**	**2**		**2**	**2**	**2**	**2**	**3**		**1**	**3**	**1**	**1**		

Coastal saltmarshes and saline reedbeds			**3**	**3**		**3**	**2**	**2**	**3**	**3**		**3**	**3**	**1**	**1**		
Intertidal sediments dominated by aquatic angiosperms			**2**	**2**		**3**	**2**	**2**		**3**	**3**	**3**	**2**	**1**	**1**		
Seagrass beds			0	1		-1	0	0		0	0	-1	0	0	1		0.67
Intertidal biogenic reefs			**1**	**2**		**2**	**2**	**2**	**2**	**3**		**2**	**1**	**1**	**1**		
Blue Mussel beds			-1	0		0	0	0	0	-1		0	1	0	1		0.63
High energy infralittoral rock			**2**	**3**		**1**	**2**	**2**	**2**	**3**	**2**		**2**	**1**	**1**		
Tide-swept algal communities			1	0		1	0	0	0	-1	1		0	-1	1		0.75
Kelp beds			1	0		1	-2	0	-2	-3	-2		-2	-1	-1		1.34
Moderate energy infralittoral rock			**2**	**3**		**1**	**2**	**2**	**2**	**3**	**2**	**2**	**2**	**1**	**1**		
Tide-swept algal communities			1	0		1	0	0	0	-1	1	0	0	-1	1		0.71
Kelp beds			1	0		1		0									0.58
Low energy infralittoral rock			**1**	**3**		**1**	**2**	**2**	**2**	**3**	**2**	**2**	**2**	**1**	**1**		
Blue mussel beds			-1	-1		1	0	0	1	0	1	0	0	0	1		0.72
Low or variable salinity habitats			1	-1		1	0	0	0	0		0	1	2	2		0.93
High energy circalittoral rock			**0**	**3**		**0**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**1**		
Northern sea fan and sponge communities			0	-1		1	-1	-1	-1	0	0		0		1		0.79
Moderate energy circalittoral rock			**0**	**3**		**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**1**		
Northern sea fan and sponge communities			0	-1		0	-1	-1	-1	0	0		0		1		0.67
Low energy circalittoral rock			**0**	**3**		**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**1**		
Subtidal coarse sediment			**0**	**2**		**1**	**1**	**1**	**2**					**1**	**1**		
Shallow tide-swept coarse sands with burrowing bivalves			0	0		1	0	-1	-1					-1	0		0.7
Maerl or coarse shell gravel with burrowing sea cucumbers			1	0			0	0	-1					0	0		0.58
Offshore subtidal sands and																	

gravels																	
Subtidal sand			**0**	**2**		**1**	**1**	**1**	**2**	**2**				**1**	**1**		
Offshore subtidal sands and gravels																	
Subtidal mud			**0**	**2**		**2**	**1**	**1**	**2**	**2**				**1**	**1**		
Low or variable salinity habitats			0	0		0	1	1	0	1				2	2		0.83
Burrowed mud - Sea-pen and burrowing megafauna communities			0	0		0	0	0	0	0				0	0		0
Burrowed mud - Burrowing megafauna and Maxmuelleria lankesteri in circalittoral mud				0		0			0	0					0		0
Inshore deep mud with burrowing heart urchins			0	0		0	0	-1	0	0				0	0		0.33
Offshore deep sea muds							0		-1	0							0.58
Subtidal mixed sediments			**0**	**2**		**2**	**1**	**1**	**2**					**1**	**1**		
Flame/ File shell beds			0	0		0	2	0	1					0	1		0.76
Native Oyster Ostrea edulis beds			0	-1		1	1	0	0					0	1		0.71
Subtidal macrophyte-dominated sediment			**2**	**3**		**3**	**2**	**1**		**3**			**2**	**1**	**1**		
Maerl beds			-1	0			0	0		0			0	0	1		0.53
Kelp and seaweed communities on sublittoral sediment			1	0		0	1	1		-1			0	-1	1		0.83
Seagrass beds			0	0		-1	0	1		0			0	0	1		0.60
Tide-swept algal communities			1	0		-1	0	1		-1			0	-1	1		0.87
Subtidal biogenic reefs			**1**	**3**		**2**	**2**	**1**	**2**	**3**		**2**	**1**	**1**	**1**		
Serpulid aggregations				0		0	1	0	0	0		-1	1		1		0.67
Blue Mussel beds			-1	-1		0	0	1	1	0		0	1	0	1		0.75
Horse mussel (Modiolus modiolus) beds			-1	-1		1	1	1	1	0		0	1	0	1		0.81
Cold-water coral reefs			-1	0				0	0	0		0	1	0	1		0.60

ANNEX 5: ECOSYSTEM SERVICE POTENTIAL PER SERVICE PROVIDING UNIT (SPU)

ES Potential per SPU

Ecosystem service potential matrix, per service providing unit (SPU)

0 = no relevant potential, unknown, not assessed or negligible
1 = Low relevant potential
2 = Moderate relevant potential
3 = Maximum relevant potential

ES Potential per SPU		Provisioning					Regulation and maintenance							Cultural			
		Farmed seaweeds	Farmed fish and shellfish	Wild harvest of seaweed	Wild capture fisheries	Genetic material	Waste remediation	Erosion control	Coastal protection	Dispersal (gamete / larvae)	Nursery habitats	Pest and disease control	Carbon sequestration	Tourism, leisure and wildlife watching	Education	Spiritual / cultural	Existence / option use / bequest
A3 Infralittoral rock	A3.1 High energy infralittoral rock	0	0	2	3	0	1	2	2	2	3	2	0	2	1	1	0
	A3.2 Moderate energy infralittoral rock	0	0	2	3	0	1	2	2	2	3	2	2	2	1	1	0
	A3.3 Low energy infralittoral rock	0	0	1	3	0	1	2	2	2	3	2	2	2	1	1	0
A4 Circalittoral rock	A4.1 High energy circalittoral rock	0	0	0	3	0	0	1	1	2	2	2	2	2	1	1	0
	A4.12 Deep circalittoral sponge communities	0	0	0	2	0	1	0	0	1	2	2	0	2	0	2	0
	A4.2 Moderate energy circalittoral rock	0	0	0	3	0	1	1	1	2	2	2	2	2	1	1	0
	A4.3 Low energy circalittoral rock	0	0	0	3	0	1	1	1	2	2	2	2	2	1	1	0
A5 Sublittoral sediment	A5.1 Subtidal coarse sediment	0	0	0	2	0	1	1	1	2	0	0	0	0	1	1	0
	A5.2 Subtidal sand	0	0	0	2	0	1	1	1	2	2	0	0	0	1	1	0
	A5.3 Subtidal mud	0	0	0	2	0	2	1	1	2	2	0	0	0	1	1	0
	A5.36 Circalittoral fine mud	0	0	0	2	0	2	1	1	2	2	2	3	1	1	1	0
	A5.4 Subtidal mixed sediments	0	0	0	2	0	2	1	1	2	0	0	0	0	1	1	0
	A5.43 Infralittoral mixed sediments	0	0	0	2	0	3	3	1	3	3	3	2	2	1	2	0

ANNEX 6: METHODS TO QUANTIFY THE STRENGTH OF THE RELATIONSHIP BETWEEN ABRASION PRESSURE AND ECOSYSTEM SERVICE PROVISION

Method 1: using the approach from the tNCAI – all possible combinations are set at 0.2 aside from combinations that have been identified as not possible or not assessed.

		Provisioning					Regulation and maintenance							Cultural			
		Farmed seaweed	Farmed fish and shellfish	Wild harvest of seaweed	Wild capture fisheries	Genetic material	Waste remediation	Erosion control	Coastal protection	Dispersal (gamete / larvae)	Nursery habitats	Pest and disease control	Carbon sequestration	Tourism, leisure and wildlife watching	Education	Spiritual / cultural	Existence / option use / bequest
A3 Infralittoral rock	A3.1 High energy infralittoral rock	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A3.2 Moderate energy infralittoral rock	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A3.3 Low energy infralittoral rock	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
A4 Circalittoral rock	A4.1 High energy circalittoral rock	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A4.12 Deep circalittoral sponge communities	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A4.2 Moderate energy circalittoral rock	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A4.3 Low energy circalittoral rock	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
A5 Sublittoral sediment	A5.1 Subtidal coarse sediment	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A5.2 Subtidal sand	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A5.3 Subtidal mud	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A5.36 Circalittoral fine mud	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A5.4 Subtidal mixed sediments	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	A5.43 Infralittoral mixed sediments	0	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Method 2: Application of the ecosystem services sensitivity approach adapted from Hooper *et al*., (2017) that accounts for the feature sensitivity to a pressure and level of ecosystem service provided by the feature

		Provisioning					**Regulation and maintenance**							**Cultural**			
		Farmed seaweed	Farmed fish and shellfish	Wild harvest of seaweed	Wild capture fisheries	Genetic material	Waste remediation	Erosion control	Coastal protection	Dispersal (gamete / larvae)	Nursery habitats	Pest and disease control	Carbon sequestration	Tourism, leisure and wildlife watching	Education	Spiritual / cultural	Existence / option use / bequest
A3 Infralittoral rock	A3.1 High energy infralittoral rock	0	0	0.5	1	0	0.2	0.5	0.5	0.5	1	0.5	0	0.5	0.2	0.2	0
	A3.2 Moderate energy infralittoral rock	0	0	0.5	1	0	0.2	0.5	0.5	0.5	1	0.5	0.5	0.5	0.2	0.2	0
	A3.3 Low energy infralittoral rock	0	0	0.2	1	0	0.2	0.5	0.5	0.5	1	0.5	0.5	0.5	0.2	0.2	0
A4 Circalittoral rock	A4.1 High energy circalittoral rock	0	0	0	1	0	0	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2	0.2	0
	A4.12 Deep circalittoral sponge communities	0	0	0	0.5	0	0.2	0	0	0.2	0.5	0.5	0	0.5	0	0.5	0
	A4.2 Moderate energy circalittoral rock	0	0	0	1	0	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2	0.2	0
	A4.3 Low energy circalittoral rock	0	0	0	1	0	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.2	0.2	0
A5 Sublittoral sediment	A5.1 Subtidal coarse sediment	0	0	0	0.5	0	0.2	0.2	0.2	0.5	0	0	0	0	0.2	0.2	0
	A5.2 Subtidal sand	0	0	0	0.5	0	0.2	0.2	0.2	0.5	0.5	0	0	0	0.2	0.2	0
	A5.3 Subtidal mud	0	0	0	0.5	0	0.5	0.2	0.2	0.5	0.5	0	0	0	0.2	0.2	0
	A5.36 Circalittoral fine mud	0	0	0	0.5	0	0.5	0.2	0.2	0.5	0.5	0.5	1	0.2	0.2	0.2	0
	A5.4 Subtidal mixed sediments	0	0	0	0.5	0	0.5	0.2	0.2	0.5	0	0	0	0	0.2	0.2	0
	A5.43 Infralittoral mixed sediments	0	0	0	0.5	0	1	1	0.2	1	1	1	0.5	0.5	0.2	0.5	0

ANNEX 7: ARTIFICIAL TIME-SERIES SHOWING CHANGE IN HABITAT CONDITON AS A RESULT OF INCREMENTAL 5% IMPROVEMENT IN LEVEL OF ABRASION EXPERIENCED BY SEABED HABITATS

% of habitats in each condition category	A (1)	B (0.75)	C (0.5)	D (0.25)	E (0)	Total		%good	%bad
2017									
A3.1	18.90	4.536952	5.19	39.93	31.45	100.00		23.43	71.38
A3.2	37.55	23.89018	0.00	5.35	33.21	100.00		61.44	38.56
A3.3	20.22	20.58877	3.76	2.84	52.59	100.00		40.81	55.43
A4.1	19.72	1.832203	12.53	38.29	27.63	100.00		21.55	65.92
A4.12	3.26	14.66034	0.00	5.96	76.12	100.00		17.92	82.08
A4.2	45.12	19.0298	9.25	4.12	22.48	100.00		64.15	26.60
A4.3	22.95	6.938227	2.72	1.81	65.57	100.00		29.89	67.38
A5.1	34.20	63.07	0.00	1.58	1.15	100.00		97.27	2.73
A5.2	18.52	38.30	10.90	12.82	19.46	100.00		56.81	32.28
A5.3	1.35	6.47	5.07	19.56	67.56	100.00		7.82	87.12
A5.36	0.00	12.95	0.90	13.14	73.00	100.00		12.95	86.14
A5.4	11.99	15.88	6.97	30.99	34.17	100.00		27.87	65.16
A5.43	29.34	2.26	7.08	4.26	57.06	100.00		31.60	61.32
							mean%	**37.96**	**57.09**
2016									
A3.1	13.90	5.965524	5.90	41.36	32.88	100.00		19.86	74.24
A3.2	32.55	25.31875	0.71	6.77	34.64	100.00		57.87	41.42
A3.3	15.22	22.01734	4.48	4.27	54.02	100.00		37.23	58.29
A4.1	14.72	3.260774	13.25	39.72	29.06	100.00		17.98	68.78
A4.12	0.00	14.3535	0.71	7.39	77.54	100.00		14.35	84.93
A4.2	40.12	20.45837	9.97	5.55	23.91	100.00		60.57	29.46
A4.3	17.95	8.366799	3.44	3.24	67.00	100.00		26.32	70.24
A5.1	29.20	65.93	0.71	2.29	1.87	100.00		95.12	4.16
A5.2	13.52	41.15	11.62	13.53	20.18	100.00		54.67	33.71
A5.3	0.00	5.67	5.78	20.27	68.27	100.00		5.67	88.54
A5.36	0.00	10.81	1.62	13.86	73.71	100.00		10.81	87.57
A5.4	6.99	17.31	7.68	32.42	35.60	100.00		24.30	68.02
A5.43	24.34	2.97	7.79	4.98	59.92	100.00		27.31	64.89
							mean%	**34.78**	**59.56**
2015									
A3.1	8.90	7.394095	6.61	42.79	34.31	100.00		16.29	77.10
A3.2	27.55	26.74732	1.43	8.20	36.07	100.00		54.30	44.27
A3.3	10.22	23.44591	5.19	5.69	55.45	100.00		33.66	61.14
A4.1	9.72	4.689345	13.96	41.15	30.49	100.00		14.41	71.63
A4.12	0.00	10.78207	1.43	8.82	78.97	100.00		10.78	87.79
A4.2	35.12	21.88694	10.68	6.98	25.34	100.00		57.00	32.32
A4.3	12.95	9.79537	4.15	4.67	68.43	100.00		22.75	73.10
A5.1	24.20	68.79	1.43	3.01	2.58	100.00		92.98	5.59
A5.2	8.52	44.01	12.33	14.25	20.89	100.00		52.53	35.14
A5.3	0.00	3.53	6.49	20.99	68.98	100.00		3.53	89.97
A5.36	0.00	8.67	2.33	14.57	74.43	100.00		8.67	89.00
A5.4	1.99	18.74	8.40	33.85	37.03	100.00		20.73	70.87
A5.43	19.34	3.69	8.51	5.69	62.77	100.00		23.03	68.46
							mean%	**31.59**	**62.03**
2014									
A3.1	3.90	8.822666	7.33	44.22	35.74	100.00		12.72	79.95
A3.2	22.55	28.17589	2.14	9.63	37.50	100.00		50.73	47.13
A3.3	5.22	24.87448	5.91	7.12	56.88	100.00		30.09	64.00
A4.1	4.72	6.117917	14.68	42.58	31.91	100.00		10.83	74.49
A4.12	0.00	7.210639	2.14	10.24	80.40	100.00		7.21	90.65
A4.2	30.12	23.31551	11.39	8.41	26.76	100.00		53.43	35.17

% of habitats in each condition category	A (1)	B (0.75)	C (0.5)	D (0.25)	E (0)	Total		%good	%bad
A4.3	7.95	11.22394	4.87	6.10	69.86	100.00		19.18	75.95
A5.1	19.20	71.64	2.14	3.72	3.29	100.00		90.84	7.02
A5.2	3.52	46.87	13.05	14.96	21.61	100.00		50.39	36.57
A5.3	0.00	1.39	7.21	21.70	69.70	100.00		1.39	91.40
A5.36	0.00	6.53	3.04	15.29	75.14	100.00		6.53	90.43
A5.4	0.00	17.16	9.11	35.27	38.46	100.00		17.16	73.73
A5.43	14.34	4.40	9.22	6.40	65.63	100.00		18.74	72.04
							mean%	**28.40**	**64.50**
2013									
A3.1	0.00	9.147351	8.04	45.64	37.17	100.00		9.15	82.81
A3.2	17.55	29.60446	2.86	11.06	38.93	100.00		47.15	49.99
A3.3	0.22	26.30305	6.62	8.55	58.31	100.00		26.52	66.86
A4.1	0.00	7.263325	15.39	44.00	33.34	100.00		7.26	77.35
A4.12	0.00	3.63921	2.86	11.67	81.83	100.00		3.64	93.50
A4.2	25.12	24.74408	12.11	9.84	28.19	100.00		49.86	38.03
A4.3	2.95	12.65251	5.58	7.52	71.29	100.00		15.61	78.81
A5.1	14.20	74.50	2.86	4.44	4.01	100.00		88.70	8.45
A5.2	0.00	48.24	13.76	15.68	22.32	100.00		48.24	38.00
A5.3	0.00	0.00	7.17	22.42	70.41	100.00		0.00	92.83
A5.36	0.00	4.38	3.76	16.00	75.86	100.00		4.38	91.86
A5.4	0.00	13.59	9.83	36.70	39.88	100.00		13.59	76.59
A5.43	9.34	5.11	9.94	7.12	68.49	100.00		14.46	75.61
							mean%	**25.27**	**66.98**
2012									
A3.1	0.00	5.5759226	8.76	47.07	38.59	100.00		5.58	85.67
A3.2	12.55	31.033035	3.57	12.49	40.36	100.00		43.58	52.85
A3.3	0.00	22.948008	7.34	9.98	59.74	100.00		22.95	69.72
A4.1	0.00	3.6918966	16.10	45.43	34.77	100.00		3.69	80.20
A4.12	0.00	0.0677814	3.57	13.10	83.26	100.00		0.07	96.36
A4.2	20.12	26.172653	12.82	11.27	29.62	100.00		46.29	40.89
A4.3	0.00	12.035908	6.30	8.95	72.72	100.00		12.04	81.67
A5.1	9.20	77.36	3.57	5.15	4.72	100.00		86.55	9.88
A5.2	0.00	46.10	14.47	16.39	23.03	100.00		46.10	39.43
A5.3	0.00	0.00	5.74	23.13	71.13	100.00		0.00	94.26
A5.36	0.00	2.24	4.47	16.72	76.57	100.00		2.24	93.29
A5.4	0.00	10.02	10.54	38.13	41.31	100.00		10.02	79.44
A5.43	4.34	5.83	10.65	7.83	71.35	100.00		10.17	79.18
							mean%	**22.25**	**69.45**
2011									
A3.1	0.00	2.004494	9.47	48.50	40.02	100.00		2.00	88.52
A3.2	7.55	32.461606	4.29	13.92	41.79	100.00		40.01	55.70
A3.3	0.00	19.37658	8.05	11.41	61.16	100.00		19.38	72.57
A4.1	0.00	0.1204681	16.82	46.86	36.20	100.00		0.12	83.06
A4.12	0.00	0	0.78	14.53	84.69	100.00		0.00	99.22
A4.2	15.12	27.601224	13.54	12.69	31.05	100.00		42.72	43.75
A4.3	0.00	8.4644794	7.01	10.38	74.14	100.00		8.46	84.53
A5.1	4.20	80.21	4.29	5.87	5.44	100.00		84.41	11.30
A5.2	0.00	43.96	15.19	17.11	23.75	100.00		43.96	40.85
A5.3	0.00	0.00	4.31	23.85	71.84	100.00		0.00	95.69
A5.36	0.00	0.10	5.19	17.43	77.29	100.00		0.10	94.72
A5.4	0.00	6.44	11.25	39.56	42.74	100.00		6.44	82.30
A5.43	0.00	5.88	11.37	8.55	74.20	100.00		5.88	82.75
							mean%	**19.50**	**71.92**
2010									
A3.1	0.00	0	8.62	49.93	41.45	100.00		0.00	91.38
A3.2	2.55	33.89018	5.00	15.35	43.21	100.00		36.44	58.56

% of habitats in each condition category	A (1)	B (0.75)	C (0.5)	D (0.25)	E (0)	Total		%good	%bad
A3.3	0.00	15.80515	8.76	12.84	62.59	100.00		15.81	75.43
A4.1	0.00	0	14.08	48.29	37.63	100.00		0.00	85.92
A4.12	0.00	0	0.00	13.88	86.12	100.00		0.00	100.00
A4.2	10.12	29.0298	14.25	14.12	32.48	100.00		39.15	46.60
A4.3	0.00	4.893051	7.72	11.81	75.57	100.00		4.89	87.38
A5.1	0.00	82.27	5.00	6.58	6.15	100.00		82.27	12.73
A5.2	0.00	41.81	15.90	17.82	24.46	100.00		41.81	42.28
A5.3	0.00	0.00	2.88	24.56	72.56	100.00		0.00	97.12
A5.36	0.00	0.00	3.86	18.14	78.00	100.00		0.00	96.14
A5.4	0.00	2.87	11.97	40.99	44.17	100.00		2.87	85.16
A5.43	0.00	1.60	12.08	9.26	77.06	100.00		1.60	86.32
							mean%	**17.30**	**74.23**

ANNEX 6: Detailed GIS method

The areas of EUNIS habitat within the Scottish Marine Region of Clyde were calculated using the mapping software QGIS 3.2.3.

Shapefiles of EUNIS habitats were downloaded from UKSeaMap (2016), and EUSeaMap JNCC, and compared on QGIS, to determine their suitability for the project. UKSeaMap (2016) was found to have higher resolution (100 m) than the EUSeaMap in areas surrounding Scotland, and was used for the project, with recommendation from JNCC. The associated raster Overall Confidence layer was also downloaded; the confidence layer gives a breakdown of the in the predicted habitats, into classes High, Moderate and Low. A shapefile displaying the Scottish Marine Regions was downloaded from data.gov.uk, and as an offshore boundary, the UK Exclusive Economic Zone (EEZ), approximately 200nm offshore, was downloaded from the UKHO Inspire Portal, as recommended by Marine Scotland.

Invalid geometries were detected by QGIS, in the UKSeaMap (2016) shapefile, and the EEZ boundary; these errors are often caused by breaks, or self-interactions in polygon boundaries, resulting in further errors when running clips to other shapefiles. These errors were fixed using the 'GRASS vClean' and then 'fix geometries' tools before any additional processing was undertaken.

To evaluate the EUNIS habitat areas and their confidence breakdown on a national scale, both the UKSeaMap (2016) and the Overall Confidence shapefiles were clipped to the EEZ boundary using the Geoprocessing tool 'Clip'. The areas of each EUNIS habitat polygon within the EEZ boundary were then calculated using the Field Calculator in the attribute table, the values were then exported as a CSV, and summed by EUNIS habitat in Excel. The areas were then converted into Km^2.

Next the Scottish Marine Regions shapefile was divided by region into separate polygons, using the 'Multipart to Singlepart' geometry tool. Following this, the UKSeaMap (2016) EUNIS shapefile was clipped to the Clyde region.

The Field Calculator in the Attribute Table of the newly clipped Polygon, 'EUNIS_ClydeRegion_Clip', was then used to calculate the areas of the individual EUNIS habitat polygons within the Clyde region. These values were then exported as a CSV, and aggregated by EUNIS habitat in Excel, and converted to Km^2, to give the total area of each EUNIS habitat in the Clyde Scottish Marine Region.

ANNEX 7: Indicator directory and appraisal worksheets

This project output is available online alongside this report. Search for the report title number at https://www.nature.scot/information-library-data-and-research/information-library

ANNEX 8: Abrasion case-study worksheets

This project output is available online alongside this report. Search for the report title number at https://www.nature.scot/information-library-data-and-research/information-library

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