Defining Marine Irreplaceable Habitats

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Further information

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Contents

List of tables

List of figures

Executive summary

Understanding which habitats should be considered irreplaceable in the marine environment is important for Natural England's marine casework and in new areas of work such as marine net gain. Knowing which habitats are irreplaceable will assist developers, planners and regulators to avoid habitats that cannot be replaced or recreated elsewhere in compensation for their loss.

The Marine Biological Association of the UK (MBA) was commissioned by Natural England to define marine habitat irreplaceability and define coastal and marine irreplaceable habitats. The commissioned project consisted of three stages:

Stage 1: A literature review on definitions of marine habitat irreplaceability.
Stage 2: Interviews with experts to further discuss and refine criteria for marine habitat irreplaceability.
Stage 3: Application of methodology to assess irreplaceability to UK Level 3 and 4 EUNIS habitats.

Stage 1: To inform the development of a definition of marine irreplaceable habitats the MBA team undertook a literature review that evaluated a wide range of sources. The review identified a number of criteria, primarily from biodiversity conservation science and initiatives that are relevant to assessing irreplaceability and the value of marine habitats. No specific definition of marine habitat irreplaceability was sourced that had been previously developed and applied. A shortened version of the review is provided in this project report as a technical appendix.

Stage 2: To support expert interviews of the project, the literature review was supplied as a stand-alone document to a range of experts in marine management, policy and ecology who were then interviewed. The expert interviewees provided a range of perspectives and comments. Key discussion points focussed on: i) criteria that should be included or excluded, ii) terminology and iii) applicability of a national generic definition of marine habitat irreplaceability based on the UK Marine Habitat Classification versus regional and local assessments.

The majority of interviewees suggested that core criteria for irreplaceability should include recovery and ease of restoration, rarity and uniqueness. Irreplaceability criteria based on connectivity, function and delivery of ecosystem services were considered important by interviewee, but are more applicable to regional and local decision making and management and not possible to assess based on the generic UK Marine Habitat Classification.

Following the interviews, the definition of irreplaceable marine habitats was refined to:

"Marine Irreplaceable habitats are those which cannot be successfully restored or created based on one or more of the following factors:

- They are *very difficult to restore or **very slow to recover:

    - *very difficult refers to feasibility and cost: difficult in-situ restoration would be that which requires significant technical input- including maintenance, supporting infrastructure and for which there are low rates of success.
    - **refers to very slow (>25 years) based on the MarLIN recovery scale and supported by information on pressures including abrasion, penetration and sediment disturbance and extraction.
- Create refers to ex-situ creation of the habitat (could be considered replacement) difficulties could result from availability of suitable habitats – supported by environmental context assessments or difficulty of creation- including translocation. Assume that habitats that are difficult to restore are also difficult to create.
- They may be nationally rare (based on extent, range and distribution) and/or have an unusual or rare environmental context."

This definition should be considered as a draft, the aim is to continue to discuss the use of this definition following publication of this report.

Stage 3: Based on previous projects and online UK Marine Habitat Classification resources, coastal and marine habitats that are present in English waters from mean high water out to the limit of the English Exclusive Economic Zone were identified. A systematic assessment of the irreplaceability of these was undertaken based on the following criteria: natural recovery potential (years to recover), rarity (based on number of records and regional distribution), and the environmental context (physical habitat, hydrodynamics) and rarity/distinctiveness of the biological assemblage. Categories were created to assess each criterion with weighted scores assigned to each category. Scores were summed to provide an overall score for irreplaceability for each habitat.

The irreplaceability assessment evaluated 32 UK EUNIS Level 3 broad-scale habitats, 79 EUNIS Level 4 biotope complexes and 225 EUNIS Level 5 biotopes. EUNIS Level 6 sub-biotopes were only assessed if they were considered likely to be irreplaceable based on characteristics such as the substratum and only twelve of these were assessed.

No threshold for scoring was identified at which a habitat moves from being considered replaceable to irreplaceable. Any habitat that scored highly for any of the assessed criteria may pose challenges for recovery, restoration or recreation. However, habitats that score above 40 were considered to score highly against the assessed irreplaceability criteria and, therefore, may be a combination of slow recovering, unfeasible to recreate, rare or unique.

Nine (28%) of the assessed EUNIS Level 3 broad-scale habitats scored highly (≥40) for irreplaceability. These were all habitats that were either characterised by long-lived slow-growing species, or were restricted physical features (seeps and vents), or deep-sea habitats (as these occur only in part of one of the assessed regions). At EUNIS Level 4, ten (12%) biotope complexes scored highly and at EUNIS Level 5, 21 (9%) biotopes were high scoring. Irreplaceability scores were frequently very variable between constituent biotopes within EUNIS Level 4 and 5 habitats. An assessment showed that most habitats that score highly against irreplaceability criteria are recognised through Marine Protected

Area (MPA) designations, conservation targets and lists of conservation interest habitats and features.

The project outputs include this technical report and an Excel spreadsheet, which provides an audit trail of the evidence and decisions made and summary scores.

Introduction

Project background

Understanding which habitats should be considered irreplaceable in the marine environment is important in Natural England's marine casework and in new areas of work such as marine net gain. There are increasing levels of activity in the marine environment, some of which are within our Marine Protected Areas (MPAs), which can lead to potentially adverse effects on the integrity of designated features. Knowing which habitats are more irreplaceable, informs an evidence based, proportionate environmental assessment process. In cases where it is determined that there is an overriding public interest in the development proceeding, competent and regulatory authorities need to work with developers to determine compensation measures for any adverse effects. Finding adequate compensation for subtidal marine habitats is not straightforward and to date has not been delivered in UK waters. The early identification of irreplaceable habitat will contribute to streamlining the examination process and assist developers, planners and regulators to avoid habitats that cannot be compensated, thus avoiding adverse effect on site integrity.

Furthermore, marine policy is being developed to ensure that the environment is left in a measurably better state following development than beforehand (termed "net gain"). The net gain concept in England originated in the terrestrial environment and builds on the approach of 'biodiversity offsetting' where conservation activities are designed to deliver biodiversity benefits that compensate for losses, in a measurable way (Defra 2012), and therefore ensure that there is 'no net loss' to biodiversity. Net gain sets a target higher than no net loss, in that habitat impacts must be offset to a level where there is a measurable positive improvement over what existed before the impact. Marine policy is being developed to possibly increase the scope of the net gain approach into the marine environment.

In order to develop Natural England's advice on this an understanding of marine irreplaceable habitats is required. Irreplaceable habitats in the terrestrial environment and down to Mean Low Water are afforded the highest level of policy protection from impacts of proposed development in the National Planning Policy Framework (NPPF). The government remains of the view that irreplaceable habitats should remain out of scope of biodiversity net gain. Their irreplaceable nature means that it is not possible to 'offset' them in such a way as to provide benefits to nature.

Project objectives

A definition and working principles of irreplaceable habitats in the marine environment has not been confirmed yet; the MBA have been commissioned to provide evidence and guidance on what marine irreplaceable habitats are. The project consists of three stages:

Stage 1: Literature review on definitions of marine habitat irreplaceability;

Stage 2: Interviews with experts to further discuss and refine criteria and following this a definition of marine habitat irreplaceability to be proposed;

Stage 3: Application of agreed definition to assess irreplaceability of England's full suite of marine and intertidal habitats out to England's Exclusive Economic Zone (EEZ).

Report Structure

This report consists of this introductory section followed by a section on existing definitions of irreplaceable habitat and a proposed definition of marine habitat irreplaceability developed by the literature review.

The Methodology section describes the literature review and interview methodology. The following sections on Stage 1 and Stage 2 provide a high-level overview of the literature review and interviews. Key sections of the literature review are provided in Appendix 6 and the collated interview notes are supplied in Appendix 7.

The Stage 3 section provides the criteria used to assess irreplaceability according to the proposed definition and discusses the application of the criteria.

The discussion section provides an overview of the project outputs and the application of the methodology and discusses limitations and conclusions.

Supplementary technical information is provided in the appendices. They supply:

- Irreplaceability scores for EUNIS Level 3 and EUNIS Level 4 and high-scoring EUNIS Level 5 and 6 habitats (Appendix 1);
- Literature review search terms (Appendix 2);
- Applicable habitat assessments sourced as part of the literature review (Appendices 3-5);
- Interview questions and notes (Appendix 6 and 8);
- Key literature review sections (Appendix 7); and
- An overview of the legislative framework for marine habitats (Appendix 9)

The criteria used to assess marine habitat irreplaceability were applied to UK EUNIS Level 3 and 4 marine habitats that are found between Mean High Water out to England's EEZ. The standalone Excel Spreadsheet (supplied separately) supplies scores and an audit trail of information used in the assessment. The habitat classification is the EUNIS Correlation table (v201801), available to download from JNCC: it provides details of the correlations between habitats in the EUNIS marine habitat classification with habitats in the JNCC Marine Habitat Classification for Britain and Ireland and also listed habitats from various other classifications. No alterations were made to that table to update recent taxonomic changes.

Definitions of Irreplaceable habitats

Few specific definitions of irreplaceability were identified with most of the literature returned from searches considering either multi-criteria assessments to support biodiversity conservation or relating to specific ecological or biological aspects e.g. function. Definitions identified are outlined below for habitats as well as a species definition of irreplaceability.

The National Planning Policy Framework (NPPF) definition of irreplaceable habitats is under review: currently irreplaceable habitats are defined as “Habitats which would be technically very difficult (or take a very significant time) to restore, recreate or replace once destroyed, taking into account their age, uniqueness, species diversity or rarity. They include ancient woodland, ancient and veteran trees, blanket bog, limestone pavement, sand dunes, salt marsh and lowland fen.” (p.68-9, National Planning Policy Framework, 2021).

Natural England is continuing to develop the definition of terrestrial irreplaceable habitats and it is anticipated that a definition will be published in late 2022. In their work to develop this definition, the group have found that habitats may be considered irreplaceable for several complex reasons such as restoration difficulty, rarity, environmental context and ecological distinctness.

The term irreplaceability has been used in the Programme of Work on Protected Areas (Convention on Biological Diversity) to identify Key Biodiversity Areas (KBAs) that are sites of global significance for selected species that are of global conservation significance. KBAs are identified using globally standard criteria and thresholds, based on the framework of vulnerability and irreplaceability widely used in systematic conservation planning (see next section for an outline). A site meets the irreplaceability criterion for KBAs if it maintains a globally significant proportion of a species’ total population at some point in that species’ lifecycle. A suggested threshold for significance is 1% or 5% of the species global population at a site (Langhammer and others, 2007).

Proposed definition of marine habitat irreplaceability

The literature literature review provided a definition of irreplaceability that was subsequently revised, following the interviews and discussions with the project steering group.

The draft definition was:

“Irreplaceable marine habitats are those which are not possible to restore, recreate or replace easily. They may be rare (based on extent, range and distribution), unique in terms of environmental context and fragile (vulnerable and slow to recover). The significance of irreplaceable habitats increases with value based on conservation interest, function and cultural heritage.”

The definition was subsequently revised, following the interviews (see Stage 2) and taking into account interviewee comments to the proposed definition:

"Marine Irreplaceable habitats are those which cannot be successfully restored or created based on one or more of the following factors:

- They are *very difficult to restore or **slow to recover: *very difficult refers to feasibility and cost: difficult in-situ restoration would be that which requires significant technical input- including maintenance, supporting infrastructure and for which there are low rates of success.
- **refers to very slow (>25 years) assessed based on the MarLIN recovery scale and supported by information on pressures including abrasion, penetration and sediment disturbance and extraction.
- Create refers to ex-situ creation of the habitat (could be considered replacement) difficulties could result from availability of suitable habitats – supported by environmental context assessments or difficulty of creation- including translocation. Assume that habitats that are difficult to restore are also difficult to create.
- They may be nationally rare (based on extent, range and distribution) and/or have an unusual or rare environmental context."

The revised definition focusses on the core criteria for assessing irreplaceability. It was considered that other criteria proposed in the draft definition around value were covered in other aspects of decision making and were not directly relevant to irreplaceability. As outlined in Appendix 8, interviewees identified considerable challenges to resolve in assessing function and cultural heritage and these values are likely to be regional or location and context specific. In terms of replacement and irreplaceability, a replacement habitat (if proposed), should have the same physical and biological character to the damaged/destroyed habitat to be considered a replacement.

Methodology

Literature review

The MBA team undertook a literature review looking at wide ranging sources globally to provide information to inform the development of a definition of marine irreplaceable habitats. The review was intended to include evidence to support the development of a definition and relevant supporting criteria. Reviewed aspects include ecological significance and functions of particular habitats and how irreplaceable or replaceable these are (considering redundancy), geographical significance, difficulty of recreation of the habitat elsewhere, risks and time frames.

The literature review began by trialling search terms (Appendix 2, Table 14) and identifying common key words within papers that were retuned by each search to identify any key concepts or attributes. Google Scholar (GS) and Web of Science were trialled as search engines. GS returned more results, than Web of Science which provided fewer results that were duplicated in the GS searches. The literature review used a two stage sift process to identify and prioritise the most relevant references. References were first downloaded into a library based on apparent relevance from title and a read of the text under each GS reference. A second sift then reviewed the reference by reading the abstract, or if this wasn't clear, a skim read of the document. References were sifted into five groups: not relevant, useful for application of criteria, priority 1, 2 and 3. First priority references for defining irreplaceability were those that were relevant to marine habitats or concept development. Papers relating to terrestrial and mobile species were considered low priority.

First priority papers were then reviewed. Key references were followed up from the papers and further searches of GS were undertaken to focus on particular aspects. For example, systematic conservation planning emerged from reviewed papers as a key search term to return information on irreplaceability, as used in relation to site selection for conservation.

We also mined relevant information sources such as the International Union for Conservation of Nature (IUCN) Red List criteria and the criteria used to identify candidate Nationally Important Marine Features and the Marine Life Information Network (MarLIN) evidence base to identify highly sensitive habitats.

It should be noted that the team focussed on an extensive review rather than an intensive review of a few aspects. The project was intended to provide a review of irreplaceability rather than habitat conservation, however, the majority of the literature reviewed related to marine conservation with some additional references for social-economic values and ecological concepts relevant to criteria for irreplaceability (recovery, rarity etc.).

Interviews

Expert opinion on defining irreplaceable habitats was sought through online interviews with staff from a range of organisations and academics. The literature review and questions (see Appendix 6 and 7) were supplied before the interviews. The interviews took the form of discussions with the interviewer providing a loose structure and ensuring that all the questions listed in Annex 6 were covered. Key points were elaborated and discussed, and the same examples of the project thinking were used in each interview to ensure the discussion on irreplaceability was consistent.

All interviews were recorded with the permission of the interviewees and attended by a note taker. These notes were then transcribed verbatim these transcripts were reviewed and the key points were then summarised more concisely. Notes from each interview were collated in turn, the verbatim transcript was checked again and where necessary the recorded interviews were re-watched where clarification was needed. The collated notes are summarised in the Stage 2 chapter and fuller comments are supplied in Appendix 8.

Stage 1 Literature review of marine habitat irreplaceability

Key sections of the literature review are provided in Appendix 7. The literature review identified a number of concepts regarding irreplaceability of marine habitats and evaluation.

The most extensive discussion of ‘irreplaceability’ as a concept relates to its use in systematic conservation planning. The focus in that context is narrow in that it focuses on optimising conservation solutions as described in Appendix 7.

Biodiversity conservation initiatives use some objectives and concepts relevant to the definition of irreplaceability. Various programs have developed biological, ecological, economic and social and governance criteria to identify areas of biodiversity importance (Vulnerable Marine Ecosystems, ecologically or biologically significant marine areas (EBSAs) for biodiversity conservation and IUCN/European Red Lists). A number of variables have been applied to quantify these criteria, although they vary across initiatives there is also a level of overlap with a relatively restricted number of criteria identified although there is variability in interpretation and proposed measures (Foley and others, 2010, Asaad and others, 2017). Criteria to assess biodiversity conservation value across a range of initiatives are summarised in Table 1. These are considered in more detail as indicators in Appendix 7 of this report.

Asaad and others (2017) reviewed 15 global initiatives that identified areas important for biodiversity conservation and the conceptual framework of the ecological and biological criteria used. They determined key criteria that were included in most initiatives to allow objective assessment of biodiversity value (see Table 1).

Table 1: Summary of biodiversity conservation indicators used in a range of assessments (note that blank cells represent the fact that the indicators are not used in that particular assessment).

	Unique/Rare	Function	Recovery	Complexity	Fragility /Vulnerability/	Structural complexity	Representativeness	Conservation interest (species)	Restricted range species or habitat
Vulnerable Marine Ecosystems	X	X	X	X	X	X			

	Unique/Rare	Function	Recovery	Complexity	Fragility /Vulnerability/	Structural complexity	Representativeness	Conservation interest (species)	Restricted range species or habitat
Ecologically and biologically significant areas	X	X			X			X	
IUCN/ European Red List					X				X
Asaad and others (2017) criteria to identify areas for biodiversity conservation	X	X			X		X	X	X

Core components of irreplaceability

The review of international and national biodiversity conservation initiatives identified a range of criteria that have potential application to assessments of habitat irreplaceability. These are outlined more fully in Appendix 7 and are:

- Recovery/Restoration potential;
- Rarity;
- Environmental Context (uniqueness);
- Fragility;
- Ecosystem function, services, goods and benefits; and
- Cultural and heritage values

Criteria excluded from a definition of irreplaceable marine habitats

The criteria naturalness and age were considered for inclusion within the definition of marine habitat irreplaceability but these were excluded from the final definition of irreplaceability. It was not clear how naturalness should be included and represented in an assessment of irreplaceable habitats and age was considered to overlap with other criteria as discussed in Appendix 7. Naturalness is captured in some of the EUNIS biotopes where disturbed biotopes are recognised. An example, is the organically enriched biotope EUNIS A5.336 (SS.SMu.ISaMu.Cap) which may become established as a result of anthropogenic activities such as fish farming and sewerage effluent but may also occur with natural enrichment as a result of, for example, coastal bird roosts (Connor and others, 1997). Biotopes that are subject to disturbance and that vary temporally and spatially were downweighted in the restoration scores for the irreplaceability assessment (see Stage 3 chapter). As disturbed biotopes are typically occupied by shorter-lived and faster recovering species the recovery and restoration scores reflect, to some extent, condition and age. Biotopes typical of less disturbed and more stable conditions are more likely to score higher on these irreplaceibility criterion.

The cost of habitat restoration was assessed separately to the definition of marine habitat irreplaceability with indicative costs presented in the results tables in Appendix 1 and as a separate tab in the supplied Excel workbook. Comparing costs between projects is difficult as these are seldom reported in full or broken down across various aspects of operations such as project planning, scientific expertise, monitoring and maintenance costs. Costs may be highly variable between operations and the degree to which costs may prevent restoration would vary between projects. In some instances, restoration costs may be only a small part of the overall budget and would not prevent restoration. Therefore, only indicative costs are provided and these are not used in the irreplaceability scoring but are included to provide an indicator of where the feasibility of restoration may be hindered by costs. Reported restoration costs were reviewed by Tillin and others, 2022) and the operation costs (per hectare) are based on that project (Table 2). Where none were available the costs were assigned based on the assumptions outlined in Table 3 (below).

Table 2: Restoration approach costs (direct operation costs) based on assessments in Tillin and others (2022)

Recovery option	Operation costs
Managed realignment; regulated tidal exchange; beneficial use of dredge sediments / sediment recharge; and manipulation of natural processes	Medium to High cost based on approach selected. By default, High cost was used.
Sediment capping applied to muds	Medium
Sediment capping applied to muddy sands/sandy mud	Medium

Recovery option	Operation costs
Mixed sediments may require a number of approaches, e.g. mud and gravel seeding.	Medium
Natural rock reef including rock pools but not caves	High
Natural rock with feasibility challenges: deeper, high energy, vertical rocks, overhangs	High
Boulder, cobble, shingle (intertidal)	Medium
Shell seeding	Medium
Gravel seeding, Dredging, Bed levelling	Low
Maerl translocation	Low
Kelp/seaweeds -transplanting, seeding, green gravel	Medium
Blue mussel artificial substrate, Blue mussel relaying	Low
Seagrass seed restoration (hessian bags) and shoot transplant	Medium
Sabellaria alveolata: boulder translocation	High
Native oyster approaches, reefs, translocating	High

Table 3: Cost assumptions for restoration approaches where evidence is unavailable (Note: not used in assessments but provided as additional information).

Costs	Operation
None	No examples

Costs	Operation
Low	Approaches that require offshore standard operations, requiring no infrastructure or living material and one-off interventions e.g. bed levelling
Medium	Approaches that require relatively simple operations without complex infrastructure, labour intensive actions and that are relatively short-term
High	Approaches that require complex operations with complex infrastructure or support from hatcheries, labour intensive actions and that are relatively long-term.

Impact thresholds for irreplaceability of broadscale habitats

No evidence was found by the literature review to assess thresholds of risk in terms of spatial area affected. Previous attempts to identify thresholds and 'tipping points' to assess resistance of habitats (Hall and others, 2008) and to identify specific percentage thresholds of change in extent or quality of near shore marine habitats (Crow and others, 2011) have been unable to develop scientifically supported limits.

In the absence of scientifically defensible limits, an assessment of irreplaceability is constrained to consider the likely scale of the feature and the scale of the feature impacted and the available information for sensitivity. Development of such risk assessments may however be limited by the lack of detailed habitat maps to identify the scale of the feature, the spatial and temporal resolution of activity data and uncertainties regarding the level of impact and recovery (the resistance and resilience of features). Assessments around scale of impacts are more applicable to regional and local assessments (see Discussion).

Literature review summary and irreplaceable habitat definition

The literature review identified a number of criteria relevant to assessing irreplaceability and value of marine habitats. Based on the literature review a definition of irreplaceability was advanced that considers two aspects: core criteria for irreplaceability rarity, environmental context (uniqueness) and fragility (considering sensitivity and difficulty of recovery, restoration or re-creation) and a component of value (conservation value, function, cultural heritage) in order to weight the significance of irreplaceable habitats. As outlined in the sections below, this defintion was subsequently revised and criteria relating to value (conservation sigificance, ecosystem services and cultural and heritage values) were excluded.

Stage 2 Interviews

The MBA interviewed 17 experts from a range of organisations (Defra, Natural Resources Wales, JNCC and Natural England). Academic experts from the Universities of Plymouth, Hull and Liverpool were also interviewed. The interviewees represented a wide range of expertise across benthic habitats (including deep-sea), marine management case work and policy. The collated notes are summarised below and fuller comments are supplied in Appendix 8.

No key evidence gaps or significant additional definitions of irreplaceability, concepts or criteria were identified by interviewees. There were very few additional measures or assessments identified, these are listed in Appendix 8 but have limited habitat coverage. No further sources of evidence on which to base assessments or to assess spatial thresholds of impact on habitats (i.e. at what point does a habitat become irreplaceable) were suggested by interviewees. There was a general consensus amongst interviewees that spatial scale assessments can only be undertaken at regional or local scales (see Discussion).

The definition of irreplaceability was discussed in all interviews and in some instances changes were suggested. A number of interviewees proposed that the definition should focus on core criteria for irreplaceability and that recovery should be a key aspect considered and that the proposed inclusion of aspects of recovery within fragility was confusing and unclear.

One of the most widely debated aspects of the proposed definition was the inclusion of criteria around function and/or ecosystem services and goods and benefits. While there was general support for including function as an aspect of irreplaceability, no clear consensus emerged on functions to include. However it was highlighted, that function and the value of functions and cultural heritage in particular are more relevant to regional scale or local assessments (see Discussion).

The proposed definition of irreplaceability was revised following the interviews to address comments around criteria and terminology. The proposed definition, as presented in an earlier section of this document, focusses on core criteria: recovery and restoration potential supported by assessments of rarity and the environmental context in which the habitat occurs. This definition is draft and will be subject to review following dissemination and discussion workshops.

Stage 3 Criteria and scaling or matrices for irreplaceability assessment

This chapter describes the stages in the development and application of irreplaceability scoring to English coastal and marine habitats. The outputs of this stage consist of this chapter and results sections including Appendix 1 which provides an overview of the results. A stand-alone Excel spreadsheet provides an audit trail for the assessment and scores.

Identifying England's full suite of marine and intertidal habitats out to the UK EEZ

To identify intertidal and marine habitats based on the UK and EUNIS marine habitat classifications that occur in English waters to the limit of the UK EEZ, the project used two key outputs previously developed by JNCC and Natural England. The first (Tillin and others, 2020a), identified offshore habitats that occur in English waters based on the UK and EUNIS Marine Habitat Classification. That project used regional divisions corresponding to the Charting Progress 2 reporting regions with some additional subdivision based on bioregions (see Figure 1). A list of relevant EUNIS biotopes was assigned to each bioregion based on a series of rules. Biotopes were listed as either 'Yes', 'Possible', 'Unlikely' or 'No' to show whether they were present in each bioregion, based upon survey data, environmental information, species records, literature and expert judgement. Two spreadsheets were produced as part of the JNCC project. The presence-absence spreadsheet (updated in July 2020 following some corrections) lists whether biotopes occur in each of the UK's offshore regional seas and sub regions. The biotope database provides the evidence behind these decisions. The current project adopted the same regions and the assessments on the presence of each habitat within a region (yes, no, possible), were matched to the UK Marine Habitat Classification in the Excel spreadsheet. The JNCC project focussed on offshore habitats, for the current project, relevant inshore habitats were identified using a spreadsheet on presence/absence of habitats within English regions. This unpublished dataset was supplied by Natural England.

This step identified which EUNIS habitats occur in the English inshore or offshore region for the irreplaceability assessment and this step and evidence is recorded in the Excel audit spreadsheet (supplied separately). It is acknowledged that there are data limitations on the extent of habitats and species in the marine environment (see discussion) and marine environments are dynamic and changing in response to climate and other factors. Further evidence may result in changes to the list of English habitats. The levels of the UK Marine Habitat Classification hierarchy are shown below in Table 4. To simplify terminology, where a range of EUNIS habitat levels were considered in this report the term 'habitat' is used to encompass all levels. Irreplaceability was assessed for English habitats at EUNIS Level 3, 4 and 5 and for some selected EUNIS Level 6 habitats.

Table 4: UK Marine Habitat Classification hierarchy showing corresponding EUNIS levels, name and brief description, edited from Connor et al. (2004).

EUNIS Level	Name	Description
Level 1	Environment (marine)	Highest level environment description, EUNIS includes terrestrial and freshwater as other categories.
Level 2	Broad habitats	Extremely broad divisions of national and international application for which EC Habitats Directive Annex I habitats (e.g. reefs, mudflats and sandflats not covered by seawater at low tide) are the approximate equivalent.
Level 3	Broad-scale habitats (Main habitats)	Main habitats in Connor et al. (2004) are frequently referred to as broad-scale habitats. These refer to very broad divisions, e.g. intertidal coarse sands, subtidal muds, which reflect major differences in biological character.
Level 4	Biotope complexes	These are groups of biotopes with similar overall physical and biological character.
Level 5	Biotopes	Typically distinguished by their different dominant species or suites of conspicuous species. This level (or the sub-biotope level), are equivalent to the communities defined in terrestrial classifications such as the UK National Vegetation Classification.
Level 6	Sub-biotopes	These are typically defined on the basis of less obvious differences in species composition (e.g. less conspicuous species), minor geographical and temporal variations, more subtle variations in the habitat or disturbed and polluted variations of a natural biotope. They will often require greater expertise or survey effort to identify.

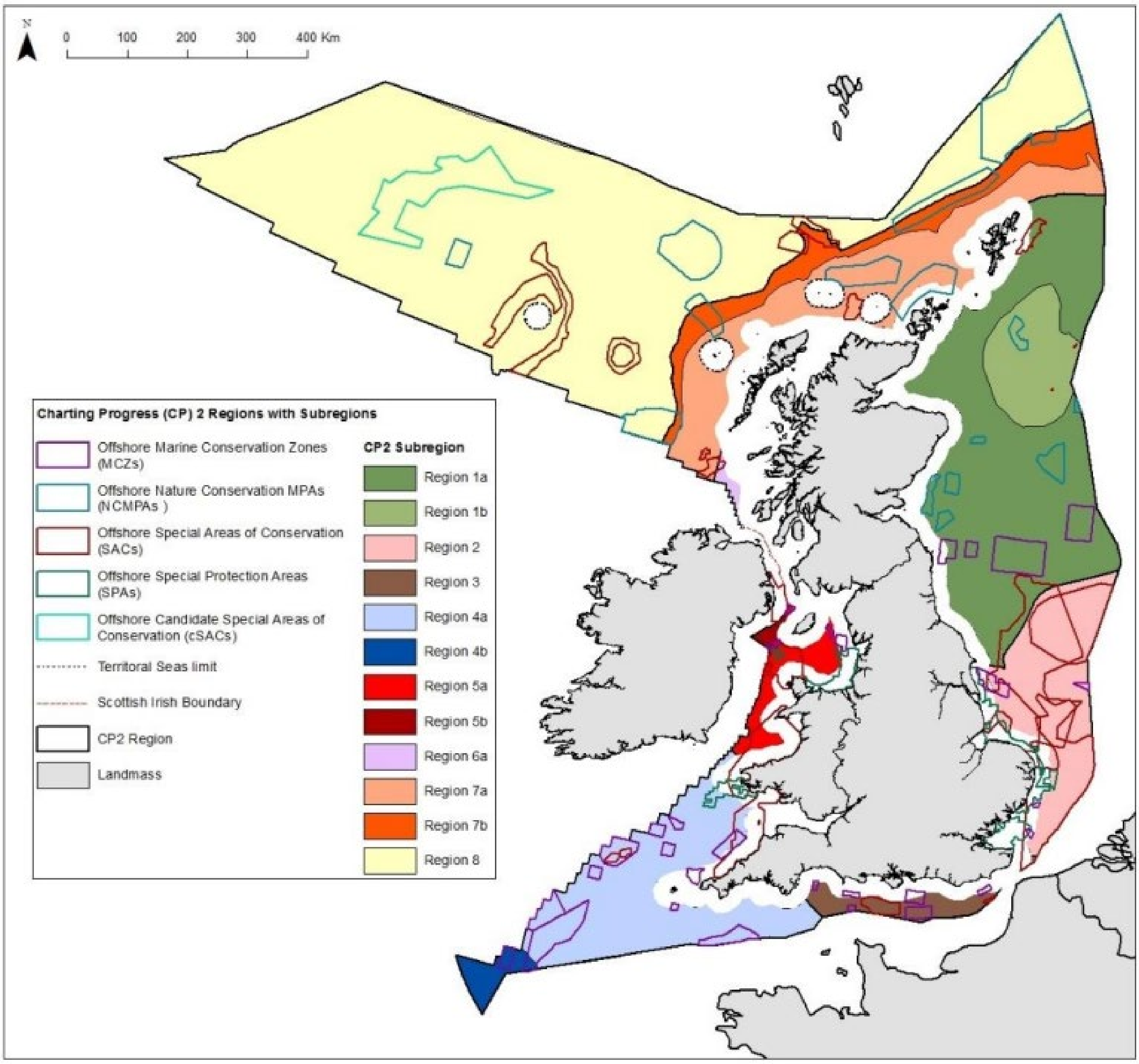

Figure 1: Charting Progress 2 reporting regions with additional subdivision based on bioregions identified by Tillin and others, 2022.

Applying recovery potential as a criterion for marine habitat irreplaceability (Criterion 1)

Recovery scores are an indication of the natural recovery potential in years and are based on the presumption that impacts or pressures have been removed to allow the habitat to recover. The MarLIN website provides extensive information to identify the recovery potential of UK habitats to a range of anthropogenic pressures. For all habitats the MarLIN recovery scores for the pressures abrasion, penetration and extraction were compiled to the audit spreadsheet from the downloadable database extract. The longest recovery period from these three pressures was used as an indicator of natural recovery potential. The recovery scores for all other pressure assessments were checked to identify if there were further pressures for which recovery was likely to be very low. Pressures which result in permanent changes to the environment; such as climate change, physical loss of habitat and introduction of invasive non-natives prevent recovery. Therefore, for these pressures, habitats are typically scored as having very low recovery. Recovery scores from these pressures do not represent natural recovery potential and were not considered within the assessment, as they would have skewed the results by scoring all habitats as slow-recovering.

Recovery potential was scored for each habitat as set out below in Table 7. MarLIN sensitivity assessments are based on EUNIS Level 5 biotopes and 6 and rarely EUNIS Level 4 biotope complexes. For most EUNIS Level 3 and 4 habitats, recovery is presented as a range, based on the constituent biotopes. For the assessment the lowest recovery rate was used for the irreplaceability assessment. Appendix 3 (Table 15) presents summary recovery rates for UK species and habitats identified as part of the literature review from MarLIN and Mazik and others (2015) for species with no or protracted recovery.

Applying ease of restoration as a criterion for marine habitat irreplaceability (Criterion 2)

The assessments for habitat restoration evaluates two aspects of restoration approaches:

- the availability of suitable methods (Criterion 2A) and
- the feasibility of restoring the habit or species (Criterion 2B)

Criterion 2A: Availability of suitable restoration methods

Restoration of a habitat involves two aspects: recovery or restoration of the physical habitat and hydrodynamics and restoration of the biological assemblage. The first requires eco-engineering approaches the second may require restocking of populations. For species populations that are common, widespread and capable of medium and long range dispersal, recovery may require only that the habitat is restored. For species that are only able to disperse over short-ranges or where populations have become isolated, active recovery may be required. Approaches include re-seeding, restocking and transplanting from donor populations or from nurseries and hatches. For each habitat we identified whether there was an approach to restore the characterising species populations and the habitat (focussed on substratum as a key factor in categorising marine habitats). For EUNIS Level 3 and 4 habitats that are defined based on substratum and energy the score for the habitat restoration approach was used in the assessment. For EUNIS level 3 4 and 5 habitats that also reference species, the highest of either the habitat or species restoration scores was used as this identifies what inhibits recovery and increases irreplaceability. For example, for the EUNIS Level 3 habitat A5.6 Sublittoral biogenic reefs, the lack of approaches to restore the biogenic habitat underlies the high score (see Table 5 for criterion scoring).

In general, approaches to restore species populations are limited to those that are of commercial value (lobsters, bivalves etc.) and habitats that are of high value, for example those that deliver services such as food provision (oyster reef) or flood management/coastal protection. The lack of identified approaches for species populations meant that most assessments that include species would have the same score. To overcome this lack of discrimination a set of scoring criteria were identified as described below and shown in Table 7.

Common habitats that were typical of disturbed environments and/or that are characterised by species with high natural recovery were scored as 5 for approach even if no suitable approaches were identified. This downweighting reflects the fact that restoration and recreation of such habitats would not be cost-effective and desirable.

Habitats were scored as 10 for restoration approach if the habitat was common but no method was identified for either the habitat or species, or the characterising species are slow recovering but habitat restoration is possible (and cost and feasibility are assessed).

To compensate for the lack of feasibility and cost scoring which would have otherwise downweighted the restoration scores, the habitat approach was scored as 20, if no method was identified to restore species and habitat and the habitat was considered to be relatively uncommon (scoring 5 or 10 for rarity) and recovery is high or medium.

Finally, habitats were scored as 30 for approach if no method was identified to restore the habitat and species and recovery is low or very low. These scores separate habitats that are likely to recover more quickly than those that have lower natural recovery potential and for which the lack of restoration approaches is more critical.

Criterion 2B: feasibility of restoring the habit or species

Feasibility evaluates the likelihood of success of approaches. To date, with some exceptions such as intertidal habitat creation using dredge sediments, the feasibility of restoring habitats is limited. Most projects to date have been small-scale and largely experimental, although progress is being made in developing methods that can be scaled over larger areas.

Table 5: Criteria 2A and 2B scores based on assessments in Tillin and others (2022)

Recovery option	Approach score	Feasibility
Managed realignment; regulated tidal exchange; beneficial use of dredge sediments / sediment recharge; and manipulation of natural processes	1	High
Sediment capping applied to muds	5	Medium
Sediment capping applied to muddy sands/sandy mud	5	Low
Mixed sediments may require a number of approaches, e.g. mud and gravel seeding.	5	Low
Natural rock reef including rock pools but not caves	1	High
Natural rock with feasibility challenges: deeper, high energy, vertical rocks, overhangs	5	Low
Boulder, cobble, shingle (intertidal)	1	Medium
Shell seeding	5	Low
Gravel seeding, Dredging, Bed levelling	5	Low

Recovery option	Approach score	Feasibility
Maerl translocation	5	Low
Kelp/seaweeds - transplanting, seeding, green gravel	5	Low
Blue mussel artificial substrate, Blue mussel relaying	5	Low
Seagrass seed restoration (hessian bags) and shoot transplant	5	Low
Sabellaria alveolata: boulder translocation	5	Medium
Native oyster approaches, reefs, translocating	5	Medium

Applying rarity as a criterion for marine habitat irreplaceability (Criterion 3)

Rare habitats occur only at a specific site or a small number of sites (Asaad and others 2017). Habitats that occur only in specific areas or have restricted ranges are highly significant for biodiversity conservation (Roberts and others, 2003). Such habitats would be irreplaceable, and their loss would increase risk of local and global species extinctions (Asaad and others, 2017). In order to assess rarity we used two sources of information which have good coverage of UK marine habitats. The original biotope classification records (97.06 classification, Connor and others, 1997a and b) identify for most habitats whether they are very common, common, uncommon, scarce and rare.

To further assess rarity, the JNCC biotope maps that are available on-line were used to assess the number of records for each habitat and regional distribution. Marine Recorder is a benthic survey data management system used widely within the UK's statutory nature conservation bodies to store and query benthic sample data across the UK's offshore and inshore waters. The biotope maps are based on a single UK-wide version of marine Recorder which is updated every six months. The current snapshot version is "2022-01-

24" and comprises 4,146 surveys, 249,815 biotope records. The current snapshot version is "2022-01-24" and comprises 4,146 surveys and 249,815 biotope records.

The scores for these two criteria (number of records and distribution) are shown in Table 7 and were combined to assess rarity as shown in Table 6 (below). This approach provided a structured, systematic method for assessing habitat rarity. Example maps of a common habitat and a rarer habitat are shown below (Figure 2 and 3). Only certain records were used in the assessment, uncertain records were not counted. Scores are recorded in the audit and score spreasheets in the supplied Excel workbook and summarised in the tables in Appendix 1.

Table 6: Combination of scores for number of records and regional distribution to assess rarity.

	No of records				
Regional distribution	**1 (>40)**	**2 >20-<40**	**3 >20-<40**	**4 (>5-<20)**	**5 (<5 records)**
1 (All regions)	1	3	3	5	10
2 (4 regions)	1	3	3	5	10
3 (3 regions)	3	5	5	5	10
4 (1-2 regions)	5	5	5	5	10
5 (1 region)	5	5	5	10	10

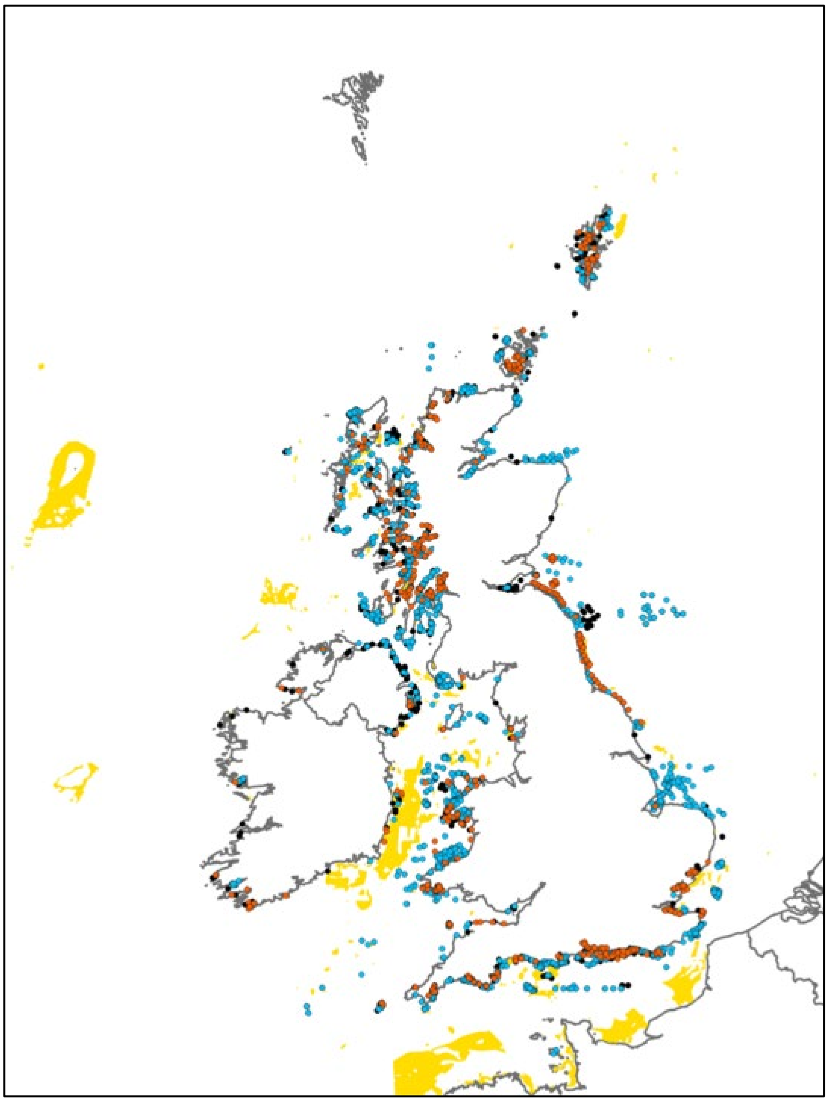

Figure 2. Map showing biotope records (as points red and blue =certain, black=uncertain, and polygons) for the broadscale (EUNIS Level 3) habitat A5.4 sublittoral mixed sediment. This habitat is common and scored 1 for rarity (see Appendix 1).

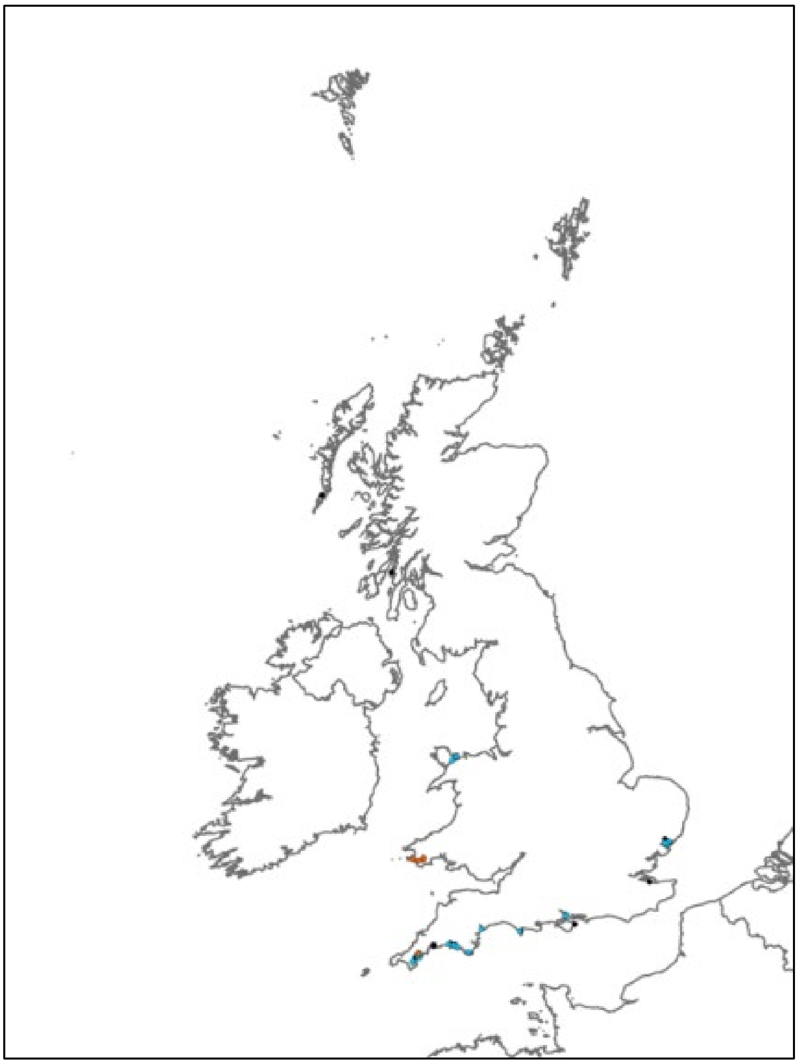

Figure 3. Map showing biotope records (as points red and blue =certain, black=uncertain,) for the EUNIS Level 4 biotope complex, A2.43 Species rich mixed sediment shores. This habitat scored 3 for rarity (see Appendix 1).

Applying environmental context as a criterion for marine habitat irreplaceability (Criteria 4)

Habitats that are unique cannot be easily recreated and they can be considered irreplaceable, especially where the extent of these is restricted. Considerations of environmental context overlap with rarity and it was therefore proposed from the literature review and interviews that the assessment of irreplaceability should consider uniqueness separately from rarity, with uniqueness identified as environmental context. The assessments of environmental context and biological assemblage therefore, provide an assessment of distinctiveness or uniqueness and indicate whether it is likely that the habitat could be recreated in other locations.

Three aspects were assessed, the physical habitat (depth and substratum) (Criteria 4A), hydrodynamics (wave exposure and currents) (Criteria 4B) and the biological assemblage (Criteria 4C). Each of these are scored as shown in Table 7 with results recorded in the

Excel audit spreadsheet. The assessments of the environment context were informed by information on the UK marine habitat classification and expert input. All three aspects of context, were scored as common, regionally restricted or rare.

The assessment for the biological assessment considered information on the likely scale of features, with those that are likely to be relatively small scale in extent and to form distinct biogenic habitats considered to have a higher weighting (score 2 or 3 depending on rarity). The distribution of species named as key characterising species were also considered (typically for EUNIS Level 5 biotopes). The online National Biodiversity Network (NBN) atlas is the UK's largest collection of freely available biodiversity data and this was consulted for a number of species to identify number of records and distribution.

Habitats that may support rare species were also considered to have more distinct biological assemblages. Rare species were identified from the UK spreadsheet of conservation designations available online from JNCC. This lists UK species and their designations, or 'badges'. Badges refer to species listed in international agreements, UK legislation, UK country lists, or which have a particular status (e.g. red list species, Nationally Rare or Scarce species). The list of species was compared to subtidal biotopes using the biological comparative tables of the Marine Habitat Classification System (Parry and others, 2015). This information identifies the habitats the rare species are found in. However, to avoid the size of the biological comparative table becoming unmanageable, JNCC only includes species recorded in more than 20% of the core biotope records for a given biotope (Connor and others, 2004). This means that species present in less than 20% of the biotope records are not included in the biological comparative tables, so that rarer species are likely to be under represented in the characterising species listed for biotopes.

The rare species assessment distinguishes between habitats for which species are key characterising species (whose absence would change the EUNIS category to which the biotope was assigned) and those for which the rare species may be present in some examples of the biotope and not others. Rare species were not considered specifically within the biological assemblage assessment (Criterion 4C) if they were present in few examples of that habitat. It is expected that site specific assessments would identify the presence of rare species where development is considered.

Criterion weighting for irreplaceability

The reviewed conservation initiatives (see Appendix 7) vary in scoring or ranking multi-criteria assessments. A number of initiatives assign an equal weight to their criteria and others set a threshold. Some initiatives considered an area important for biodiversity conservation if it met a single criterion (Convention on Biological Diversity (CBD), 2008), while others applied multiple criteria.

Achieving a high ranking for one of the core irreplaceability criterion, however, should be sufficient for habitats to be considered as potentially irreplaceable. Tabulating relative measures across multiple criteria as in the supplied Excel spreadsheet and tables in

Appendix 1 provide combined scores that provide an indication of where a particular habitat lies on the continuum from replaceable to irreplaceable.

Criteria and weighting scores used to assess the irreplaceability of marine habitats are shown below (Table 7). Two weighting scenarios were tested: one with lower weights and one with higher, as shown in Table 7. In this report only the results from the high scoring approach are provided and discussed as this approach was considered more successful at discriminating between habitats.

Table 7: Evaluation criteria and low and high score weightings used to assess the irreplaceability of marine habitats.

<table>
<tr><th>Criteria</th><th>Low Score Weighting</th><th>High Score Weighting</th></tr>
<tr><td rowspan="4">Core Criterion 1: Slow to recover- based on MarLIN abrasion resilience scores. (Scores based on lowest recovery where this is a range of EUNIS Records, i.e. for EUNIS Level 3 and 4)</td><td>1=High resilience (<2 years)</td><td>1=High resilience</td></tr>
<tr><td>2= Medium resilience (2-10 years)</td><td>2= Medium resilience</td></tr>
<tr><td>3=Low resilience (10-25 years)</td><td>5=Low resilience</td></tr>
<tr><td>4= Very Low resilience (>25 years)</td><td>10= Very Low resilience</td></tr>
<tr><td rowspan="5">Core Criterion 2A: Restoration potential Approach identified to restore/create: (no weighting change for high or low scenario)</td><td colspan="2">1= Relevant method applicable to species/habitat (based on the habitat for EUNIS Level 3 and 4- unless species are specified) and elements that underpin slow recovery EUNIS Level 5 and selected Level 6).</td></tr>
<tr><td colspan="2">5 =Potential but uncertainties around application, e.g. experimental studies, those used in other countries with different species or No method identified to restore habitat and species and recovery is high or medium and species are common and likely to recover rapidly (natural recovery potential outweighs restoration requirement)</td></tr>
<tr><td colspan="2">10 No method identified for either habitat or species, or species are rare or slow recovering but habitat restoration is possible (feasibility of restoration are assessed for habitats in this instance).</td></tr>
<tr><td colspan="2">20 No method identified to restore species and habitat but rarity (is ≥5) and recovery is high or medium</td></tr>
<tr><td colspan="2">30=No method identified to restore habitat and species and recovery is low or very low</td></tr>
<tr><td rowspan="2">Core Criterion 2B; Feasibility of restoration</td><td>1=Yes: approach tested, well understood and largely successful in recovering to a similar habitat.</td><td>1=Yes: approach tested, well understood and largely successful in recovering to a similar habitat.</td></tr>
<tr><td>2=Approach tested but limitations in understanding or rating success, or, approach tested but not in UK or with same species,</td><td>5=Approach tested but limitations in understanding or rating success or approach tested but not in UK or with same species,</td></tr>
</table>

Criteria	Low Score Weighting	High Score Weighting
	3 =Approach is subject to high failure rates and applicable only to specific locations, or is experimental and largely or wholly untested.	10 =Approach is subject to high failure rates and applicable only to specific locations, or is experimental and largely or wholly untested.
Cost of restoration methods (excluded from final assessment)	1=Low cost intervention with low capital and labour investment costs for implementation and maintenance (<£25,000/hectare).	1=Low cost intervention with low capital and labour investment costs for implementation and maintenance (<£25,000).
	2=Medium cost: Aspects of implementation or intervention require high investment (<£250,000/hectare).	5=Medium cost: Aspects of implementation or intervention require high investment (<£250,000/hectare).
	3=High cost or investment High (>£250,000/ha).	10=High cost or investment (>£250,000/ha).
Core Criterion 3: Rarity (Number of records and distribution)	**Number of records**	**Distribution**
	1= Multiple records (estimate >40 between regions)	1= Present in every region but some local restrictions, e.g. lack of rock habitat on east coast
	2=Multiple records >20<40	2=Present in most areas/regions but some gaps e.g. lacking in 1
	3=Multiple records (>5 but <20) dispersed	3=Present 3 regions not necessarily continuous
	4=Multiple records (>5 but <20) clustered	4=Present 1-2 regions not necessarily continuous
	5=<5 records	5= Present in one region
Criterion 4A: Environmental context (physical habitat, substratum or features such as caves or lagoons)	1= Common, widespread,	1= Common, widespread,
	2= Restricted regionally, present 1-2 regions only or likely to be very restricted in extent where it does occur	5= Restricted regionally, present 1-2 regions only or likely to be very restricted in extent where it does occur
	3= Setting relatively unique with limited extent and distribution (based on substratum, depth).	10= Setting relatively unique with limited extent and distribution (based on substratum, depth).
Criterion 4B: Environmental context (hydrodynamic, wave exposure, currents)	1= common, widespread	1= common, widespread,
	2= restricted regionally	5= restricted regionally,
	3= setting relatively unique with limited extent and distribution	10= setting relatively unique with limited extent and distribution

Criteria	Low Score Weighting	High Score Weighting
Criterion 4C: Environmental context biological assemblage (based either on key characterising species or the biological assemblage)	1= Nationally common, occurs around English coasts with high numbers of records, widespread,	1= Nationally common, occurs around English coasts with high numbers of records, widespread
	2= Restricted distribution may be regionally common, or widespread but few records	5= Restricted distribution may be regionally common, or widespread but few records
	3= Rare species	10= Rare species

Worked example of habitat irreplaceability

The approach to identifying relevant habitats is demonstrated below in Figure 4 and Table 8. These worked examples indicate for a broadscale-habitat and constituent biotope complexes and biotopes how criterion were scored.

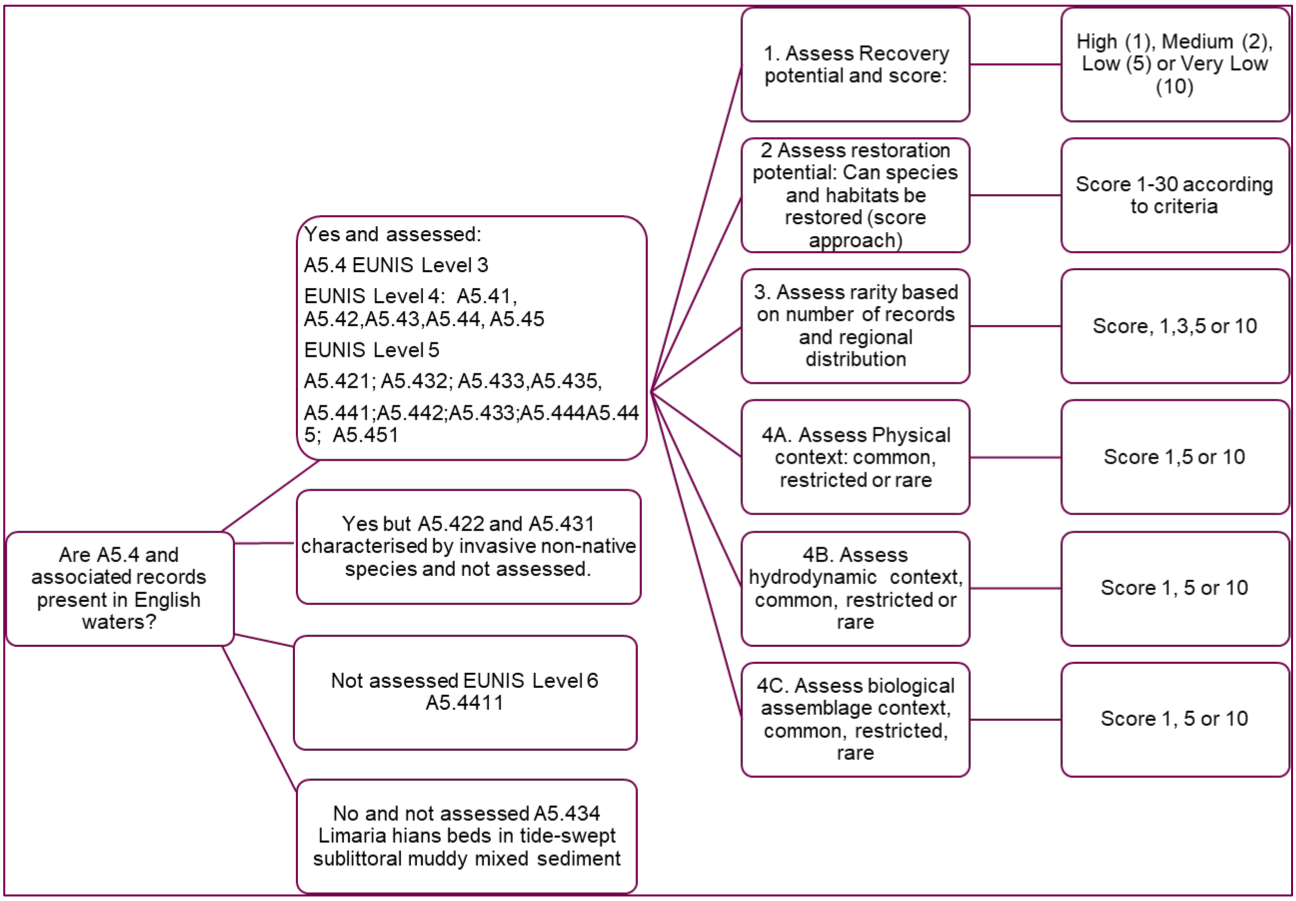

Figure 4: Overview of irreplaceability assessment from identifying relevant habitats for assessment to scoring against criteria. Final scores are summed to provide an overall irreplaceability score.

Table 8 Worked example of four mixed sediment habitats including child biotopes within the EUNIS broad-scale habitat A5.4 Sublittoral mixed sediments. Darker shading indicates the scores that are summed to produce the final irreplaceability score.

	A5.4 Sublittoral mixed sediments	**A5.43 Infralittoral mixed sediments**	**A5.432 *Sabella pavonina* with sponges**	**A5.435 *Ostrea edulis* beds**
Screening for relevance: Occurs inshore or offshore England?	Yes	Yes	Yes	Yes
Criterion 1: Recovery potential (Extraction pressure from MarLIN)	High to Very low (based on level 5)	Medium to Very low (based on Level 5)	Medium	Very Low
Criterion 1: Recovery potential Score (High)	**10**	**10**	**2**	**10**
Criterion 2A: Restoration potential: approach: Habitat	Recreating mixed substrata may be technically challenging and require a number of approaches, e.g. mud and gravel seeding.			
Criterion 2A: Restoration potential: species	No approaches relevant to species assemblage identified.	10: species: revised to 5 based on medium recovery in child biotopes or assisted recovery approaches for some species	10: species but revised to 5 based on medium recovery and rarity (not rare)	5: species, based on restocking, nurseries, habitat enhancement (cultch)

	A5.4 Sublittoral mixed sediments	**A5.43 Infralittoral mixed sediments**	**A5.432 *Sabella pavonina* with sponges**	**A5.435 *Ostrea edulis* beds**
		and rarity (not rare)		
Criterion 2A Restoration potential score	5	5	5	5
Criterion 2B Restoration feasibility easibility	Restoring mixed sediments is likely to be technically challenging.	Restoring mixed sediments is likely to be technically challenging	Restoring mixed sediments is likely to be technically challenging	Feasibility of oyster restoration increasing as approaches tested,
Feasibility score	10	10	10	5
Criterion 3: Rarity: No of records (Category)	1 (JNCC: Marine recorder snapshot)	1 (JNCC: Marine recorder snapshot)	3 (JNCC Marine recorder snapshot)	3 (revised based on NE biotopes)
Criterion 3: Rarity: Distribution (Category)	1 (JNCC: Marine recorder snapshot)	1 (JNCC: Marine recorder snapshot)	3 (JNCC Marine recorder snapshot)	No records JNCC, 3: NE Biotopes
Criterion 3: Rarity (combined)	1	1	5	5
Criterion 4A: Environmental Context (physical)	All 1: common habitat type (based on Marine recorder snapshot A5.4)			

	A5.4 Sublittoral mixed sediments	A5.43 Infralittoral mixed sediments	A5.432 *Sabella pavonina* with sponges	A5.435 *Ostrea edulis* beds
Criterion 4A: Environmental Context (physical)	1	1	1	1
Criterion 4B: Environmental context: (hydrodynamics)	All 1: common habitat (based on Marine recorder snapshot)			
Criterion 4B: Environmental Environmental context: hydrodynamics	1	1	1	1
Criterion 4C: Environmental Context (biological)	Rarity =1 and biotope and associated species are widespread and common	Rarity =1 and biotope and associated species are widespread and common	*Sabella pavonina* common and widespread, occurs in all English regions	*O. edulis* nationally rare (Hiscock, et al. 2013)
Criterion 4C: Environmental Context (biological)	Criterion 4C: Environmental Context (biological)	1	1	10
Irreplaceability Score (High)	29	29	25	37

Review of legislative framework for irreplaceable marine habitats

The framework of current marine policy and legislation that protects English marine habitats was reviewed and is outlined in Appendix 9. The relevant UK legislation which coastal and marine habitats are protected under include Special Areas of Conservation (SACs) Annex 1 habitats under the Habitats Directive, Habitats of Principal Importance (HPI) in section 41 of the Natural Environment and Rural Communities Act (NERC), Marine Conservation Zones (MCZs) Habitats of Conservation Interest (HOCI) and MCZ Broad Scale Habitats in the Marine and Coastal Access Act (MCAA). Some Habitats are recognized in The Marine Strategy Framework Directive (MSFD) Predominant Habitats list 2012 and Benthic Broad Habitats list 2017, as contributions to policy objectives to achieve Good Environmental Status (GES), these are not always also protected by UK legislation. All habitats assessed for irreplaceability are matched to relevant policies in the underlying EUNIS correlation table which was downloaded from JNCC and forms the basis of the audit spreadsheet (supplied separately). The relevant policies for habitats that are highly scored for irreplaceability are summarised in Table 12 in the Results and discussion section and presented in more detail in Appendix 9.

Results

Draft definition of irreplaceability

The project has proposed a draft definition of irreplaceability that was subsequently revised following the expert interviews and discussion with the project steering group.

The final definition proposed by this project is:

"Marine Irreplaceable habitats are those which cannot be successfully restored or created based on one or more of the following factors:

- They are *very difficult to restore or **slow to recover:

*very difficult refers to feasibility and cost: difficult in-situ restoration would be that which requires significant technical input- including maintenance, supporting infrastructure and for which there are low rates of success.
**refers to very low (>25 years) assessed based on the MarLIN recovery scale and supported by information on pressures including abrasion, penetration and sediment disturbance and extraction.

- Create refers to ex-situ creation of the habitat (could be considered replacement) difficulties could result from availability of suitable habitats – supported by environmental context assessments or difficulty of creation- including translocation. Assume that habitats that are difficult to restore are also difficult to create
- They may be nationally rare (based on extent, range and distribution) and/or have an unusual or rare environmental context."

Habitat irreplaceability assessment

The irreplaceability assessment evaluated 32 UK EUNIS Level 3 broad-scale habitats, 79 EUNIS Level 4 biotope complexes and 225 EUNIS Level 5 biotopes. EUNIS Level 6 sub-biotopes were only assessed if they were considered likely to score highly against the irreplaceability criteria, based on characteristics such as the substratum: only twelve of these were assessed. The full assessments for EUNIS Level 3, 4, and selected high-scoring level 5 and Level 6 habitats are presented in Appendix 1. No threshold for scoring was identified at which a habitat moves from being considered replaceable to irreplaceable. Any habitat that scored highly for any of the assessed criteria may pose challenges for recovery, restoration or recreation. However, habitats that score above 40 (using the high score weighting) were considered to score highly against irreplaceability criteria and are flagged using red shading in the results tables (see Appendix 1 Tables 11, 12 and 13). The highest scoring habitats (irreplaceability score >55) are shown below in Table 9.

Of the assessed EUNIS Level 3 broad-scale habitats, nine (28%) scored highly (>40) for irreplaceability. These were all habitats that were either characterised by long-lived slow-growing species (A5.5 Sublittoral macrophyte-dominated sediment, A5.6 Sublittoral biogenic reefs), restricted physical features (A5.7 Features of sublittoral sediments based on seeps and vents) or deep-sea habitats (as these occur only in part of one of the assessed regions). In general, the broad-scale habitats defined by substratum and energy alone are common (with the exception of deep sea habitats) and therefore have low scores in terms of uniqueness (environmental context). Those present in areas of higher-energy tend to recover quickly and those that are littoral or present in shallower areas are more readily restored.

Of the EUNIS Level 4 biotope-complexes, ten (12%) scored highly (≥40) against the assessed criteria. More irreplaceable EUNIS level 4 habitats are those that score highly across three or four of the criterion, although some were assessed as irreplaceable based largely on the difficulty of restoration. All littoral biotopes, tended to recover rapidly, be restorable and to be common. Species-poor biotopes-complexes, such as A2.22 Barren or amphipod dominated mobile sand shores (score 11), scored low for irreplaceability indicating the importance of the biological assemblage within the irreplaceability framework.

EUNIS level 4 sublittoral biotope-complexes that were assessed as more irreplaceable include: A4.12 Sponge communities on deep circalittoral rock, as these are characterised by rare and long-lived species that are slow to recover. Similarly, the biotope-complex A4.23 Communities on soft rock, are an example of a habitat that cannot recover from pressures that damage the habitat and the habitat is not readily restorable. The age of characterising species is captured in recovery scores and a number of habitats characterised by long-lived, slow-recovering species scored highly against irreplaceability criterion, these include A5.51 Maerl beds and A5.63 Circalittoral coral reefs and A6.62 Deep-sea sponge aggregations. In terms of environmental context: all biotope-complexes that received a high score in one or more categories (physical, hydrodynamics, biological assemblage) scored highly overall as these were likely to be difficult to recreate.

For the assessed biotopes at EUNIS Level 5, 21 (9%) scored 40 or more across the assessed criteria. The results follow the patterns described for EUNIS Level 4 biotope-complexes described above. Only two littoral biotopes were identified as scoring highly for irreplaceability, these are characterised by substratum types that are restricted in extent and not possible to restore (peat, clay and soft rock). Sublittoral sub-biotopes assessed as more irreplaceable were again slow recovering, less feasible to restore and to be relatively rare with a distinct biological assemblage. The assessments at this level identified more irreplaceable biotopes nested within less irreplaceable biotope-complexes (EUNIS Level 4).

The assessments indicate that habitats likely to be considered to be more irreplaceable are typically defined based on the biological assemblage present (EUNIS Level 5) rather than the physical characteristics and hydrodynamics that define the majority of EUNIS level 3 broadscale habitats and some EUNIS Level 4 biotope complexes. This difference would have been more apparent had the recovery scores for EUNIS Level 3 and 4 habitats been evaluated without reference to the associated biological assemblage.

While some of the high-scoring EUNIS Level 5 and 6 biotopes were nested within EUNIS Level 3 and 4 broadscale habitats and biotopes complexes that were identified as more irreplaceable, others were nested within more replaceable broadscale habitats and biotope-complexes. The range of underlying irreplaceability scores of EUNIS Level 5 and 6 biotopes and sub-biotopes are shown in the results tables (Table 11 and 12) in Appendix 1. From these it is apparent that there can be considerable variation in the degree of irreplaceability. Broad-scale habitats and biotope complexes with a wide variation in highest and lowest irreplaceability scores that weren’t assessed as highly irreplaceable, include A1.1 High energy littoral rock and A3.2 Atlantic and Mediterranean moderate energy infralittoral rock (both 40 point variation) and A4.1 Atlantic and Mediterranean high energy circalittoral rock (35 point variation). More narrowly defined EIUNIS level 3 habitats include A5.1 Littoral coarse sediments which include one EUNIS Level 4 child biotope and two level 5 sub-biotopes with irreplaceability scores of 12 and 27.

The high levels of variation within some broad-scale habitats and biotope complexes indicate that many irreplaceable habitats are nested within broad-scale habitats and biotope complexes and that at the EUNIS Level 3 broadscale habitat level there may be considerable uncertainty around the underlying irreplaceability of habitats.

Table 9: EUNIS habitats scoring >55 on the irreplaceability criterion. Cell shading is used to differentiate between scores with lighter and darker blue differentiating low and medium criterion scores. Higher scores are highlighted using red.

EUNIS code 2007	EUNIS level	Recovery timescale	Restoration method	Feasibility	Rarity	Physical habitat	Hydrodynamics	Biological assemblage	Score
A1.127 *Ceramium* sp. and piddocks on eulittoral fossilised peat	5	10	30	0	10	10	1	1	62
A1.223 *Mytilus edulis* and piddocks on eulittoral firm clay	5	10	30	0	5	5	1	5	56
A3.362 *Cordylophora caspia* and *Electra crustulenta* on reduced salinity infralittoral rock	5	1	30	0	10	10	1	5	57
A5.63 Circalittoral coral reefs (and child biotope A5.361)	5	10	30	0	10	5	1	10	66
A5.71 Seeps and vents in sublittoral sediments	4	10	30	0	5	10	1	1	57
A5.711 Bubbling reefs in the sublittoral euphotic zone	5	10	30	0	10	1	1	10	62
A5.712 Bubbling reefs in the aphotic zone	5	10	30	0	10	1	5	10	66
A6.1 Deep-sea rock and artificial hard substrata and child biotopes A6.11 and A6.14)	3	10	30	0	10	10	1	5	66
A6.2 Deep-sea mixed substrata	3	10	30	0	10	10	1	5	66
A6.3 Deep-sea sand	3	2	30	0	10	10	1	5	58

EUNIS code 2007	EUNIS level	Recovery timescale	Restoration method	Feasibility	Rarity	Physical habitat	Hydrodynamics	Biological assemblage	Score
A6.4 Deep-sea muddy sand	3	2	30	0	10	10	1	5	58
A6.5 Deep-sea mud	3	2	30	0	10	10	1	5	58
A6.6 Deep-sea bioherms (including child biotopes A6.611 and A6.62)	3	10	30	0	10	10	1	5	66

Overview of legislative framework applicable to more irreplaceable habitats

Many of the 45 habitats which have high irreplaceability scores (score 40 and above) are protected under UK legislation and recognized in the alignment of policy goals and frameworks (see summary Table 10 below and Appendix 9). For example, the biotope A1.127 *Ceramium* sp. and piddocks on eulittoral fossilised peats (irreplaceability score 57) is recognised by all relevant UK legislation.

The biotopes A3.362 *Cordylophora caspia* and *Electra crustulenta* on reduced salinity infralittoral rock and A3.363 *Hartlaubella gelatinosa* and *Conopeum reticulum* on low salinity infralittoral mixed substrata also have high irreplaceability scores (57 and 51) and are not only protected by relevant UK legislation and policy but are also Nature Conservation Marine Protected Areas (NCMPA) Search Features and Priority Marine Features and are therefore protected under specific Scottish marine legislation. This is a positive outcome as it shows the habitats with the highest irreplaceability scores are being protected by UK legislation.

There are some gaps in designations amongst the high scoring irreplaceable habitats. The Broadscale-habitat A5.7 Features of sublittoral sediments (irreplaceability score 51) is the only habitat type not protected by any UK legislation or aligned in UK policy. In addition to this, another notable gap is for A4.71 Communities of circalittoral caves and overhangs and the child biotope A4.711 Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock (score 48 and 52 respectively). These habitat types are recognised by the MSFD contributing to GES objectives and are characterised as Annex 1 reef habitats in the Habitats Directive, however are not protected by any other UK legislation. There are SACs which protect reefs as a marine interest feature, nevertheless because SACs are site specific, there could be natural occurrences of these habitats which are protected and fall outside of the SAC protection.

Maerl beds are also recognised in the European Red List, and are classed as vulnerable. However, it should be recognised in the exercise to identify Red List biotopes (Gubbay and others. 2016), 60% of the researched biotopes came out as 'Data deficient' which means that potentially irreplaceable habitats may not have been categorised. A list of European Red List habitats, applicable to the UK are provided in Appendix 4 (Table 16).

Table 10: Protections and statutory designations for more irreplaceable habitats (irreplaceability score >40). Habitats for which the parent or child biotopes are designated are shown with grey shading and '*', blank cells represent no statutory designation, a more detailed table is provided in Appendix 9.

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A1.127 *Ceramium* sp. and piddocks on eulittoral fossilised peat		Y	Y	
A1.2143 *Fucus serratus* and piddocks on lower eulittoral soft rock	Y	Y	Y	
A1.223 *Mytilus edulis* and piddocks on eulittoral firm clay		Y	Y	
A1.4114 *Cystoseira* spp. in eulittoral rockpools				
A3.2113 *Laminaria digitata* and piddocks on sublittoral fringe soft rock		Y	Y	
A3.217 *Hiatella arctica* and seaweeds on vertical limestone / chalk		Y	Y	
A3.362 *Cordylophora caspia* and *Electra crustulenta* on reduced salinity infralittoral rock		Y		Y
A3.363 *Hartlaubella gelatinosa* and *Conopeum reticulum* on low salinity infralittoral mixed substrata		Y		Y
A4.12 Sponge communities on deep circalittoral rock				Y

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A4.121 *Phakellia ventilabrum* and axinellid sponges on deep, wave-exposed circalittoral rock		Y	Y	Y
A4.1311 *Eunicella verrucosa* and *Pentapora foliacea* on wave-exposed circalittoral rock		Y	Y	
A4.23 Communities on soft circalittoral rock		Y	Y	
A4.231 Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay		Y	Y	
A4.232 Polydora sp. tubes on moderately exposed sublittoral soft rock		Y	Y	
A4.233 Hiatella-bored vertical sublittoral limestone rock		Y	Y	
A4.71 Communities of circalittoral caves and overhangs				
A4.711 Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock				
A5.51 Maerl beds	Y	Y	Y	Y
A5.511 *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	Y	Y	Y	Y
A5.512 *Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel	Y	Y	Y	Y
A5.513 *Lithothamnion corallioides* maerl beds on infralittoral muddy gravel	Y	Y	Y	Y
A5.5343 *Ruppia maritima* in reduced salinity infralittoral muddy sand		Y	Y	Y
A5.6 Sublittoral biogenic reefs	*	*	*	*

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A5.62 Sublittoral mussel beds on sediment	*	*	*	*
A5.621 *Modiolus modiolus* beds with hydroids and red seaweeds on tide-swept circalittoral mixed substrata	Y	Y	Y	Y
A5.622 *Modiolus modiolus* beds on open coast circalittoral mixed sediment	Y	Y	Y	Y
A5.623 *Modiolus modiolus* beds with fine hydroids and large solitary ascidians on very sheltered circalittoral mixed substrata	Y	Y	Y	Y
A5.624 *Modiolus modiolus* beds with *Chlamys varia*, sponges, hydroids and bryozoans on slightly tide-swept very sheltered circalittoral mixed substrata	Y	Y	Y	Y
A5.63 Circalittoral coral reefs	Y	Y	Y	Y
A5.631 Circalittoral *Lophelia pertusa* reefs	Y	Y	Y	Y
A5.7 Features of sublittoral sediments	*	*	*	*
A5.71 Seeps and vents in sublittoral sediments		Y	Y	Y
A5.711 Bubbling reefs in the sublittoral euphotic zone		Y		Y
A5.712 Bubbling reefs in the aphotic zone		Y		Y
A6.1 Deep-sea rock and artificial hard substrata	Y		Y	Y
A6.11 Deep-sea bedrock	*	*	*	*
A6.14 Boulders on the deep-sea bed	*	*	*	*
A6.2 Deep-sea mixed substrata	Y		Y	Y
A6.3 Deep-sea sand	Y		Y	Y

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A6.4 Deep-sea muddy sand	Y		Y	Y
A6.5 Deep-sea mud	Y		Y	Y
A6.6 Deep-sea bioherms	*	*	*	*
A6.61 Communities of deep-sea corals	Y	Y	Y	
A6.611 Deep-sea *Lophelia pertusa* reefs	Y	Y	Y	Y
A6.62 Deep-sea sponge aggregations	Y	Y	Y	Y

Discussion and limitations

Evidence used to assess irreplaceability

The irreplaceability assessments are based on the UK National Marine Habitat Classification, aligned to the EUNIS classification based on the EUNIS correlation tables available from JNCC. The assessments relied on information sources that are readily available and provide consistent or systematic assessments for a wide range of habitats. Information sources include the MarLIN website (recovery scores), the Marine Recorder snapshot (available via JNCC) and recent project outputs including habitat distribution assessments and restoration assessments (Tillin and others, 2020 and Tillin and others, 2022). The project also used expert judgement to assess distribution.

Within the project timescale it was not possible to complete an extensive review to support irreplaceability assessments. The JNCC biotope descriptions were referred to and key characterising species were considered in the assessments where possible (typically through distribution assessments using the NBN atlas) with information on rare species added from the JNCC Conservation designation work. The biotope descriptions refer only to species recorded in more than 20% of core biotope records (Connor and others, 2004) and the assessments do not reference every species listed on the JNCC website as characterising. It is possible that biotopes that score low in terms of irreplaceability may provide habitat in some instances for rare species. In some regions these associations may be relatively consistent compared to others, or in some locations biotopes may provide habitat for rare species or unique combinations of species and be unusually species rich. These regional and local variations are not captured in the assessments that are based on the generic national framework. This limitation should be considered when using assessments and local and regional experts may be able to provide additional insight and recommendations.

Assessing recovery

The recovery assessments provide a guideline to natural recovery potential. The MarLIN project identifies a number of limitations regarding the sensitivity assessments produced by the project and that are applicable to the recovery assessments used to assess irreplaceability. The assessments are generic and not site-specific and therefore do not take into account factors such as connectivity and larval supply that may determine recovery. They are based on the likely effects of a pressure on a ‘hypothetical’ population in the middle of its ‘environmental range’ and species and habitats in more marginal areas that are less suitable may not recover as rapidly. They are general assessments that indicate the likely effects of a given pressure (likely to arise from one or more activities) on habitats but do not take account of spatial or temporal scale or the scale of the feature. Recovery from an impact that removed all of the habitat from an area, or that removed key connected habitats, could result in prolonged or no recovery and so the recovery scores presented could underestimate the natural recovery potential. Recovery is assumed to have occurred if a species population and/or habitat returns to a state that existed prior to the impact of a given pressure, not to some hypothetical pristine condition. Furthermore, sensitivity assessment assumes recovery to a ‘recognizable’ habitat or similar population of species, rather than presuming recovery of all species in the community and/or total recovery to prior biodiversity. Recovery scores may therefore underestimate the time required for rarer species to recover.

Assessing restoration: evidence gaps and uncertainties

Restoration techniques and application are more developed for coastal and intertidal habitats and are driven by coastal protection efforts to manage flood risks and coastal erosion (Elliott and others, 2016). Examples include the restoration of saltmarsh through managed realignment and the placement of dredged sediments to replenish beaches and sediment flats (beneficial re-use) and through eco-engineering approaches such as the creation of artificial rock habitats. Habitat restoration efforts for the subtidal have focussed on biogenic habitats characterised by eco-engineers, such as seagrass and bivalve beds (particularly oysters). Efforts for restocking fisheries such as release of captive bred species are also applicable to restoration of biological populations. The focus on species that create habitats with high value to humans (high level of ecosystem services and/or commercial fisheries) means that for most species there are no applicable techniques developed. Outside of coastal, enclosed areas, restoration efforts have largely taken the form of removing pressures and/or designating protected areas to allow habitats and species to recover naturally (Geist and Hawkins, 2016). These limitations mean that many habitats score highly against the approach criterion as no suitable approaches are available.

Feasibility of restoration is also difficult to assess given the variability of techniques and that feasibility is likely to be variable as it depends on location specific factors, which include characteristics of the ecosystem, approaches applied and factors such as proximity and availability of supplies of material such as natural rock quarries, aggregate and active dredging areas to supply materials (Bayraktarov and others, 2016). Many approaches are largely experimental and unsuitable for restoration of large areas due to costs and other factors. While natural recovery rates and rarity may indicate the likelihood of natural recovery potential and therefore species recolonisation and recovery rates for most populations, the trajectory of establishment and reintroduction cannot be controlled. For example, a natural rock reef may be constructed but the species establishing on this may be subject to stochastic factors influencing recruitment such as supply of larvae from adjacent populations as well as factors such as competition and predation. The presence of invasive non-native species may further influence and in worst-cases prevent recovery. Populations may undergo successional changes and changes over time (Sheehan and others, 2020). In many cases, recreating an exact habitat match may be challenging and the impacts this may have on species recolonisation may not be fully understood. Negative feedbacks such as sediment instability and increases in wave exposure may result from loss of complex, biogenic habitats and prevent or inhibit restoration (de Paoli and others, 2015). The restoration scores must therefore be seen as indicative only and low scoring habitats may not necessarily be feasibly restored at specific locations or to current extents.

Spatial extent of habitats

A key evidence gap for assessing irreplaceability is the lack of evidence for the spatial extent of habitats and associated species. This data gap is particularly apparent for habitats that occur offshore in deeper waters and which are less easily surveyed. The offshore regions of the UK largely consist of sediment plains that are less well-studied than inshore areas and there is limited information on the distribution of many biotopes. For these habitats in particular reported extents may underestimate the true extent of the habitat. Records may also be out of date. This evidence gap is applicable to the scoring of rarity and also environmental context.

Given the dynamic nature of marine habitats, it is possible that distributions and ranges are shifting and may change over time. This may result in habitat extents reducing or expanding and habitats may also shift regional distributions. In some instances this may change the context for irreplaceability assessments. For example the biotope A4.134 *Neocrania anomala* and *Protanthea simplex* on sheltered circalittoral rock, was classified as not present in English inshore/offshore based on information from the NBN atlas, Tillin et al 2020 and the Natural England assessments. This biotope is common in Scotland, as are a number of others that require the sheltered habitat provided by sealochs. Should an isolated example of this biotope be found in England it would be irreplaceable in an English context but not a Scottish context.

National vs local or regional application.

A number of interviewees raised the issue that application of a national assessment of marine irreplaceable habitats had limitations and that regional or local assessments could apply more criteria for irreplaceability. Examples provided by interviewees of how and why regional or location specific assessments can capture additional information, include:

Habitat condition is variable between locations. For example, no two maerl beds are the same and exactly the same set of maerl beds in them, or the same architecture. Some types of maerl bed have extremely high coverage of live maerl, like St Mawes Bank in Falmouth, and in Scotland are precious as most maerl beds have low cover because of storm disturbance. There may also be regional differences in the recovery potential of the same biotope and that are not accounted for in the generic MarLIN assessments. For example, the *Eunicella verrucosa* and *Pentapora foliacea* biotope (A4.1311) and more particularly *E. verrucosa* could recolonise very quickly on the southern coast of south-west England but is in a poor condition at Lundy, mainland North Devon (and Skomer) and in a regional assessment should be considered irreplaceable there.

Cultural heritage values that were excluded from the definition of irreplaceability are likely to be regional or site rather than habitat specific and suitable for local site management rather than national application for EUNIS Level 3 and 4 habitats. Some assessments that could be proposed include accessibility (for divers and snorkelers, heritage links such as particular food or other materials obtained (some collection may be on-going) and site-specific considerations (for more localised assessments).

Irreplaceability may depend on a combined suite of factors in a specific location, assessments that consider these singly would not necessarily identify the uniqueness and therefore irreplaceability of a location. For example, there is a sandbank close to Flamborough Head with a good sandeel population within an easy flying range of the seabirds close to the cliffs where the birds nest at in Flamborough Head. If this sandbank was further offshore the seabirds couldn't access it as easily. From the perspective of seabirds, the combination of nesting site and sandeel population makes the sandbanks at that location irreplaceable.

Assessments of spatial scale are possible at the regional and local level. For example, there are maerl beds in Orkney that are far larger than the St Mawes Bank in Falmouth which is the best and only example of a maerl bed in England. The irreplaceability of the St Mawes maerl bed and the degree to which impacts may be permitted is different to the Orkney maerl beds.

Connectivity and regional importance varies between habitats of the same type in different locations. A habitat which is extensive and distributed widely in a region is expected to recover more easily and expect it to occur in other places – If it occurs in isolated patches restoration or creation becomes much more difficult (due to sediment supply or larval dispersal limitations).

These examples demonstrate that scale of application (national vs regional vs local) influences the criteria that can be incorporated into assessments of irreplaceability.

There is a consensus that there is no evidence to assess spatial scales or thresholds for a generic, national index but that this would be more tractable (but still without defensible evidence) at regional or local scales.

Overcoming uncertainty around underlying irreplaceability variation.

Within the EUNIS Level 3 broadscale habitats, the constituent biotope complexes and biotopes may represent a wide range of irreplaceability scores. As there are no geographical/regional considerations within the biotope classifications (EUNIS Habitat Classification and the UK Marine Habitat Classification), a regional or site irreplaceability assessment using the broadscale habitat irreplaceability score ranges may be based on biotopes that do not occur in that particular area. Conversely, although a broadscale habitat may be listed (in directives, conventions and statutes) as 'rare, scarce, threatened, fragile or vulnerable (sensitive)' some biotopes within that broad habitat may be robust and/or have high recovery potential. To reduce uncertainty and exclude irrelevant biotopes from regional level assessments, the underlying biotope composition and associated variation could be reduced by linking the irreplaceability scores to refined lists of potential biotopes in each region and sub-region. Suitable region and bioregion assessments have been created for inshore areas (Hiscock, 2016) and the UK offshore region (Tillin and others, 2020).

Conclusions

The project has systematically assessed habitats at EUNIS Level 3, 4 and 5 against criteria for habitat irreplaceability. While not identifying a cut-off threshold at which habitats can be definitively described as irreplaceable, the project has identified habitats that can be described as more irreplaceable against the draft definition. Habitats that are more irreplaceable are slow recovering, less feasible to restore and are relatively rare with a distinct environmental context including biological assemblage. Many of the more irreplaceable habitats are recognised by conservation designations but this does not mean that they are protected at every site at which they occur. Any habitat that scored highly for any of the assessed criteria may pose challenges for recovery, restoration or recreation. However, habitats that score above 40 were considered to score highly against the assessed irreplaceability criteria and, therefore, may be a combination of slow recovering, unfeasible to recreate, rare or unique

There are limitations for the scientific evidence on the distribution and extent of habitats and associated species and for the ecology of features and their responses to environmental pressures on which the irreplaceability assessments have been based.

Habitats that may have been assessed as largely replaceable based on the generic national framework, may be considered irreplaceable at specific locations or regions as they may host rare species or unique combinations of species or may support unique and irreplaceable functions or services. This project was carried out to inform national policy and understanding how to define irreplaceable marine habitats. The assessments are generic and the section above highlights some examples of site-specific and regional considerations that would be considered for local projects, plans and management. It is recommended that application of assessments at a site-specific, regional or local level is supported by coastal and marine experts.

Appendix 1. Marine irreplaceable habitats

Table 11: Irreplaceability scoring for EUNIS Level 3 broad-scale habitats. Cell shading is used to differentiate scores with lighter and darker blue differentiating low and medium criterion scores. Higher scores are highlighted using red. The score range refers to the underlying EUIS Level 4, 5 and 6 biotopes and shows the underlying variability of irreplaceability in constituent biotopes. The number in brackets refers to the number of level 4, 5 and 6 constituent child biotopes, not all of these are assessed). Cost (of restoration) was not included in the scoring but is provided for information (letters refer to High, Medium and Low or Not assessed).

Broadscale Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	3. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assemblage	Score	Score range	Cost
A1.1 High energy littoral rock	10	1	1	1	1	1	1	16	12-57 (23)	H
A1.2 Moderate energy littoral rock	10	1	1	1	1	1	1	16	12-56 (13)	H
A1.3 Low energy littoral rock	5	1	1	1	1	1	1	11	12-56 (21)	H
A1.4 Features of littoral rock	2	1	1	1	1	1	1	8	11-20 (27)	H
A2.1 Littoral coarse sediment	1	1	1	1	1	1	1	7	7-27 (3)	M

Broadscale Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	3. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assemblage	Score	Score range	Cost
A2.2 Littoral sand and muddy sand	1	5	10	1	1	1	1	20	7-24 (23)	M
A2.3 Littoral mud	1	1	1	1	1	1	1	7	11-13 (14)	H
A2.4 Littoral mixed sediments	2	1	1	1	1	1	1	8	11-20 (11)	H
A2.6 Littoral sediments dominated by aquatic angiosperms	10	5	10	3	1	1	5	35	32 (2)	M
A2.7 Littoral biogenic reefs	5	5	10	1	1	1	5	28	22-28 (7)	M
A2.8 Features of littoral sediment	1	5	10	1	1	1	1	20	20 (2)	M
A3.1 High energy infralittoral rock	2	1	5	1	1	1	1	12	15-22 (22)	H
A3.2 Moderate energy	10	1	1	1	1	1	1	16	11-52 (26)	H

Broadscale Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	3. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assemblage	Score	Score range	Cost
infralittoral rock										
A3.3 Low energy infralittoral rock	2	1	1	1	1	1	1	8	13-57 (26)	H
A3.7 Features of infralittoral rock	1	1	1	1	1	1	1	7	18-33 (10)	H
A4.1 High energy circalittoral rock	10	1	5	1	1	1	1	20	17-52 (23)	H
A4.2 Moderate energy circalittoral rock	10	1	5	1	1	1	1	20	15-52 (32)	H
A4.3 Low energy circalittoral rock	2	1	5	5	5	5	1	24	29 (9)	H
A4.7 Features of circalittoral rock	5	10	0	1	1	1	1	19	48-52 (5)	N/A

Broadscale Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	3. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assemblage	Score	Score range	Cost
A5.1 Sublittoral coarse sediment	2	5	10	1	1	1	1	21	13-30 (18)	M
A5.2 Sublittoral sand	2	5	10	1	1	1	1	21	20-35 (24)	M
A5.3 Sublittoral mud	5	5	10	1	1	1	1	24	7-37 (42)	M
A5.4 Sublittoral mixed sediments	10	5	10	1	1	1	1	29	20-37 (19)	M
A5.5 Sublittoral macrophyte-dominated sediment	10	10	10	1	1	1	10	43	22-52 (29)	M
A5.6 Sublittoral biogenic reefs	10	10	10	1	1	1	10	43	27-66 (12)	M
A5.7 Features of sublittoral sediments	10	5	10	10	10	1	5	51	23-66 (12)	M

Broadscale Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	3. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assemblage	Score	Score range	Cost
A6.1 Deep-sea rock and artificial hard substrata	10	30	0	10	10	1	5	66	66	N/A
A6.2 Deep-sea mixed substrata	10	30	0	10	10	1	5	66	N/A	N/A
A6.3 Deep-sea sand	2	30	0	10	10	1	5	58	N/A	N/A
A6.4 Deep-sea muddy sand	2	30	0	10	10	1	5	58	N/A	N/A
A6.5 Deep-sea mud	2	30	0	10	10	1	5	58	N/A	N/A
A6.6 Deep-sea bioherms	10	30	0	10	10	1	5	66	N/A	N/A

Table 12: Irreplaceability scoring for EUNIS Level 4 biotope complexes. Cell shading is used to differentiate scores with lighter and darker blue differentiating low and medium criterion scores. Higher scores are highlighted using red. The score range refers to the underlying EUIS Level 4, 5 and 6 biotopes and shows the underlying variability of irreplaceability in constituent biotopes. The number in brackets refers to the number of level 5 and 6 constituent child sub-biotopes and biotope complexes, not all of these are assessed). Cost (of restoration) was not included in the scoring but is provided for information (letters refer to High, Medium and Low or Not assessed).

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A1.11 Mussel and/or barnacle communities	2	5	1	1	1	1	1	12	12-27 (8)	H
A1.12 Robust fucoid and/or red seaweed communities	10	5	1	1	1	1	1	20	13-57 (9)	H
A1.15 Fucoids in tide-swept conditions	5	5	1	3	1	1	1	17	14-24 93)	H
A1.21 Barnacles and fucoids on moderately exposed shore	2	5	1	1	1	1	1	12	12-52 (8)	H
A1.22 Mussels and fucoids on moderately exposed shores	2	5	1	3	1	1	5	18	18,56 (3)	H
A1.31 Fucoids on sheltered marine shores	2	5	1	1	1	1	1	12	12,20 (13)	H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A1.32 Fucoids in variable salinity	2	5	1	1	1	1	1	12	12-20 (7)	H
A1.41 Communities of littoral rockpools	2	5	1	1	1	1	1	12	11-25 (10)	H
A1.42 Communities of rockpools in the supralittoral zone	1	5	1	1	1	1	1	11	11 (1)	H
A1.44 Communities of littoral caves and overhangs[1]	2	20	0	1	1	1	1	26	25-35 (11)	N/A
A1.45 Ephemeral green or red seaweeds (freshwater or sand-influenced) on non-mobile substrata	1	5	1	1	1	1	1	11	13 (2)	H
A2.11 Shingle (pebble) and gravel shores	1	1	1	3	1	1	1	9	7, 27 92)	M
A2.21 Strandline	1	1	1	3	1	1	1	9	11 (2)	H
A2.22 Barren or amphipod-dominated mobile sand shores	1	5	1	1	1	1	1	11	8-11 (7)	M

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A2.23 Polychaete/amphipod-dominated fine sand shores	1	5	1	1	1	1	1	11	11 (4)	M
A2.24 Polychaete/ bivalve-dominated muddy sand shores	2	5	10	1	1	1	1	21	12-23 (5)	M
A2.31 Polychaete/ bivalve-dominated mid estuarine mud shores	1	5	1	1	1	1	1	11	11-13 (3)	H
A2.32 Polychaete/ oligochaete-dominated upper estuarine mud shores	1	5	1	1	1	1	1	11	11-13 (9)	H
A2.41 *Hediste diversicolor* dominated gravelly sandy mud shores	1	5	1	1	1	1	1	11	11 (6)	H
A2.42 Species-rich mixed sediment shores	2	5	1	5	5	1	1	20	20 (1)	H
A2.43 Species-poor mixed sediment shores	1	5	1	1	1	1	1	11	13 (1)	H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A2.61 Seagrass beds on littoral sediments	10	5	10	5	1	1	5	32	(1)	M
A2.71 Littoral *Sabellaria* reefs	2	5	5	3	1	1	5	22	22 (1)	H
A2.72 Littoral mussel beds on sediment	2	5	10	1	1	1	5	25	28 (4)	M
A2.82 Ephemeral green or red seaweeds on mobile substrata	1	5	10	1	1	1	1	20	20 (1)	M
A3.11 Kelp with cushion fauna and/or foliose red seaweeds	2	5	5	1	1	1	1	16	15-20 (13)	H
A3.12 Sediment-affected or disturbed kelp and seaweed communities	2	5	5	1	1	1	1	16	17-22 (7)	H
A3.21 Kelp and red seaweeds (moderate energy infralittoral rock)	10	5	1	1	1	1	1	20	11-52 (25)	H
A3.22 Kelp and seaweed communities in tide-swept sheltered conditions	2	5	1	3	5	1	1	18		H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A3.31 Silted kelp on low energy infralittoral rock with full salinity	2	5	1	5	5	1	1	20		H
A3.32 Kelp in variable salinity on low energy infralittoral rock	1	5	1	5	5	1	1	19		H
A3.36 Faunal communities on variable or reduced salinity infralittoral rock	2	10	1	3	5	1	1	23		H
A3.71 Robust faunal cushions and crusts in surge gullies and caves	1	20	0	3	5	1	1	31		N/A
A4.11 Very tide-swept faunal communities on circalittoral rock	1	5	5	3	1	1	1	17		H
A4.12 Sponge communities on deep circalittoral rock	10	10	5	5	1	1	10	42	1 (52)	H
A4.13 Mixed faunal turf communities on circalittoral rock	10	10	5	1	1	1	1	29		H
A4.21 Echinoderms and crustose	2	10	5	3	1	1	1	23		H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
communities on circalittoral rock										
A4.22 Sabellaria reefs on circalittoral rock	2	5	5	3	1	1	1	18		H
A4.23 Communities on soft circalittoral rock	10	30	0	3	5	1	1	50		N/A
A4.24 Mussel beds on circalittoral rock	2	5	5	3	1	1	1	18		H
A4.25 Circalittoral faunal communities in variable salinity	2	10	5	5	1	1	1	25		H
A4.31 Brachiopod and ascidian communities on circalittoral rock	2	10	5	5	5	1	1	29		H
A4.71 Communities of circalittoral caves and overhangs	5	30	0	1	1	1	10	48	52 (1)	N/A
A5.12 Sublittoral coarse sediment in variable salinity (estuaries)	1	5	10	5	1	1	1	24	N/A	M
A5.13 Infralittoral coarse sediment	1	5	10	1	1	1	1	20	21,25 (7)	M

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A5.14 Circalittoral coarse sediment	1	5	10	1	1	1	1	20	20-30 (25)	M
A5.15 Deep circalittoral coarse sediment	1	5	10	1	1	1	1	20	13,23 (2)	M
A5.21 Sublittoral sand in low or reduced salinity	2	5	5	5	5	5	1	28	N/A	M
A5.22 Sublittoral sand in variable salinity (estuaries)	1	5	10	1	1	1	1	20	22-24 (3)	M
A5.23 Infralittoral fine sand	1	5	10	1	1	1	1	20	20-34 (4)	M
A5.24 Infralittoral muddy sand	2	5	10	1	1	1	1	21	N/A	M
A5.25 Circalittoral fine sand	1	5	10	1	1	1	1	20	23,25 (2)	M
A5.26 Circalittoral muddy sand	2	5	10	1	1	1	1	21	21,30 (2)	M
A5.27 Deep circalittoral sand	2	5	10	1	1	1	1	21	20,35 (2)	M

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A5.31 Sublittoral mud in low or reduced salinity	2	5	5	3	5	5	1	17	N/A	H
A5.32 Sublittoral mud in variable salinity (estuaries)	1	1	1	1	1	1	1	7	19-33 (7)	H
A5.33 Infralittoral sandy mud	5	5	10	3	1	1	1	26	17-34 (6)	M
A5.34 Infralittoral fine mud	5	5	5	3	1	1	1	21	18-30 (4)	M
A5.35 Circalittoral sandy mud	2	5	5	3	1	1	1	18	25-33 (6)	M
A5.36 Circalittoral fine mud	2	5	5	1	1	1	1	16	27-37 (4)	M
A5.37 Deep circalittoral mud	2	5	5	5	5	1	1	24	28-34 (8)	M
A5.41 Sublittoral mixed sediment in low or reduced salinity	2	5	5	5	5	5	1	28	N/A	H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A5.42 Sublittoral mixed sediment in variable salinity (estuaries)	1	5	10	3	1	1	1	22	25 (2)	M
A5.43 Infralittoral mixed sediments	10	5	10	1	1	1	1	29	25-37 (5)	M
A5.44 Circalittoral mixed sediments	5	5	10	1	1	1	1	24	21-37 (6)	M
A5.45 Deep circalittoral mixed sediments	1	5	10	1	1	1	1	20	25 (1)	M
A5.51 Maerl beds	10	10	10	5	1	1	10	47	52 (6)	L
A5.52 Kelp and seaweed communities on sublittoral sediment	2	5	10	3	1	1	1	23	22-34 (12)	H
A5.53 Sublittoral seagrass beds	10	5	10	5	1	1	5	37	32-40 (4)	M
A5.54 Angiosperm communities in reduced salinity	2	10	1	5	5	5	1	29	N/A	H

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
A5.61 Sublittoral polychaete worm reefs on sediment	2	10	10	3	1	1	5	32	27-24 (3)	M
A5.62 Sublittoral mussel beds on sediment	5	10	10	1	1	1	10	38	30-52 (5)	M
A5.63 Circalittoral coral reefs	10	30	0	10	5	1	10	66	66 (1)	N/A
A5.71 Seeps and vents in sublittoral sediments	10	30	0	5	10	1	1	57	62-66 (8)	N/A
A5.72 Organically-enriched or anoxic sublittoral habitats	1	5	0	10	5	1	1	23	28 (1)	N/A
A6.11 Deep-sea bedrock	10	30	0	10	10	1	5	66	N/A	N/A
A6.14 Boulders on the deep-sea bed	10	30	0	10	10	1	5	66	N/A	N/A
A6.61 Communities of deep-sea corals	10	30	0	10	10	1	5	66	66 (1)	N/A
A6.62 Deep-sea sponge aggregations	10	30	0	10	10	1	5	66	N/A	N/A

EUNIS Level 4 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Score Range	Cost
[1]A1.44 Communities of littoral caves and overhangs can have 'important' communities but also be heavily scoured and devoid of anything except juvenile stages of opportunistic species.										

Table 13: Summary table of EUNIS Level 5 and 6 habitats that score >40 for irreplaceability. Cell shading is used to differentiate between scores with lighter and darker blue differentiating low and medium criterion scores. Higher scores are highlighted using red. Cost (of restoration) was not included in the scoring but is provided for information. (letters refer to High, Medium and Low or grey shading and '*' for Not assessed).

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A1.127 *Ceramium* sp. and piddocks on eulittoral fossilised peat	10	30	0	5	10	1	1	57	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A1.2143 *Fucus serratus* and piddocks on lower eulittoral soft rock	10	30	0	5	5	1	1	52	*
A1.223 *Mytilus edulis* and piddocks on eulittoral firm clay	10	30	0	5	5	1	5	56	*
A1.4114 *Cystoseira* spp. in eulittoral	10	5	10	10	1	1	5	42	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
rockpools									
A3.2113 *Laminaria digitata* and piddocks on sublittoral fringe soft rock	10	30	0	5	5	1	1	52	*
A3.217 *Hiatella arctica* and seaweeds on vertical limestone / chalk	10	30	0	5	5	1	1	52	*
A3.362 *Cordyl*	1	30	0	10	10	1	5	57	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
ophora caspia and *Electra crustulenta* on reduced salinity infralittoral rock									
A3.363 *Hartlaubella gelatinosa* and *Conopeum reticulum* on low salinity infralittoral mixed	1	10	5	10	5	10	10	51	H

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
substrata									
A4.121 *Phakellia ventilabrum* and axinellid sponges on deep, wave-exposed circalittoral rock	10	10	10	10	1	1	10	52	H
A4.1311 *Eunicella verrucosa* and *Pentapora foliacea* on wave-expos	10	10	5	5	1	1	10	42	H

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
ed circalittoral rock									
A4.133 Mixed turf of hydroids and large ascidians with *Swiftia pallida* and *Caryophyllia smithii*	10	30	0	5	5	1	1	52	H
A4.231 Piddocks with a sparse associated fauna in sublitt	10	30	0	3	5	1	1	50	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
oral very soft chalk or clay									
A4.232 *Polydora* sp. tubes on moderately exposed sublittoral soft rock	10	30	0	5	5	1	1	52	*
A4.233 *Hiatella*-bored vertical sublittoral limestone rock	5	30	0	5	1	1	10	52	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A4.711 Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock	10	10	10	10	1	1	10	52	*
A5.511 *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coars	10	10	10	10	1	1	10	52	L

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
e sand									
A5.512 *Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel	10	10	10	10	1	1	10	52	L
A5.513 *Lithothamnion corallioides* maerl beds on infralittoral	10	5	10	3	1	1	10	40	L

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
muddy gravel									
A5.5343 *Ruppia maritima* in reduced salinity infralittoral muddy sand	10	10	10	5	1	1	10	47	M
A5.621 *Modiolus modiolus* beds with hydroids and red seaweeds…	10	10	10	5	1	1	10	47	M

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A5.622 *Modiolus modiolus* beds on open coast circalittoral mixed sediment	10	10	10	10	1	1	10	52	M
A5.623 *Modiolus modiolus* beds with fine hydroids and large solitary ascidians…	10	10	10	10	1	1	10	52	M

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A5.624 *Modiolus modiolus* beds with *Chlamys varia* …	10	30	0	10	5	1	10	66	M
A5.631 Circalittoral *Lophelia pertusa* reefs	10	30	0	10	10	1	1	62	*
A5.711 Bubbling reefs in the sublittoral euphotic zone	10	30	0	10	10	1	5	66	*

EUNIS Level 5 and 6 Habitat	1. Recovery potential	2A. Restoration method	2B. Feasibility	2. Rarity	4A. Physical habitat	4B. Hydrodynamics	4C. Biological assembl.	Score	Cost
A5.712 Bubbling reefs in the aphotic zone	10	30	0	10	10	1	5	66	*
A6.611 Deep-sea *Lophelia pertusa* reefs	10	30	0	5	10	1	1	57	*

Appendix 2. Literature Review Search Terms

Table 14: Literature review search terms.

Phrase	Number of results	Key words	Search details
Marine irreplaceability	21,900	MPAs, marine conservation hotspots, key conservation sites, marine reserve networks, reserve design	Not searched
Marine habitat irreplaceability	13,600	Marine reserves, marine reserve network, habitat directive, sustainable, conservation, habitat diversity, reserve selection	29/11/21 searched as marine habitat irreplaceab* 16,100, first 71 pages searched. Stopped after no more relevant references within 3 pages of results. BIOSIS Citation search 21 results. Web of science Core collection 34
Irreplaceable habitat	29,800	Habitat fragmentation, conservation, conservation of threatened species, biodiversity conservation, sustainability, ecosystem services, valuable, pressures	Not searched
Marine Irreplaceable habitat	13,300	Biodiversity, unique sites, conservation prioritization, protection equality, protected areas, reserve design	Google: 11/11/21 6,950,000 results, searched first 10 pages. Grey literature downloaded. Key papers added from Google scholar
Marine irreplaceable	7,190	Restored, natural services, conservation goals, value,	Not searched

Phrase	Number of results	Key words	Search details
habitat restoration		strategies, biodiversity, strict conservation efforts	
Marine habitat restoration	329,000	Historical loss, alteration of habitats, ecological impacts, degraded, effective management, ecological restoration, habitat loss, monitoring, functions, functional diversity, species diversity, genetic diversity	
Marine habitat sensitivity	332,000	Biodiversity, conservation, climate change, structural fragility, valuable, extinction risk, vulnerability, biological functions, extreme, sensitive areas, habitat damage, MPA, marine reserves, management, monitoring, ecological limit	Not searched
Marine habitat vulnerability	166,000	Risk, resistance, resilience, prioritise, sensitivity, loss, global warming, climate change, anthropogenic impacts, invasive, degradation, MPA, extinction, biodiversity, conservation, recovery, Red List, invasion, EUNIS habitats, adverse effects, biodiversity	Not searched
Unique irreplaceable marine habitats	9,540	Conservation, special protections, economic valuation, prioritization, protection, priority areas, MPAs, critical habitat, fragmentation, loss, biodiversity, vulnerability, marine reserves, targeted conservation, MPA networks, management	Not searched
Unique marine habitats	487,000	Unique characteristics, ecosystem services, biodiversity, marine	Not searched

Phrase	Number of results	Key words	Search details
		reserve networks, representative unique habitats, extreme habitats, ecosystem services, MPAs, classification, conservation, monitoring, decision making, Red List, vulnerable habitats, natural environment, novel and unique	
Unique irreplaceable marine habitats	9,540	Conservation, special protections, economic valuation, prioritization, protection, priority areas, MPAs, critical habitat, fragmentation, loss, biodiversity, vulnerability, marine reserves, targeted conservation, MPA networks, management	Not searched
Unique marine habitats	487,000	Unique characteristics, ecosystem services, biodiversity, marine reserve networks, representative unique habitats, extreme habitats, ecosystem services, MPAs, classification, conservation, monitoring, decision making, Red List, vulnerable habitats, natural environment, novel and unique	Not searched
Representative unique habitats	297,000	MPA networks, extremely vulnerable habitats, special, biodiversity, MPA, conservation frameworks, reserves, connectivity, ecological linkages, valuable	Not searched
Marine habitat rarity	55,500	Vulnerability, marine community, biodiversity, marine reserves, MPA, variability, habitat diversity, functional redundancy	Not searched

Phrase	Number of results	Key words	Search details
Non recovery marine habitats			Google Scholar: 2/12/21 473,000, download focussed on habitats and species strongly associated with benthic habitats e.g. oyster, not mobile species and animals in Europe/UK and not habitats such as mangrove- searched first 46 pages of results-
Marine habitats unique and rare	341,000		Google Scholar:11/11/21 473,000, focussed on habitats and species strongly associated with benthic habitats e.g. oyster, not mobile species and animals in Europe/UK and not habitats such as mangrove- searched first 46 pages of results-
Vulnerable marine ecosystems	382,000		Google scholar 3/12/21 Searched first 4 pages
Ecologically biologically significant areas	217,000		Google scholar 3/12/21: p11 onwards all citations

Appendix 3. Benthic species and habits with protracted or no recovery

Table 15: Benthic species and habitats that are slow recovering.

Species	Recovery timescale	Source
Modiolus modiolus	If possible, likely to take tens or hundreds of years	Mazik and others, 2018
Maerl	If possible, likely to take tens or hundreds of years	Mazik and others, 2018
Arctica islandica	If possible, likely to take tens or hundreds of years	Mazik and others, 2018
Limaria hians	(10 - >100 years) (no assessment of associated community)	Mazik and others, 2018
Zostera	Zostera species where small scale patchy disturbance may be followed by recovery over a few years but recovery may not be possible following large-scale disturbance or complete removal of a bed (Neckles and others, 2005; Boese and others, 2009).	Mazik and others, 2018
Geodia and other massive sponges on Atlanto-Arctic upper bathyal coarse sediment	Very low resilience to abrasion	MarLIN
Geodia and other massive sponges on Atlanto-Arctic upper bathyal mixed sediment	Very low resilience to abrasion	MarLIN
A1.112 - *Chthamalus* spp. on exposed eulittoral rock	Very low resilience to abrasion	MarLIN
A1.1122 - *Chthamalus* spp. and *Lichina pygmaea* on steep exposed upper eulittoral rock	Very low resilience to abrasion	MarLIN

Species	Recovery timescale	Source
A1.127 - *Ceramium* sp. and piddocks on eulittoral fossilised peat	Very low resilience to abrasion	MarLIN
A1.2143 - *Fucus serratus* and piddocks on lower eulittoral soft rock	Very low resilience to abrasion	MarLIN
A3.2113 - *Laminaria digitata* and piddocks on sublittoral fringe soft rock	Very low resilience to abrasion	MarLIN
A4.12 - Deep sponge communities	Very low resilience to abrasion	MarLIN
A4.121 - *Phakellia ventilabrum* and axinellid sponges on deep, wave-exposed circalittoral rock	Very low resilience to abrasion	MarLIN
A4.1311 - *Eunicella verrucosa* and *Pentapora* foliacea on wave-exposed circalittoral rock	Very low resilience to abrasion	MarLIN
A4.231 - Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay	Very low resilience to abrasion	MarLIN
A5.434 - Limaria hians beds in tide-swept sublittoral muddy mixed sediment	Very low resilience to abrasion	MarLIN
A5.51 - Maerl beds	Very low resilience to abrasion	MarLIN
A5.511 - *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	Very low resilience to abrasion	MarLIN
A5.5111 - *Phymatolithon calcareum* maerl beds with red	Very low resilience to abrasion	MarLIN

Species	Recovery timescale	Source
seaweeds in shallow infralittoral clean gravel or coarse sand		
A5.5112 - *Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand	Very low resilience to abrasion	MarLIN
A5.512 - *Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel	Very low resilience to abrasion	MarLIN
A5.513 - *Lithothamnion corallioides* maerl beds on infralittoral muddy gravel	Very low resilience to abrasion	MarLIN
A5.613 - *Serpula vermicularis* reefs on very sheltered circalittoral muddy sand	Very low resilience to abrasion	MarLIN
A5.631 - *Lophelia* reefs	Very low resilience to abrasion	MarLIN
A5.71 - Seeps and vents in sublittoral sediments	Very low resilience to abrasion	MarLIN
A5.712 - Bubbling reefs in the aphotic zone	Very low resilience to abrasion	MarLIN
A6.611 - Atlantic upper bathyal live ***Lophelia pertusa*** reef (biogenic structure)	Very low resilience to abrasion	MarLIN
A6.621 - *Pheronema carpenteri* field on Atlantic lower bathyal mud	Very low resilience to abrasion	MarLIN
A6.621 - *Pheronema carpenteri* field on Atlantic mid bathyal mud	Very low resilience to abrasion	MarLIN

Appendix 4. European Red List Habitats identified as threatened

Table 16: Habitats present in the UK and identified as European red List habitats.

Critically endangered	Endangered	Vulnerable
A5.53 Seagrass beds on Atlantic infralittoral sand (non-Macaronesian)	A2.31 Polychaete/bivalve-dominated mid-estuarine Atlantic littoral mud	A5.13 Faunal communities in marine Atlantic infralittoral coarse sediment
	A2.32 Polychaete/oligochaete-dominated upper estuarine Atlantic littoral mud	A5.14 Atlantic upper circalittoral coarse sediment
	A2.33 Marine Atlantic littoral mud with associated communities	A5.15 Atlantic lower circalittoral coarse sediment
	A2.72 Mussel beds in the Atlantic littoral zone	A5.44 Atlantic upper circalittoral mixed sediment
	A5.25 Atlantic upper circalittoral fine sand	A5.45 Atlantic lower circalittoral mixed sediment
	A5.26 Atlantic upper circalittoral muddy sand	A5.51 Atlantic maerl beds
	A5.27 Atlantic lower circalittoral sand	
	A5.35 Atlantic upper circalittoral fine sandy mud	
	A5.36 Atlantic upper circalittoral fine mud A5.37 Atlantic lower circalittoral mud	
	A5.37 Atlantic lower circalittoral mud	

Appendix 5. Nationally Important Marine Features (NIMF)

Table 17: Habitats identified as Nationally Important Marine Features with comments provided by K. Hiscock

Feature	Comments
Underboulder communities (c.f. Fser.Fser.Bo & Ldig.Ldig.Bo) *Laminaria digitata* and under-boulder fauna on sublittoral fringe boulders (IR.MIR.KR.Ldig.Bo) and *Fucus serratus* and under-boulder fauna on exposed to moderately exposed lower eulittoral boulders (LR.MLR.BF.Fser.Bo)]	The 'headline' biotope name is misleading. This biotope is for underboulder communities which may be rich and include unusual species and not for the open shore algal communities that are named. Underboulder communities are susceptible to boulder-turning.
Deep sponge communities (CR.HCR.DpSp)	
Lophelia reefs (SS.SBR.Crl.Lop) [	Deep communities were much less known in 2006/7. Some *Lophelia* reefs would recover quickly – maybe. So, restrict to deep habitats with long-lived, slow-growing species
Eunicella verrucosa and *Pentapora foliacea* on wave-exposed circalittoral bedrock (CR.HCR.XFa.ByErSp.Eun	The Annex I habitats of the Habitats Directive which the biotope forms a part is very broad and includes many widespread habitats that are not rare or threatened. Although the BAP criterion has been fulfilled, it is not considered, by itself, to justify inclusion of the habitat as a BAP Priority Habitat." [This is a difficult one as I believe that there are examples – locations – where the biotope holds rare and scarce species that may be irreplaceable – so, not 'across the board' but specific locations

Feature	Comments
	where the biotope would be 'irreplaceable'.]
Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock (CR.FCR.Cv.SpCup)	Often includes rare and scarce species and is a very restricted habitat.
Ceramium sp. and piddocks on eulittoral fossilised peat (LR.HLR.FR.RPid)	Unusual habitat in a very few locations. Piddocks are harvested for food.
Mytilus edulis and piddocks in eulittoral firm clay (LR.MLR.MusF.MytPid)	Unusual habitat in a very few locations. Piddocks are harvested for food.
Littoral caves & overhangs (LR.FLR.CvOv) [	To a great extent, the inclusion of this habitat is a Habitats Directive artefact/aberration. The great majority of such habitats are scoured and include nothing that would not recolonise rapidly. There are caves/tunnels in the IoM and Guernsey that would likely qualify as they hold unusual communities and (Sugarloaf caves in the IoM) unusual species.
Faunal communities on variable or reduced salinity infralittoral rock (IR.LIR.IFaVS) [	Maybe also include intertidal rock in variable salinity.
Sparse *Modiolus modiolus*, dense *Cerianthus lloydii* and burrowing holothurians on sheltered circalittoral stones and mixed sediment (SS.SMx.CMx.ClloModHo)	*Modiolus modiolus* provides a habitat for an often rich variety of species. The secondary species are widespread.
Seapens and burrowing megafauna in circalittoral fine mud (SS.SMu.CFiMu.SpnMeg)	May not be relevant to England – widespread in Scottish lochs and greatly damaged by mobile fishing gear and fish farm pollution.

Feature	Comments
Burrowing megafauna and *Maxmuelleria lankesteri* in circalittoral mud (SS.SMu.CFiMu.MegMax)	An unusual community only recorded at a few locations.
Halcampa chrysanthellum and *Edwardsia timida* on sublittoral clean stone gravel (SS.SCS.ICS.HchrEdw)	The two anthozoans that characterise this biotope are very rarely seen.
Branchiostoma lanceolatum in circalittoral coarse sand with shell gravel (SS.SCS.CCS.Blan)	An unusual habitat with a characterising species that is rarely found. Vulnerable to heavy mobile fishing gear.
Methane-derived authogenic carbonate (MDAC) reef (EUNIS code: A5.1)	
Ostrea edulis beds on shallow sublittoral muddy mixed sediment (SS.SMx.IMx.Ost)	This biotope was once much more widely occurring and is now subject to several restoration projects. Native oysters are valued for food and also for their role in filtering water (improving 'quality'). [Key questions are about what constitutes a 'bed' and whether beds that are of imported *Ostrea edulis* 'count'.]
Ruppia maritima in reduced salinity infralittoral muddy sand (SS.SMp.SSgr.Rup)	A rarely occurring habitat and 'seagrass' is listed in international directives and conventions.

Appendix 6. Interview Questions

Completeness and comprehensiveness of review

Question 1. For many aspects of irreplaceability and the associated criteria suggested by the review, the literature is extensive and we are not able to review fully in the timescale. We would like to identify any key gaps in the literature review, are you aware of any further definitions of irreplaceability, concepts or criteria that we should consider?

Suggested definition of marine habitat irreplaceability

Question 2. We have proposed a definition of irreplaceability (see below), that considers key criteria for irreplaceability: difficulty of recovery, restoration or re-creation, rarity, environmental context and fragility and a component of value (conservation value, function, cultural heritage) in order to understand the significance of irreplaceable habitats. What aspects of this do you disagree with? What do you think should be changed, if anything?

Suggested definition of marine habitat irreplaceability “Irreplaceable marine habitats are those which are not possible to restore, recreate or replace easily. They may be rare (based on extent, range and distribution), unique in terms of environmental context and fragile (vulnerable and slow to recover). The significance of irreplaceable habitats increases with value based on conservation interest, function and cultural heritage.”

Question 3. Do you agree with the criteria (restoration/recovery potential, rarity, environment context, fragility) provided? We have identified where we interpret concepts to overlap in order to develop a subset that encompasses the key criteria identified in the review. Do you agree with the groupings and definitions presented in Table 2 and 3? Should further criteria be added to the definition or should some of these be removed?

Question 4. What makes a habitat irreplaceable? Is it that it cannot be physically recreated/replaced exactly elsewhere or is it more that the function it is providing cannot be recreated/replaced elsewhere? There are issues with the definition that are difficult to resolve, for example, questions around scale of loss and the point at which replaceable broad scale habitats become irreplaceable and whether irreplaceability has a location dependency?

Applying the definition to assess the irreplaceability of EUNIS Level 3 and 4 habitats

Question 5. We have identified a number of measures to evaluate each criteria, would you suggest any revisions, deletions or alternatives to these? If you are aware of additional key evidence sources to support assessments against each criteria, could you identify these and if possible provide a link or copy.

Question 6. What issues do you foresee assessing the irreplaceability of marine habitats according to the definition? A key uncertainty identified by the review is identifying spatial thresholds at which impacts may render habitats that are larger in extent irreplaceable. Are you aware of any assessments or reviews that would support setting thresholds for the scale of impact on specific habitats?

Question 7. Do you think a sliding scale or matrix approach will be helpful in determining which habitats are irreplaceable, or do you have other suggestions for the method and scoring? What do you see as the benefits or limitations of this approach and its application?

Appendix 7. Literature review summary

The following sections provide the main body of the literature review provided to interviewees. The content has been reduced in places, for example introductory sections including the non-technical summary and guidance for interviewees as well as the proposed definitions and criteria have been removed as the latter were subsequently updated following the interviews.

Identifying irreplaceable habitat criteria

International examples relevant to defining irreplaceability

Systematic Conservation Planning

Systematic conservation planning (SCP) is a field of conservation biology concerned with delivering on-the-ground actions that achieve conservation goals. It describes a set of operational models that cover both design and implementation of conservation, with a strong focus on mobilising the collective action typically required to implement conservation. An extensive review of this field was not possible due to the many thousands of publications using these terms and the review here was based largely on Kukkala and Moilanen (2013).

The field of SCP has developed biogeographic-economic analysis, frequently called spatial conservation prioritisation or conservation assessment, to identify where important areas for biodiversity are and how conservation goals might be achieved efficiently. Kukkala and Moilanen (2013) reviewed the usage and meaning of the 12 core concepts of SCP: adequacy, complementarity, comprehensiveness, effectiveness, efficiency, flexibility, irreplaceability, replacement cost, representation, representativeness, threat, and vulnerability.

In terms of irreplaceability, relevant SCP concepts are complementarity, threat and vulnerability and irreplaceability.

Definition of complementarity used in systematic conservation planning

Complementarity- was defined by Margule and Pressey (2002), as “a measure of the extent to which an area, or set of areas, contributes unrepresented features to an existing area or set of areas. In terms of site selection the precise measure depends on the targets that have been identified and on the type of data. It can be thought of as the number of unrepresented species (or other biodiversity features) that a new area adds.”

Complementarity is related to irreplaceability. Irreplaceability in terms of SCP reflects how important a specific area is for the efficient achievement of conservation objectives (Carwardine and others, 2007). The irreplaceability (or uniqueness) of a site is the degree to which geographic (or spatial) options for conservation will be lost if that particular site is lost (Pressey and others 1994). In an extreme example, a site is completely irreplaceable if it contains one or more species that occur nowhere else. In contrast, when sites contain only species that are widely distributed, many alternatives exist for conserving these species. Sites that hold significant fractions of a species' entire population during particular periods of the year (e.g., migratory bottlenecks and routes) are also highly irreplaceable (Langhammer and others, 2007).

Definition of irreplaceability used in systematic conservation planning

Irreplaceability provides a quantitative assessment of the contribution of areas for meeting conservation targets and its statistical assessment is treated by Ferrier and others (2007). A completely irreplaceable area is considered essential for meeting conservation objectives, whereas an area with low irreplaceability can be substituted by other sites. Irreplaceability in SCP is therefore analogous to rarity/uniqueness in other assessment systems.

Definition of threat and vulnerability used in systematic conservation planning

Threat and another important SCP concept, vulnerability, are described by Kikkala and Molanene (2013) as often tightly linked together. Threat refers to the presence of a process that may cause losses to biodiversity; vulnerability, on the other hand, categorises the sensitivity of particular biodiversity features to a specific threat (e.g. climate change or other pressures from human activities). Habitats are vulnerable if they are threatened and sensitive to that threat. In the literature, threat has been compared to the concept of fragility which is often referred to as vulnerability (Kukkala and Moilanen, 2013).

Vulnerability is complementary to threat, and can be defined as the risk of the area being transformed via damage caused to biodiversity features by threatening processes. Before the emergence of the specific term vulnerability, the concept was discussed as fragility (Kukkala and Moilanen, 2013, references therein). Vulnerability is a measure of the likelihood of the biodiversity in an area being lost to current or threatening processes (Pressey and Taffs 2001). Vulnerability can also be seen as a measure of irreplaceability (in SCP terms), but over time, rather than space. Sites facing low threat will retain options for conservation in the future. Vulnerability may be measured on a site basis (likelihood that the species will be locally extirpated from a site) or a species-basis (likelihood that the species will go globally extinct).

The reserve system design tools, Marxan and C-Plan, both calculate the irreplaceability of sites in terms of meeting biodiversity targets (Carwardine and others, 2007). Tests show that irreplaceability values of sites using both tools were related to their rarity (Carwardine and others, 2007) but also whether the site contains a small or large amount of a feature relative to its target and relative to other occurrences in the region.

Vulnerability (based on Red List threat status) and irreplaceability measures (based on range) as used by SCP are proposed to define Key Biodiversity Areas for the protection of threatened species and similar criteria are used for the identification of Important Bird Areas and Important Plant Areas (Langhammer and others, 2007). Similar criteria for irreplaceability based on range are applicable to habitats and discussed below in the report section on irreplaceable habitat criteria.

Vulnerable marine ecosystems

The United Nations General Assembly (UNGA) called upon States and Regional Fisheries Management Organizations to identify areas beyond national jurisdiction where vulnerable marine ecosystems (VME) occur, or are likely to occur, and to prevent significant adverse impacts (UNGA, 2006). The Food and Agricultural Organization (FAO) of the United Nations subsequently developed guidelines for the management of deep-sea fisheries in the high seas (FAO, 2009). This included criteria for defining what constitutes a VME.

Vulnerable marine ecosystems: assessment criteria

The FAO list of characteristics used as criteria in the identification of VMEs are (FAO, 2009):

- Uniqueness or rareness: an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems.
- Functional significance of the habitat: discrete areas or habitats that are necessary for the survival, function, spawning/reproduction, or recovery of fish stocks, particular life-history stages (e.g., nursery grounds or rearing areas), or of rare, threatened or endangered marine species.
- Fragility: an ecosystem that is highly susceptible to degradation by anthropogenic activities.
- Recovery: Life-history of species make recovery difficult: ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics: slow growth rates, late age of maturity, low or unpredictable recruitment, or long-lived.
- Structural complexity: an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features.

Application of criteria to identify Vulnerable Marine Ecosystems

A wide range of literature and examples on the definition of VMEs exists. For the Northwest Atlantic, over 500 benthic invertebrate megafaunal taxa caught in research vessel surveys were classified initially into broad taxonomic groupings and considered by experts against the life history and functional significance criteria drawn from the FAO Guidelines. In addition to the coral and sponge taxa that had previously been addressed, three additional groups emerged as potential indicators of VMEs: crinoids, erect bryozoans and large sea squirts. In order to establish functional significance, it was the dense aggregations (beds/fields) that were assumed by the Northwest Atlantic Fisheries Organisation (NAFO) Scientific Committee to be VMEs.

Morato and others (2018) applied VME criteria to identify VME based on indicator taxa. The degree to which each VME indicator group (not the individual taxa contained) fit each of the five FAO criteria was scored from 1 (low) through 5 (high). The scoring procedure was discussed and agreed by a group of deep-sea scientists through an ICES Expert Group using existing informed expert judgment, and the following specific guidelines:

- Rarity: was scored according to presence on the IUCN red list, and if the indicator was known to be endemic, rare, threatened, or declining.
- Functionality: was scored by evaluating if the indicators were known to create nursery areas for other species, or known for having higher level ecosystem role, such as nutrient cycling and water filtration.
- Fragility: was scored according to the fragility of the indicator against physical contact, the height and complexity of its structure, and the capacity for retraction, retention or re-growth or if being naturally protected in some way.
- Life-history: was scored against the longevity, fecundity, age at maturity, growth rate, and known frequency of recruitment success.
- Structural complexity: was scored based on structural habitat created, frame-building, and presence of commensal or closely associated species.

Ecologically or Biologically Significant Marine Areas

In 2008, the Convention on Biological Diversity adopted seven criteria for identifying ecologically or biologically significant marine areas (EBSAs) for biodiversity conservation (CBD, 2012). The criterion used to define these areas are outlined below (see also Table 1 although note these criteria have been grouped in some instances (e.g. fragility and naturalness).

Criteria Definition:

- C1 Uniqueness or rarity: The area contains either (i) unique (the only one of its kind), rare (occurs only in few locations) or endemic species, populations or communities; and/or (ii) unique, rare or distinct, habitats or ecosystems; and/or (iii) unique or unusual geomorphologic or oceanographic features.
- C2 Special importance for life-history stages of species: Areas that are required for a population to survive and thrive.
- C3 Importance for threatened, endangered or declining species and/or habitats: Areas containing habitats for the survival and recovery of endangered, threatened or declining species or areas with significant assemblages of such species.
- C4 Vulnerability, fragility, sensitivity, or slow recovery. Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.

- C5 Biological productivity. Areas containing species, populations or communities with comparatively higher natural biological productivity.
- C6 Biological diversity. Areas containing comparatively higher diversity of ecosystems, habitats, communities or species, or has higher genetic diversity.
- C7 Naturalness. Areas with a comparatively higher degree of naturalness as a result of the lack of, or low level of human-induced disturbance or degradation.

IUCN/European Red List

Red Lists have been compiled by IUCN, HELCOM and many national teams for different groups of species and habitats. The red list status has often been considered as a synonym of the conservation priority of a species. The European Red List of Habitats (Gubbay and others, 2016) provides an overview of the risk (threat) of collapse (degree of endangerment) of marine, terrestrial and freshwater habitats, based on a consistent set of categories and criteria (see below), and detailed data and expert knowledge from involved countries.

Red List assessments were carried out for 86 benthic habitats in the North-East Atlantic region. Of these, 60% (52 habitats) were Data Deficient. Most of these are thought to have a wide distribution and extensive occurrence. They are therefore unlikely to be threatened under criterion B 'Restricted Geographical Distribution'. Of the remaining 40% (34 habitats), 59% were threatened (Vulnerable to Critically Endangered); these were almost exclusively sediment habitats from estuarine, littoral, infralittoral and circalittoral (see Appendix 2). Overall, the most frequent criterion used for habitats with a threatened status was C/D1, indicating a decline in quality. The thresholds for a threatened category were rarely met under criteria B, as virtually all the habitats are known to have a wide range (Gubbay and others, 2016).

IUCN and European Red List of Habitats criteria

The following criteria definitions were taken from Keith and others (2013).

Criterion A. Reduction in quantity (area or distribution)

- A1 Present decline (over the last 50 years)
- A2a Future decline (over the next 50 years)
- A2b Future/present decline (over a 50-year period including
- present and future)
- A3 Historic decline

Criterion B. Restricted geographic distribution

- B1 Restricted Extent of Occurrence (EOO)
- B2 Restricted Area of Occupancy (AOO)
- B3 Present at few locations

Criterion C. Reduction in abiotic quality

Criterion D. Reduction in biotic quality

C/D1 Reduction in quality over the last 50 years

C/D2 Reduction in quality in the future or in a period including present and future

C/D3 Historic reduction in quality

Criterion E. Quantitative analysis of probability of collapse

Because habitats comprise assemblages of plants and animals inextricably linked with the environmental context which sustains them, it can be difficult or impossible to distinguish declines in abiotic quality from the biotic. It was therefore agreed that for assessments Criteria C and D Trends in quality could be combined. Also, different degradation processes were often added together to assess overall quality decline, using a simplified qualitative scheme of stage of quality degradations caused by all acting pressures together.

For Criterion C/D with a few exceptions (e.g. seagrass beds and various biogenic reef types), there is still much uncertainty on detailed quality parameters for EUNIS level 4 habitats, and even less on trends for any measures of quality that can be quantified.

Gubbay and others (2016) also state that each pressure can have a differing severity of impact across the variation within the habitat. Converting such terms as 'moderate' or 'severe' declines in quality into numerical values for calculating the scale and extent of changes in quality was therefore largely an exercise based on expert judgement. Indeed, for marine habitats there was considerable reliance on expert judgement, and joint assessment by several experts working together, through regional sea groups, was a useful approach.

UK examples and assessments

Nationally Important Marine Features

Nationally Important Marine Features in Britain (Connor and others, 2002). Were assessed based on a range of criteria including:

- rarity, (present in eight or less of the 10 km squares in the 3-mile limit of territorial seas around the UK or expert judgment further offshore);
- proportionally important (the UK holds more than 25% of the global population/extent of habitat or 30% of the NE Atlantic population/extent of habitat,
- species that have declined in abundance or extent by more than 25% in the past 25 years habitats that have declined in extent to 90% or less of formal natural extent;
- it is predicted that the species will decline by 50% in a current or next 25 year period / the habitat is likely to suffer significant decline as defined.

Appendix 5 (Table 17) identifies a list of habitats extracted from the Nationally Important Marine Features (NIMF) database which were assessed as 'worth consideration' biotopes. They do not include biotopes that 'passed' Biodiversity Action Plan (BAP) criteria only because they qualified under international obligations (the very broad biotopes in the Habitats Directive). The list does not include habitats that are only known to occur in Scotland, Wales, the Isle of Man or Northern Ireland.

Note that the 2006/7 exercise pre-dated EUNIS and so those codes are not included. Saline lagoons seem under-represented (East Anglia ones supposed to contain rare/scarce species). *Phymatolithon calcareum*, *Lithothamnion corallioides*, *Zostera marina* and *Zostera noltii* beds did not feature in the database.

UK Features of Conservation Importance

The current list of UK Features of Conservation Importance (FOCI) includes features on the OSPAR List of Threatened and/or Declining species and habitats, the schedules of protected species of the Wildlife and Countryside Act 1981 and the UK BAP list of priority habitats and species. These lists cover an extensive array of habitats and species that are present in UK waters (in order to ensure that the range of habitats and species found in Secretary of State waters are protected). The ethos behind the FOCI list was that unique or important features in UK seas were given protection as part of Marine Conservation Zone (MCZ) designations. Subsequent to the publication of the MCZ FOCI list, there have been some legislative changes or amendments to the original lists that formed the basis for the MCZ FOCI list. Particularly, following the introduction of Section 41 of the Natural Environment and Rural Communities Act 2006. These provide a checklist of species of conservation interest and the criteria used to define these.

Irreplaceable habitat criteria

Core components of irreplaceability

The review of international and national biodiversity conservation initiatives identified a range of criteria that have potential application to assessments of habitat irreplaceability. These are discussed below and potential measures that could be used to assess habitats against the criteria are identified.

Recovery/Restoration potential

A review of the literature by Mazik and others (2015) indicated a high degree of variation in the use and interpretation of the term ‘recovery’. They proposed that ‘recovery’ should refer to a process or trajectory and ‘recovered’ should refer to an end point: “Recovery is considered as: a consistent trajectory, detectable above natural variability, of a representative set of feature properties from a previous (or otherwise defined) state towards the Recovered Reference Range, throughout a spatially explicit area”.

Rarity

Rarity and uniqueness are one of the most commonly used criteria for evaluating the importance of natural areas and are often combined (Smith and Theberge, 1986, Asaad and others, 2017). Uniqueness is considered below in terms of environmental context.

Rare habitats occur only at a specific site or a small number of sites (Asaad and others 2017). Habitats that occur only in specific areas or have restricted ranges are highly significant for biodiversity conservation (Roberts and others, 2003). Such habitats would be irreplaceable, and their loss would increase risk of local and global species extinctions (Asaad and others, 2017).

Identifying the rarity of habitats should consider the spatial scale, either global, regional or local (Derous and others, 2007). Some habitats may be considered as rare at the local level, but abundant elsewhere in the world. A globally rare habitat is significant even if it is relatively abundant within a specific region.

Evidence sources: This criterion can be evaluated through data on the distribution, occurrence, or relative abundance of species or habitats. It should be noted that the European Red List assessment (Gubbay and others, 2016) identified that few habitats met the criterion for restricted range and therefore this is likely to be a useful criterion to discriminate between habitats. Population data are frequently lacking and ‘area of occupancy’ concept may be used as a proxy to assess the number and location of rare species within a study area (Sanderson 1996a,b; Connor and others 2002). This approach was adopted for the UK’s Review of Marine Nature Conservation (DEFRA 2004, Lieberknecht and others 2004a) and the UK Biodiversity Action Plan for marine species and habitats (UK BAP 2005), both in combination with other criteria. JNCC have compiled information on rare taxa from a variety of published sources such as Red lists, Taxon Status Reviews, UK Priority species lists and schedules of international and national legislation.

Measures include: Global importance: proportion of the global extent of a habitat or proportion of the global population of a species occurring within England (Connor and others 2002; Lieberknecht and others, 2004a, b).

- Regional importance: proportion of the regional (e.g. NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subarea within the study area. (Connor and others, 2002);Lieberknecht and others, 2004a,b)
- National importance: proportion: of the national extent of a habitat or proportion of the national population of a species occurring in a certain subarea within territorial waters. (BWZee workshop definition (2004)
- Nationally rare habitat = habitat type restricted to a limited number of locations in territorial waters (Defra, 2002)
- Regionally rare habitat = habitat type occurring in less than 2% of the 50 x 50 km UTM grid squares (Connor and others, 2002).

Environmental Context (Uniqueness)

Uniqueness is considered in terms of environmental context, definitions of uniqueness include:

(i) unique (the only one of its kind),
(ii) endemic (unique to a particular geographic location)
(iii) unique or distinct habitats or ecosystems; and/or
(iv) unique or unusual geomorphologic or oceanographic features. (CBD, 2012)

Unique habitats include those that are formed in settings which no longer exist, for example peat and clay exposures and the even earlier chalk habitats, formed by phytoplankton. These unique habitats defined by environmental context contrast with habitats that are rare but may occur in environmental settings that occur over large extents and in multiple regions (nationally or internationally).

Habitats that are unique cannot be easily recreated and they can be considered irreplaceable, especially where the extent of these is restricted. Considerations of environmental context overlap with rarity and it is therefore proposed that in a definition of irreplaceability rarity is considered separately from uniqueness with uniqueness being identified as environmental context.

The Nationally Important Marine Features work, KBA and VME, Ardon and others (2014) provide examples of range measures which would support identification of habitats that meet this criterion. Expert review and judgement and information on habitat distribution and characteristics would support ranked scores of unique habitats.

Fragility

Fragility has been recognised as a high probability of extinction or damage of a species, feature, or system. High fragility implies a high probability of "extinction" or "damage" of a species, feature, or system. Fragility is often considered alongside threat, vulnerability, sensitivity and recovery, for example the CBD criterion (CBD, 2012). To assess irreplaceability it is suggested that this criterion is considered separately to recovery and restoration potential (see below) and considers the capacity of habitats to absorb or resist alteration when exposed to pressures.

Evidence sources to assess fragility as sensitivity of habitats based on resistance to pressures, include the MarLIN website which provides information to support marine conservation, management and planning. MarLIN hosts the largest review of the effects of human activities and natural events on marine species and habitats yet undertaken and provides a systematic assessment of habitat sensitivity using the MarESA method which combines an assessment of resistance to pressures and recovery. MarLIN sensitivity assessments are available for 396 biotopes within the UK Marine Habitat Classification. For specific habitats and species there are a wide range of references available.

Ecosystem function, services, goods and benefits

The UK Natural Capital Committee (2017) define Ecosystem Services as: "functions and products from nature that can be turned into benefits with varying degrees of human input." Benefits are the changes in human well-being or welfare that result from the consumption or use of goods and services or from knowing something exists. A range of frameworks have been developed for assessing the provision of ecosystem services. The CICES framework assesses final ecosystem services, classified into three groups, provisioning, regulating and maintenance and cultural. Currently there are over 70 marine relevant ecosystem service classes in CICES V5.1 (HainesYoung & Potschin, 2018).

In other frameworks such as that developed by Potts and others (2014) consideration is given to the underlying ecosystem processes and functions which provide supporting and regulating services or ecosystem function and these may be of greater interest when considering irreplaceability from a conservation perspective, while goods and benefits support assessments of socio-economic benefit.

Recent reviews have identified that for UK marine habitats there is more information to asses some provisioning and regulating services, evidence for cultural services is more limited (Tillin and others, 2019a and b). Many of the ecosystem services are based on potential evidence, rather than actual evidence that the service is realised (Behrendt and others, 2021). Some services that are restricted by habitat type are classification artefacts for example only seagrasses contribute to seed dispersal whereas all habitats (unless defaunated, abiotic) are considered to support gamete dispersal. Other services may only have limited demand or require small amount of material, e.g. collection of seaweed spores to seed farms or bioprospecting. Other services are difficult to assign to habitats due to lack of evidence (or review or assessment limitations) and may therefore only be attributed to a limited number of habitats, for example pest and disease control. The importance of services and which are to be considered depend on objectives, of particular interest for irreplaceability would be functions and services that are supported by few taxa, particularly those that are vulnerable. Studies have shown low functional redundancy in some systems with rare and vulnerable species having distinct traits and contributions (Mouillot and others, 2013).

One approach may be to identify habitats that provide a greater degree of service compared to broadscale habitats as a proxy or that supply higher levels of service groups, e.g. regulating and supporting services. Previous work by Tillin and others (2018) found that differences in ecosystem service provision between habits of conservation interest identified as Priority Marine Features (PMF) 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 but also biogenic reef communities such as horse mussel beds and native oyster beds. In all of these cases, PMF habitats scored more highly on ecosystem service provision indicating disproportionately high contributions of ecosystem services and therefore that these habitats are of particular interest for service delivery (Tillin and others, 2018). In terms of maintaining species, habitats that protect vulnerable life stages of key species may be of interest (Roberts and others 2003). Areas which support vulnerable life stages include spawning grounds and nursery habitats.

Evidence sources: The evidence base used to support the assessment of ecosystem service provision for a range of habitats could be sourced from reviews such as Fletcher and others, Potts and others (2014), Tillin and others (2018, 2019a and b, 2020b), Behrendt and others (2021). However, a key question to elucidate is which functional or ecosystem services and goods and benefits should be selected in order to assess function or ecosystem service.

Cultural and heritage values

Most subtidal habitats are visited only by snorkelers and divers and this inaccessibility also reduces public awareness and use so that cultural value is lower compared to terrestrial habitats. Some species, however, may be important to local communities such as species targeted for food or other uses. In Orkney, for example, kelp was assessed as having a strong cultural value which was evidenced and supported by heritage and historical uses (Behrendt and others, 2021).

Some locations are important (and irreplaceable) for historical reasons. For instance, a long-term monitoring station like the Marine Biological Associations L4 station should not be damaged (as was proposed by moving the spoil disposal site from off Rame Head to L4 location or nearby).

Excluded criteria

The criteria naturalness and age were considered for inclusion within the definition of marine habitat irreplaceability but we suggest these are excluded from the final definition of irreplaceability as discussed below.

Naturalness (Quality or Condition)

Naturalness is described by Derous and others (2007) as the degree to which an area is pristine and characterized by native species (i.e. absence of perturbation by human activities and absence of introduced or cultured species). Naturalness as a characteristic is considered to also encompass concepts of quality (condition) as sites that are closer to natural (unimpacted) condition are assumed to be better quality than those that are impacted by anthropogenic pressures.

Marine ecosystems are generally natural in management terms compared to terrestrial, in that they are rarely the result of positive intervention, unlike some terrestrial habitats considered to be of high conservation value, e.g. moors, lowland heaths and meadows, are semi-natural in that positive intervention through the maintenance of certain human activities is required to preserve them in their modified state (Sutherland and Hill, 1995, cited from Jones, 2002). However, marine ecosystems may be impacted by a range of pressures which modify their state (condition).

Data that can be used as direct indicators of 'condition' of marine habitats is largely limited in the marine environment to small spatial scales. Direct assessments of condition can be based on biological, chemical and physical parameters, such as assessments of population characteristics, the presence of contaminants or measures of variables such as oxygen and salinity or substratum condition.

It is not clear how naturalness should be included and represented in an assessment of irreplaceable habitats. Naturalness was considered to be incorporated within the assessment of fragility as those habitats that are fragile but that persist in the marine environment are likely to be relatively unimpacted (and therefore natural) as exposure to pressures would have resulted in their removal. For example, Cook and others (2013) found that even a single pass of towed bottom fishing resulted in nearly 60% to 90% reduction in the horse mussel beds. Hiscock and others (2012) suggested that many inshore rocky habitats are largely in a natural state which accords with the European Red List assessment which largely identified sedimentary habitats as being threatened (and therefore less natural). It should be noted that difficulties applying the quality criterion for the European Red List assessment are described above from Gubbay and others (2016), suggesting that this is difficult to apply.

In summary, naturalness as a criterion was considered to be a redundant and to be represented by fragility. Dependent on expert review this criteria could be revisited. However, limited monitoring evidence to assess condition has been identified by previous projects as an issue for coastal and marine environments (Tillin and others, 2018). For many benthic habitats there may be some data on extent but site-specific annual data on condition are rare. Where data based on direct monitoring of condition of habitat assets is absent an alternative is to use proxy measures to assess condition based on exposure to pressures (European Environment Agency, 2015). Assessments that combine evidence for exposure to pressures with an assessment of the sensitivity or impact on receptors may sometimes be referred to as a risk assessment or vulnerability assessment and would implicitly include fragility criteria.

Age of habitats and habitat forming species

Age of habitats and habitat forming species (e.g. ancient woodland) was considered a criteria for defining irreplaceability for terrestrial habitats. Based on the review, age may be a redundant criteria for assessing irreplaceability. In the marine environment there are many long-lived and slow growing organisms for example, the bivalve *Arctica islandica*, some fish species and also habitat forming species such as corals, some sponges and maerl beds. These habitats and species are generally fragile in that they are sensitive to impacts and slow to recover and or, in general it is not possible to restore or recreate the habitat (for habitats or habitat forming species). It is therefore proposed that age (in terms of habitat and habitat forming species) is not included as a separate criteria for irreplaceability but is considered under fragility and recovery restoration potential.

In general rock and sedimentary habitats are all ‘old’ in that the physical materials originate over geological timescales and in comparison, habitats such as peats and clays and chalk are comparably young. The irreplaceability of habitats such as peat and clay exposures and chalk are captured through the criteria: rarity, uniqueness, fragility and recovery potential. In terms of marine environments, stability and lack of perturbations may be a more suitable proxy for the age criteria used in terrestrial environments. While some of these habitats may have high species richness and distinctiveness (part of age considerations for terrestrial habitats), evidence for increased species richness in habitats formed by long-lived species was not sourced. Assessments of conservation value may be more appropriate to weight the conservation value of a habitat rather than an assessment based on age (or stability and lack of perturbation).

Appendix 8. Interviews: summary of collated notes

The following sections summarise comments provided by interviewees. A range of comments on the project purpose or more general context were collated and passed to the project steering group. As these are not directly relevant to defining irreplaceable habitats they are not shown below. It should be noted that the comments expressed below are of the interviewees, who in some cases were representing personal opinions rather than organisational stances. The comments do not necessarily represent the position of Natural England or of other organisations interviewed. While the comments are presented largely verbatim some changes have been made to increase clarity or to reduce statement length.

General comments on irreplaceability

- Everything is replaceable really. A lot of deep sea habitats are very difficult to restore but not necessarily irreplaceable. Irreplaceable overlines the timescales relevant to mankind (relevant to comments by another interviewee on temporal scale and defining this below).
- Should the project explore temporary irreplaceability whereby if human interaction and activity are bought about could this make a habitat irreplaceable - there are different scales of damage to irreplaceable habitats.
- Ecosystems are changing, both because of invasive species and because of warming. All of these habitats are changing because of changing water chemistry and changing temperatures, and changing nutrients and so irreplaceability for me sits a bit uncomfortably given that they're morphing, they're changing. And given enough time, like 1000s of years, some of them can be replaced.
- Climate change creates an in combination effect – Lagoons as an example - if sea level is rising the lagoons would move but they can't due to humans (coastal squeeze) so if humans were not present, they would not be irreplaceable
- Maybe more needs to be done in discovering what has been done in terms of habitat creation – example in introduction, terrestrial habitats being more recreatable as a result of human intervention – this may not be the same in the marine environment.
- When biotopes were being created (David Connor and Jim Allen), a massive database analysis was carried out and looked at all environments, what species were these, characterising species etc - A characterising species does not need to be a dominant species, they were finding that some of these species were quite rare but are still a characterising species of a biotope - It may not be a dominant species to a habitat but it only occurs there and it is important to that habitat. Then this links to dependencies – does that species only occur there because something else does. Irreplaceable habitat with irreplaceable species within that of key interest.

- Inshore we can replace habitats, we can create mudflats, salt marshes but offshore we can't do this without losing another habitat and need to create the right hydrodynamic conditions to ensure sediment supply etc– this is difficult. With offshore areas we don't have the ability to engineer and help the habitat to recover – we will remove the stressor and hope that/expect it to recover on its own.

Question 1. Evidence Gaps

For many aspects of irreplaceability and the associated criteria suggested by the review, the literature is extensive and we are not able to review fully in the timescale. We would like to identify any key gaps in the literature review, are you aware of any further definitions of irreplaceability, concepts or criteria that we should consider?

Overall no interviewees highlighted significant gaps. Pointers for additional information were to consider connectivity as an additional aspect. In terms of essential fish habitats and other projects (such as INSITE) one of the challenges is how much does connectivity make a habitat essential or irreplaceable? And is it is one of the features of replaceability, the fact that it is linked in some way to something else?

Question 2. Definition of irreplaceability

We have proposed a definition of irreplaceability, that considers key criteria for irreplaceability: difficulty of recovery, restoration or re-creation, rarity, environmental context and fragility and a component of value (conservation value, function, cultural heritage) in order to understand the significance of irreplaceable habitats. What aspects of this do you disagree with? What do you think should be changed, if anything?

Suggested definition of marine habitat irreplaceability "Irreplaceable marine habitats are those which are not possible to restore, recreate or replace easily. They may be rare (based on extent, range and distribution), unique in terms of environmental context and fragile (vulnerable and slow to recover). The significance of irreplaceable habitats increases with value based on conservation interest, function and cultural heritage."

General considerations around irreplaceability definition

- Nothing wrong with the definition
- Definition should focus on aspects that can be measured– whether this is going to be a quantifiable measurement or using best expert judgement.
- The suggested definition is similar to the National Marine Planning Framework (NMPF) definition, if the same definitions can be used this is good because it can avoid confusion and the risk of having too many definitions. The first sentence of the NMPF would be useable and the second sentence would be

tweaked –. Align/use the definition with the terrestrial definition – streamline the definition

- What you are doing is splitting the definition into what are the main characteristics and then what are the tools for using those characteristics? So things like significance may actually come into the tool for identifying feature significance and then that leads into well, how do we merge all these? How do we weight them? I don't know whether the endpoint is to come up with that the number that says an area is irreplaceable.

General points on definition and irreplaceability

- Ultimate definition should focus on the irreplaceability
- Nothing wrong with the definition (no changes suggested)
- The definition I don't have any particular issue with because I think the first sentence sums it up that irreplaceable marine habitats are those which is not possible to restore, recreate, or replace easily. And I think that that's fine. Because that would cover a whole suite of particular impacts or whether that's significant damage.
- Interviewees liked the definition and suggested the inclusion of the scale element
- Discussions on definition are taking place with essential fish habitats, the definition for essential fish habitats has become more complex because of the issue that a short definition does not cover everything. Providing complexity can therefore improve a definition.
- Questioned why restoration, recreation and replacement are included in the definition – these are similar terms, how are they different? – the word restore may be being used in the way the interviewee would use the word recover – restoration suggests something active, recovery imply natural recovery without human intervention.
- Are we saying a habitat restoration/recovery can be achieved or is it not achievable – if we don’t make this clear it could leave the definition up for interpretation and make applying the definition difficult, could raise interesting discussions down the line
- Does irreplaceable according to the definition equal irrecoverable? – if stressors are removed can it recover on its own - through either active or passive recovery?
- The 3 values – cultural heritage, function, conservation interest are very location specific so maybe they should not be included in the definition and more the application of the definition, stating that these are what needed to be considered to assess the significance – significance is important but perhaps does not come in at the same stage

Suggested improvements to definition

- Add recovery to definition

- Interviewee questioned the use of the word easily -that's a subjective term, what is easy to, to one or a group of people may be different for others. And it depends on the expertise at the time, the knowledge at the time and considerations around funding and desire as well. If a sandbank feature was somehow destroyed or swept away, it can’t very easily be replaced, certainly not by us anyway. (MBA: Could “easily” be caveated by technical feasibility and cost)
- Interviewee suggested altering the first sentence on the definition to say “marine irreplaceable habitats are those where effects of either single or in combination impact leveraged upon a habitat would mean that restoration recreation or replacement would not be easily achievable”
- Combination of restoration and recovery, the interviewee suggested that these are different/separate, stating that recover is natural recovery rates whereas restoration potential is more anthropogenic restoration – for example you could have a habitat which has a long natural recovery potential like cold water coral reefs but humans can’t restore these, so therefore the 2 are conflicting.
- Criteria are more focused on assessing the conservation importance of habitat rather than irreplaceability – felt more like a weighting for the importance of habitats rather than whether they are replaceable. For example in discussion, extensive areas of sediments which may be widespread and therefore of lower conservation value but this does not necessarily make them more recreatable/replaceable. Caution that this potentially could downgrade their importance in conservation terms but can also be an approach which leads to the common place becoming rare, because it is less valued. How do you create sediment habitat, for example, if you needed to? You can improve the quality of existing sediment habitat or increase the quality of existing reef habitat. But if you lose it in its totality, then it is irreplaceable.

Discussion on criteria included in the definition

- Include recovery in definition and include information to separate the restoration potential and recovery rather than combining them
- Replace is slightly more nuanced in that it could be argued that if lost it's replaced by the fact that its widespread elsewhere and that could be a slight concern. But then I think that replacement is then covered by looking at rarity and significance in the subsequent two sentences.
- Consider artificial replacement of habitats – this will come up with developers.
- Interviewee suggested in the last sentence of the definition – function element is important consideration in significance part of the definition.
- Function move into the core considerations rather than using it for significance, without it the definition may be too narrow and we won’t be bringing in some habitats which would be considered irreplaceable if we are considering the functions.
- Species diversity is not part of the criteria – how will the species factor into the criteria in terms of the habitat

Discussions around significance criteria

- Drop the part of the definition which looks at significance
- I think with the two part approach is a good system, and I think this should be used together, actually, to define what is irreplaceable and what should be considered essential. I think that's a really wise thing to do.
- Interviewees interested in the significance and value aspects within the definition, suggested that this is more of the weighting of significance rather than irreplaceability - saying that something is irreplaceable due to those ecosystem services. Does not think that function should come into the definition just application of the definition, in order to apply the definition you may then want to think about significance.
- If you remove the aspect of significance from the definition this will make the definition easier to align with the NMPF definition.
- Significance is an important thing to consider but interviewee does not think that alone you can assign a habitat as irreplaceable based on function, cultural heritage or conservation interest.
- Conservation interest, function and cultural heritage, are all good. I wondered if there was a socio economic point to include around commercial value, like commercially important fish stocks, tourism and similar.
- Interviewees have suggested that we need to be clear in what we include in terms of value.
- How do you make the significance operational? -- Horizon Europe proposal – valuing marine biodiversity being split up into ecological valuation, socio economic valuation, socio ecological valuation. The socio ecological and socio economic can be monetized – in the environment with two sets of currency, ecological currency (in our project) is more touchy feely nice things in the environment and the others more concrete and can be monetized
- Describe what is meant in terms of conservation value – no explanation for 'conservation value'

Discussions around cultural heritage

Cultural aspects – may be going too far into the project that isn't required – are we saying that something is irreplaceable for the natural functioning of the system or irreplaceable for the way we use the system.

Cultural heritage has a lot of meaning in decision making but is one aspect of value however there are many others which are more or equally as important, depending on the potential contribution in an area.

Cultural Heritage – expand this to include habitats classed as geological features in MCZs as some of them act as more than that (for example English channel outburst features) are these considered irreplaceable because they were formed by glaciation and melting ice caps, they are not going to be reformed and are considered valuable – will this fit in with cultural heritage or expand the definition to include these sorts of situations- significant to our countries paleontological heritage not cultural (MBA note: Some of these habitats may be picked up in environmental context)

There are locally relevant aspects of value and these will effect decision making – a habitat may be more valuable to a particular function or aspect of natural capital in one area than it is in another. If it's not considered at local levels then theoretically irreplaceable habitats could be lost

"All aspects of Natural Capital and how habitats contribute to them (i.e. regardless of whether resulting, provisioning or cultural) will be given consideration when it comes to decision-making about developments and net gain.

If there is flexibility in the list or sliding scale – assessments on the cultural element will include a lot more habitats which the interviewee wouldn't necessarily have said were irreplaceable, and might be too focused on anthropogenic perspectives.

Changes to criteria: those that have been or should be excluded

No reason that you would have to exclude age it's just that you can because it is covered by other aspects such as fragility – If we are trying to keep a consistent definition the interviewee does not think by having age there it would cause any problems like adding in different habitats that we wouldn't consider being irreplaceable in the marine environment – potentially tweak the definition to specifically refer to age.

Question 3. Criteria, definitions and groupings

Do you agree with the criteria (restoration/recovery potential, rarity, environment context, fragility) provided? We have identified where we interpret concepts to overlap in order to develop a subset that encompasses the key criteria identified in the review. Do you agree with the groupings and definitions presented in Table 2 and 3. Should further criteria be added to the definition or should some of these be removed?

Restoration and recovery potential as criteria

- All Marine Habitats are very difficult to recreate, but the cost of damage is higher when the conservation importance is higher –, which probably doesn't help you in terms of defining what irreplaceable habitats are, but it does help in terms of scoring what their overall value is, in terms of common currency.
- Recovery – recovery of habitats and recovery of species is related to the length of time they've been there for habitat or the longevity of a species –there is a paper which looked at if you have a habitat that has a high turnover, or a species which has a quick rate short life cycle/reproduction, these will be expected to recover more quickly than something that hasn't – same with a habitat with mobile components is likely to recover more quickly than those

which only have sedentary ones - this may link to problems with application and grouping those, will have those that recover, those that don't recover and the large group in the middle
- Consider location specific context when assessing recovery potential.

Rarity as a criterion

- Terrestrial net gain application – bring things into a common currency, the rare (nationally or locally) requires a higher value than the widespread. And it's not to say that any of them are more replaceable than others.
- Rarity is harder concept in marine environment due to not having full coverage habitat maps to know where all habitats are, so we might just have limited data on something which is common, but due to limits in evidence/data they would be classed as rare - hard criteria to assess unless it is a geographically distinct habitat
- Uniqueness and rarity can be merged together as they feel similar – anything that would be considered unique will also be high on the rarity scale – there are differences as something rare in one region might not be rare in another region. However this was countered as interviewee who noted you might have something that is unique to the UK or to English waters, but it's not particularly rare in regions of the UK, it might be the only place in the world where this species or whatever exists, but it can be found in most waters around the UK.
- There is a distinction there but also lots of overlap – but to not miss any habitat out you should still keep rarity and uniqueness separate
- In response to suggestion by the interviewer that we may be able to incorporate rare species into conservation interest or function: this is a different question to what we are trying to answer as advice on the species separate to advice on the habitat so would not matter – there are only a few rare species which are habitat forming and are then included in the EUNIS classification. Rare species will be advised on in their own right anyway (Check interview and/or transcript).
- Interviewee noted that a lack of knowledge could be interpreted as rarity for things like the Lagoon species we don't know very much about their distribution, and how well they distribute, redistribute and where they're located, some are hard to identify and so with limited distribution knowledge the species may be well – might be an artifact of under recording
- Rare species are a challenge - under reporting of species which are considered rare – another reason why EUNIS level 3 habitats won't work – challenge how we associate rare species with habitats in a habitat based definition

Environmental context/uniqueness as criteria

- Uniqueness – Interviewee suggested that uniqueness is based on unique combination of features. For example, medium sand is an extensive and widely distributed habitats, but a given sediment type of organic input and given delivery of recruiting stages because its in the path of a current which goes from another patch of sand but only reason this patch of sand works is because it is connected to another patch of sand somewhere else that delivers the recruiting stages to it – it is partly a unique feature but it is actually a unique combination of features. If you remove one of those in the combination, so removing one unique feature with makes up an area it will impact the whole system.

- Generally if the physics is right then the biology will recolonize or colonise up to a limit, problems arise from not understanding the physics when trying to create the biology – are habitats irreplaceable because a certain type of physics is controlling them or is it because of the biology. The niche and biology which influences things such as predator prey trophic relations, competition etc, this creates the unique community.
- Environmental context is hard to understand what it means – rarity and uniqueness are similar
- Merge together rarity and unique – changing environmental context to uniqueness could make it easier to understand but still overlaps with rarity
- Is there a better word which encompasses both rarity and uniqueness
- Hard for something to be unique without it being rare but it could be rare without it being unique. There is overlap between them all
- Climate change can also be linked into uniqueness – if looking at uniqueness within a bio region and where the habitat is located

Fragility as a criterion

- Fragility = resistance – measures grouped under fragility, interviewee comments on these measures relating to resilience rather than resistance (MBA: the traits used to assess fragility relate to both resistance and resilience)
- Fragility and recovery are similar/overlap – interviewee interpreted recovery as resilience and fragility as resistance
- Interviewee was not sure on the use of the word fragility as the name for the criterion, suggested 'resistance' instead. Fragility has a specific meaning and could be misused when applying the criteria, users could just think about physical fragility but the project are using the word to describe a broader resistance to any kind of pressures/impacts. My concern is that if, if it was applied with that term, it could some people could misinterpret what that means and will result in the assessment being used incorrectly for this criterion. I agree it cannot be called sensitivity, because you have (quite rightly) separated recovery and resistance here (the two aspects of sensitivity)". The term resistance is not that well understood but may be a broader word than fragility.
- Rate of growth, reproduction, colonisation and recruitment differs across deep sea habitats we are worried about and consider vulnerable – different magnitudes of vulnerability are captured by the criteria: for example:
    - *Lophelia petusa* can spread and grow rapidly if the conditions are right, whereas some of the other deep sea corals grow slowly and don't recruit very much especially Antipatharians
    - Antipatharians are an order of magnitude more vulnerable

- Some deep sea corals (Antipatharians) are so long lived and fragile, they are especially vulnerable. These would be flagged up the most – these will be picked up under fragility, age of organisms and growth rate – flagged as irreplaceable
- Ones that form their habitats away from the main reefs, deep sea trawlers don't avoid them as they are delicate Antipatharians and don't damage the net or fish.

Should further criteria be added to the definition?

- Species richness discussed as an additional criteria. Including species could feed into the protective sites narrative in terms of when saying a habitat is important in the conservation advice biotopes will be listed, why these are rare, why unique and the species complexity
- Connectivity was highlighted as being of particular value (see uniqueness above), habitats that are more connected could result in greater impacts from removal. How much does connectivity make a habitat essential or irreplaceable – is one of the features of irreplaceability that fact that the habitat is linked in some way to something else or is the linking that makes it function?
- The paper covers spatial scale. I wondered if there needs to be the inclusion of a temporal scale as well, and how that matters for replicability or recoverability. Are we talking about recoverability? Over 10s of years, hundreds of years? What is the temporal scale that we're using, and we want to use? Based around discussion in the interview it was suggested that in terms of policies and ambition for the marine environment for favourable condition etc. that 25 years, 25 -30, 40 years is realistic and measurable.

Adding functional criteria

Interviewees were asked for viewpoints on including criteria or measures of ecological functioning and if this should be included, did they have any suggestions on which functions.

- Function needs to be considered – the Seven Estuary mobile muds example – Even though it can be assumed that just because nothing/not a lot is living in the Seven Estuary it is not irreplaceable but it must be delivering some function, playing a part in that ecosystem from a biodiversity point of view it is irreplaceable
- Separating out the functions with goods and benefits that are of interest to humans (provisioning services) and focusing on the ecological processes and functions – Interviewee suggested a ranking system, if you separate the truly physical habitats that can't be recreated then function is a useful criteria to then identify the importance of things in terms of irreplaceability, the separating will be useful in the main section of the report.
- I do think that the function element is really important. I can see where maybe some of the cultural heritage sites, you wouldn't want to weight it too heavily.

And I think, you have the truly physically irreplaceable habitats. And then you had this scale about how do you decide the amounts and the types of habitat and at what stage do they become irreplaceable? And I do think that function has to be an important consideration there. I know, it's not part of your upfront criteria. But to me, I feel that we do relate back to structure and function a lot. It might not be as easy to evidence and especially when it's complex, but I did feel like that was a really key element there as well, the functional side of things.

- Function is not that well defined, consider function more widely in terms of services and natural capital – this is the direction decision making is going in. if you've really separated out, physical habitats that can't be recreated, then, in my mind, I think function is a useful criteria to then whittle down the importance of things in terms of replaceability.
- Function is one of the attributes used in JNCC conservation advice, function is important – have a look at the conservation advice might give information on how JNCC look at function
- Agree that the function aspect will become location specific, for example in the JNCC HPMA work function is being considered.
- Worth looking at what policy objectives there are that drive decisions of relevance to ecosystem services – if you have a habitat that is supporting quite a few services that politically are important because of these policy objectives, then these are important and of value regardless of economic value.
- Could make things complex but if there was a way of grouping functions it will be a useful element to the decision making.
- Interviewee did not see a reason for giving cultural heritage services more prominence than other important ecosystem service values "(e.g. contribution to coastal erosion prevention, climate regulation, habitat provisioning for commercially important species)" When discussing scale of irreplaceability and referring to the functions, interviewee suggested including a suite of functions, range of services and level of provision
- Include blue carbon and filtering in function – where would blue carbon come into the value aspect?
- If looking at species and people these are external receivers of the function/services but for habitats perhaps we should we focusing on the functions which maintain or support the habitat or other – environmental/ecological importance – would not include provisioning services
- Functional measures could consider the amount of services/functions that a habitat can provide/deliver (providing services such as life cycle for species, carbon capture related) rather than focusing on one particular function on its own.
- Criteria may need to look at whether the habitat in the location being considered is either providing a unique contribution to an important service for that area or contributing to many services that are of relevance in terms of the contribution in that area.
- Where functions are distinctive or there's only one of that function represented (at a regional scale), then that must have intrinsic value. For example, the only reef on the east coast of England would clearly be more important than

hundreds upon hundreds of reefs on the West of England, but that's covered with the geographical uniqueness. However, giving it a value in terms of the functions like larval dispersal, nurseries for juvenile fish, or juvenile species, nutrient and CO2 uptake? I don't know if I could say which one's more important than others? If there's a habitat that provides many functions, but not a high level of any of them. Is it more intrinsically valuable or more irreplaceable than one that only provides one function but to a high level. That's a difficult one to answer honestly.

- Essential fish habitat, consider habitat functions, through key spawning grounds, for example, rocky spawning habitats, so that might provide the weighting for particular, particular habitats as well, or of particular habitats in particular locations.
- If considering provision of habitat, or provision of shelter, if that then includes species, that adds complexity because then you've got the functions of those species there but that may be worth considering. Does the habitat provide a biome for unique species or unique communities?
- Including rare species as an ecosystem function of a habitat – a habitat will support rare species that might otherwise not be considered by a characterising species of that biotope or habitat but when the rare species do occur they plan an important part, may be ecosystem engineers - but are they though?
- If an area was the last remaining recorded nursery for an incredibly endangered species, but that habitat itself might not be particularly distinguishable from others, you know, but the fact that its acting as that one remaining nursery, that does imply some sort of a irreplaceability - knock on effect of losing that habitat could lead to the potential extinction or at least local national extinction of a highly endangered species.
- There is increased understanding more broadly within conservation bodies on considering provisioning services/services that have economic value is important, as well as ones that don't have economic importance.
- Worth looking at what policy objectives there are that drive decisions of relevance to ecosystem services – if you have a habitat that is supporting quite a few services that politically are important because of these policy objectives, then these are important and of value regardless of economic value - this is one of the problems with applying the definition.
- Interviewee suggested we don't know enough about the function of each community or biotope for lots of different levels enough at the moment to use natural capital as a definition – then it becomes hard to use natural capital and functions to define irreplaceability - we could use those factors to define but we haven't got the evidence to inform/define it.
- We don't have the joined up evidence for functions – something to consider for the future*

Question 4. What makes a habitat irreplaceable

What makes a habitat irreplaceable? Is it that it cannot be physically recreated/replaced exactly elsewhere or is it more that the function it is providing cannot be recreated/replaced elsewhere. There are issues with the definition that are difficult to resolve, for example, questions around scale of loss and the point at which replaceable broadscale habitats become irreplaceable and whether irreplaceability has a location dependency?

- Why does irreplaceability matter – is it the function of the habitat what makes it irreplaceable or the kind of habitat itself? In the way that we are working, there is now more emphasis being put on the functioning of the system but often nature conservation, policy and discussion is based on structure how much of something there is.
- Function is a very anthropocentric metric, which is applied to the natural world or ecology, if we were to just use function, and the consideration that things are similar or equal if they provide the same functions or ecosystem services that will do an injustice to the uniqueness. So I'm glad that function, uniqueness and other criteria are used in conjunction. Because, personally, I see there's an intrinsic, almost immeasurable value in diversity. So I'm really glad that that was captured.
- Function will depend if that habitat is the only or the main habitat performing a specific function - if that same function is being carried out/delivered somewhere else is it still irreplaceable?
- Invasive species, the functions an invasive species can provide may be the same function as a native species can provide. Habitats formed by invasive species something to consider – we have invasive species forming habitats now and providing ecosystem services – can't ignore it
- Irreplaceability needs to consider both function and the physical recreation/replacement potential in the definition – important to consider for example "how unique is the function contribution of that habitat in that place" – this will vary by location – could have a habitat that is functionally really important/unique in one area but not in another – this needs to be considered and is a drawback for applying an index at the national scale.
- Something that's a valuable habitat may be more valuable for particular functional aspects of natural capital in one area than it is another. So I think that needs to be looked at.
- Interviewee suggested that the spatial scales are of lesser importance: what should be prioritized is what is physically irreplaceable, or is there a complex mix of things going on which make the habitat irreplaceable?

Examples of location dependency for irreplaceability and function

- European project on Maerl beds revealed no two Maerl beds are the same and no two have exactly the same set of Maerl beds in them, or the same architecture. Some types of Maerl bed which have extremely high coverage of live Maerl, like St Mawes Bank in Falmouth and in Scotland, are precious – most Maerl beds have low cover because moved around by storms

- Flamborough Head –a local sandbank has a good sandeel population within an easy flying range of the seabirds and close to where the birds nest in Flamborough Head– if this sandbank with a good sandeel population was further offshore they wouldn't access it as easily – example showing it is the combination (suitable nesting site, sandeel population and seabirds) which makes the sandbanks irreplaceable.
- Irreplaceability and spatial scale. Depends on the Maerl resource that is there – Orkney Maerl bed is large but the St Mawes Bank in Falmouth which is the best and only example of a Maerl bed in England, don't want damage to occur here
- Dogger Bank some people would describe as irreplaceable in terms of the geological aspect – would Dogger Bank be considered irreplaceable as fragility relates to sensitivity and the sand here is considered moderate/high sensitivity. Another interviewee raised the difference between Dogger Bank and inshore sands. Dogger bank is a relic from the ice age whereas sandbanks and coarse sediments which are inshore and very mobile will recover quickly as long as the physical conditions are created.
- In an area with only one patch of a habitat (for example circalittoral rock along the East coast) this is physically no more irreplaceable than an area of that habitat (for example, circalittoral rock in the south west) where this is common and extensive. The loss of that habitat will be the same in terms of irreplaceability but in terms of conservation importance you could argue the smaller patch (circalittoral rock on the East coast) is more important because it is much less wide spread in that area. This feeds into spatial scale considerations, if you have a patch of habitat (circalittoral rock) that is isolated (little or no circalittoral rock around it), there won't be much chance of colonisation so does this increase its importance and make it irreplaceable. (This point is picked up by interview discussions around connectivity).
- Is a habitat more irreplaceable if it is less connected or if its more connected? If connected to lots of other things it is expected to recover more easily and expect it to occur is other places – If it is not connected, isolated, a habitat on its own, there is no way you are going to recreate it. The interviewee described another paper of his which focused on connectivity in ecological and management sector and listed a large set of connectivity's (economic, ecological, legislative connectivity etc) – connectivity is important. Connectivity could be included stating that it is important for functioning, but we might not need to include it in terms of irreplaceability because if something is more connected it is less vulnerable (MBA Note: but this would need to be made explicit).

Question 5. Measures to evaluate criteria

We have identified a number of measures to evaluate each criteria, would you suggest any revisions deletions or alternatives to these? If you are aware of additional key evidence sources to support assessments against each criteria, could you identify these and if possible provide a link or copy.

There were very few additional measures or assessments identified, some examples but with limited habitat coverage are provided at the end of this document. A clear evidence gap was information on extent, distribution and rarity of habitats. One interviewee noted they had published a paper on distribution of octocorallia worldwide – for every organism you can spend days finding out how prevalent it is. Interviewee spent 3 months compiling a list of where deep sea corals lived based on what was published in the MBA library.

Question 6. Issues assessing irreplaceability

What issues do you foresee assessing the irreplaceability of marine habitats according to the definition? A key uncertainty identified by the review is identifying spatial thresholds at which impacts may render habitats that are larger in extent irreplaceable. Are you aware of any assessments or reviews that would support setting thresholds for the scale of impact on specific habitats?

Issues assessing irreplaceability according to the definition

- What, if it's difficult to determine physically or biologically habitats and recovery (for habitats that don't sit readily within EUNIS classification)?
- How are evidence poor habitats treated? Where we don't know if they are irreplaceable, or if we don't know if it fits this definition, once supplied? I would probably err on the side of the precautionary approach. And if a habitat doesn't have enough information on it, then surely we should try and conserve as much as possible.
- A number of the criteria only make sense for decision making at a location specific scale
- Lack of consistent overviews for habitats is an issue in applying the criteria – lack of evidence
- Lack of evidence for habitats, particularly deep sea habitats, where we don't know much about the recoverability of those habitats, they're very difficult to survey.
- The lack of data and evidence gaps, scarcity of information in areas. The difficulty that the marine environment is really in flux, and difficult to measure time on time

Assessments or reviews that would support setting thresholds for the scale of impact on specific habitats?

There is a consensus that there is no evidence to assess spatial scales or thresholds for a generic, national index but that this would be more tractable (but still without defensible evidence) at regional or local scales.

- No evidence missed
- Not aware of any threshold evidence
- Criteria can apply to a location or for a site or a region, but actually nationally, that that's more of a challenge to make a blanket statement and say subtidal sands are replaceable, but you can lose 10% but they stay present

- Don’t want to say nothing can happen to a Maerl bed ever, this is not a manageable situation – caution is required but will depend on the scale of the feature and the type of feature and is therefore location specific.
- No, these are site specific and difficult to set a threshold – challenging when setting the threshold with different site sizes.
- Setting spatial scale and thresholds is location specific
- No, in an answer, I've literally just come off a call discussing thresholds for exactly that reason. And I think we all agreed it was very difficult, very science specific. So it's quite challenging. But certainly in terms of setting thresholds, when you say, for example, 1% of habitat loss, you know, is okay, or 2% is significant, or whatever, , that that may be fine when you're applying it to a relatively small site. But when you start applying it to something the size of say the Severn, then you could lose, quite a few hectares of mudflat before the threshold was breached. So I think I think any measure has to be site specific and based on a whole series of factors like review, regional consideration in terms of local rarity versus national rarity.
- Around casework you have to make that judgement, based on a lot of different factors. According to the site, really. Difficult to consistently apply across the country.
- Problem of loss of area and using a criterion - if you lose 1% in one area, is this the same as losing 1% in another area and/or losing 1% in one area might be as bad as losing 5% or more in another area – David Connors original work on limits of acceptable change, (what could we include and not worry about change) – worry about putting percentages on it, as when it comes to policy decision making the percentage will become set in stone.
- Spatial thresholds for loss – interviewee noted some work related to the MSFD and will find those thresholds
- Reports for David Connor (JNCC or English Nature) limits of acceptable change was going to include how they were going to implement the habitats directive – limits of acceptable changes, is an irreplaceable habitat which you can’t put back afterwards – may be a limited range of habitats
- Only thing aware of around thresholds is the relationship with biodiversity and species area curve – there is info on how to work this out but it varies on location and habitat and difficult to collect the data to back this up – also this is only about spatial scale that is needed to protect a certain amount of the biodiversity of the habitats, not about the broader value – the only form of quantitative approach to application but limited in terms of application and what it says, it is resource intensive.
- There are studies out there which describe the relationship between area and functions but again not enough data in UK to apply that.
- I wonder if the only considerations of that would be anything on the industrial scale for example, large dredging works, or piling which is left after gas infrastructure. Obviously, that has a huge impact on quite a small spatial scale, relatively, of course. But that does transform habitat quite considerably. Or the other way around, has the change transformed one habitat to another and therefore replaced it.

- Approach should be applied at regional seas level which has its own difficulties because the variability within them is so huge, but But I think it can only can be considered at that level. I think that's probably the most sensible approach until we find, perhaps a better approach. But I think you need to apply an approach before you can find a better one.
- Habitat classification and level of assessment
- EUNIS level 3 coverage of data is good but not workable for irreplaceability assessments because it is too broad, hard to state that a level 3 is irreplaceable – this risks losing the weighting of the criteria.
- Difficulties with biotopes anyway due to their nature as a dynamic system -to try and categorise habitats and biological communities which live upon them is so difficult. It's all in flux. It's very dynamic. A survey is simply a single time point. If it's if it's any more detailed or specific than EUNIS four, there may be issues because then you just get into greater variability, you've got more variables to try and deliver. In the field identifying the boundaries can be challenging- has the habitat been lost if circalittoral gravel shifts to circalittoral sand and at what boundary point does that shift happen?
- After trying an impact assessment on EUNIS level 3, we have found it doesn't work because you exclude massive areas to certain impacts–you risk losing significance and credibility trying to do it at level 3 from a planning perspective if only 5% is irreplaceable someone may just ignore the assessment all together
- Problems are created by only using EUNIS level 3 and 4 habitats because so many of the characterising features are at 5 and/or 6 – where you will see ecosystem engineers and really dominant species – example one sandbank is not equivalent to another
- The EUNIS classification is structured based on characteristic species rather than rare species – there are a few habitats where the key structural and functional species are apparent but for other biotopes these aren't so clear.
- Functional link to mobile species may not be adequately represented through the habitat classifications – make this clearer in the report –, that sort of functional question around habitats that are providing a key area for a life stage, seahorses and seagrass would probably be one of those clear examples.

Question 7. Suggestions for method and scoring

Do you think a sliding scale or matrix approach will be helpful in determining which habitats are irreplaceable, or do you have other suggestions for the method and scoring? What do you see as the benefits or limitations of this approach and its application.

General comments on assessing irreplaceability

- Need to think about the scale of significance – is it the more boxes it ticks, more irreplaceable?

- Be careful of colours used/ avoid colours– often colours can indicate if something is bad (red) or something is good (green) but in this topic we should avoid the good and bad, and focus on is it irreplaceable or not and can be recovered in some way
- Suggestion to carry out a cluster analysis to try and look at what pressures/criteria/measures would come out clustered together – set of habitats which are scored according to the criteria, within the criteria the measures are given a score and then do a cluster analysis of those to say which of our habitats should be treated in a similar way, which seem to be as irreplaceable as other ones
- Identify what is the ideal diagram that you would want? – then you can compare this to the diagrams created from the scoring
- Complexity is good when showing the complexity of the system
- NE will need a look up tool, to look at different habitats and all their scores

Weighting irreplaceability

General consensus emerged from the interviews that criteria should be weighted and with a range of scores rather than a yes or no. Around core irreplaceability criteria meeting a single criterion should be enough to flag up a habitat as irreplaceable.

- Despite evidence gaps a red flag on some of the criteria should be enough to identify a habitat with low replaceability or more vulnerable – this should be enough
- Don't treat the criteria as the same as each other – they are not equal and there is a hierarchy within the criteria
- Multi metric approach – measure lots of things and try to bring them all together to give that a number/score need to think about weighting, is everything equal? Is some measures/criteria more equal than others or are we double counting?
- All criteria are not equal so need a prioritisation approach to determine habitats rather than a single score at the end – (if x,y,z happens, then this is irreplaceable and this needs protection)
- Might be a good idea to state which criteria are relevant regardless of location and which need location specific consideration and for those which need location specific consideration can you give a range of possible outcomes for someone to look at.
- When applying score to criteria – some criteria for example uniqueness – is either yes its unique or its not – this might skew when scoring – may need to be a weighting on the criteria, a score from less important to move important for example.
- To avoid issues of evidence gaps - in the matrix include certain level of expertise and leave an option there for any other factors which may help argue that this habitat is irreplaceable so we don't lose any level of information
- Suggest a test run of scoring criteria – working through the different biotopes, see the scores, ignoring the process on how you got there, and see what results are gained, which habitats are flagged up as irreplaceable and which aren't – then adjust the criteria based on that – an assessment and then modify a set of criteria

Matrices: for and against

- Depending on your use, or, you know, whoever is using the information, it may be very aligned, with what they do and how they operate- used by industry, and everyone. It does give a wealth of information, I would say but it's not the easiest thing to look at. If it’s for engagement for public or, or those that are perhaps less informed, this can seem a little bit intimidating. That's where I think the sliding scale and the radar mapping, I think are interesting and certainly give different aspects of information.
- Sliding scale and radar plots illustrate things clearly on a single habitat scale but when taking it to a developer, having a score on a matrix saying this is irrelaceable, has high irreplaceability and this site has low irreplaceability (scoring low, medium and high) – application of this may be easier. So having a Matrix with scores may be easier and simpler for everyone to understand.
- Scores on the Matrix would need to take into account different weighting you apply to different criteria
- Could assign a confidence/confidence assessment to each criteria to solve problems on evidence gaps – have different degrees of confidence levels because you might have evidence on only some of the measures assessing the criteria – for example you may have evidence on a habitat location but no evidence on rarity – these different levels can contribute to an overall confidence score.

Sliding scale: for and against

- Sliding scale looks good.
- I personally don't like the sliding scales, but I can see the value and I think it's a nice way of displaying information.

Radar plots: for and against

- Radar plot – set of characteristics for each criteria, scored characteristics from centre to outer, then give it a colour which reinforces it, join the points up giving a spiders web – then you can say how does this area compare with another area according to the shape
- Could come up with the area of the radar plot as a single score in terms of overall replace ability – will come up with a single number
- Radar plots good for multiple criteria, but might end up with every habitat having its own radar plot.
- I personally really like the radar maps, I actually think that's really nice. And I just like, I like the visual element of a radar map. And it's a singular image, despite the fact it holds quite a lot of information at times. And, of course, the more criteria you add your five point, Pentagon like this one, measuring against five metrics, makes a lot of very clear. Very nice. If you added more criteria it would become a little bit more difficult to distinguish. Radar plots support comparison and can show progression.

Habitats identified by interviewees as irreplaceable

- Lagoons have a rare natural recovery
- Living Maerl beds stand out as irreplaceable habitat. Top most important Maerl bed types, will be the ones that have got rare Maerl species which construct them – don't think there are any in England. Attempts to move a long lived habitat from one place to another are never going to work properly – can't replace a Maerl bed by moving it, maybe you could with other habitats – translocation of individuals – risky and might not ever be as good as the original – might never restore to the end point. Main transplantation occurred in Milford Haven, Wales – try to move to Maerl bed but it did not survive. Experimental transplantation in Fal – where they transplanted dead Maerl habitat, the sparse growing species that live in the habitat came back quickly as you might aspect but the problem with the study is it did not look at live Maerl and did not look at the long lived slow growing Maerl itself or long lived organisms that live in Maerl (such as long-lived bivalves)
- Deep sea corals and deep sea sponges are vulnerable but vulnerability is variable between species: Deep sea coral reefs/sponge reefs – Lophelia pertusa grow quickly (4cm a year), know this from how quickly they grow on oil rigs, our knowledge of how quickly/easily they can restore has increased/evolved. If enough food, oxygen and other things that they need in the water they can grow quickly – whereas the habitats grow slowly.

Additional information identified

- NE work on defining essential fish habitats – unlikely will be ready before our project is done but worth flagging up of future alterations.
- List of key influential structural and functional species may be a way of including species in habitat definition/criteria
- OSPAR threatened and declining list - match up with the classification
- For work on recovery- Lyme Bay monitoring reports and the Lyme Bay monitoring surveys (interviewee offered to provide).
- Culhane and others (2019) Annex 1 - provides evidence on the link between habitats and all CICES ESs (version 4 I think). This is at a broad habitat level, but it gives examples based on species (animals, plants, algae) that are resident and how the habitat is known to supply each service – broad level so won't take to biotope level, but because of some of the examples used it will cover some of the biotopes
- S. Gubbay comments on pressures – discussing what is a pressure and where it is coming from – a risk and hazard typology was published – of this list of hazards and lists what are they vulnerable to?
- Paleoenvironment evidence – the Interviewee will have a chat with one of the NE geomorphologists because they have struggled to work on case work on MCZs which have got paleo features, there may be something in the previous geological conservation review (GCR) that gives this information. MCZ designation documents – in ecological network guidance documents they had links to various sites from the

GCR which were considered to have importance – find some of the information in these documents.

- Rarity resources – Favourable conservation status documents in NE for Annex 1 MCZ BSH – these do summaries of things like rarity but there is not much detail, and only have a few marine ones
- Anna Tornroos (work in Finland) PhD thesis on life history traits and the valuation of those, it is in a Baltic context. https://www.doria.fi/handle/10024/94513
- There is a lot of work on the way species are connected – Marine Conservation Zone work where they were looking at is an area connected if it's between 40 and 80 km apart (on the basis that this is the distance a larvae will travel), this has never been tested.

Appendix 9. Review of Legislative Framework for Marine Habitats

The policy map (Figure 4) illustrates the complex framework of current marine policy and legislation that protects English marine habitats. The centre of the policy map includes habitats which are protected through Marine Protected Area (MPAs) designations, conservation targets and lists of conservation interest habitats and features. As the map expands it shows the legislative frameworks that designated the different forms of protection which marine habitats are placed under. The international legislations and European directives that are represented in the policy map show the broader scale conservation regulations and these legislations are transposed into UK regulations, providing the foundation to conserve English marine habitats.

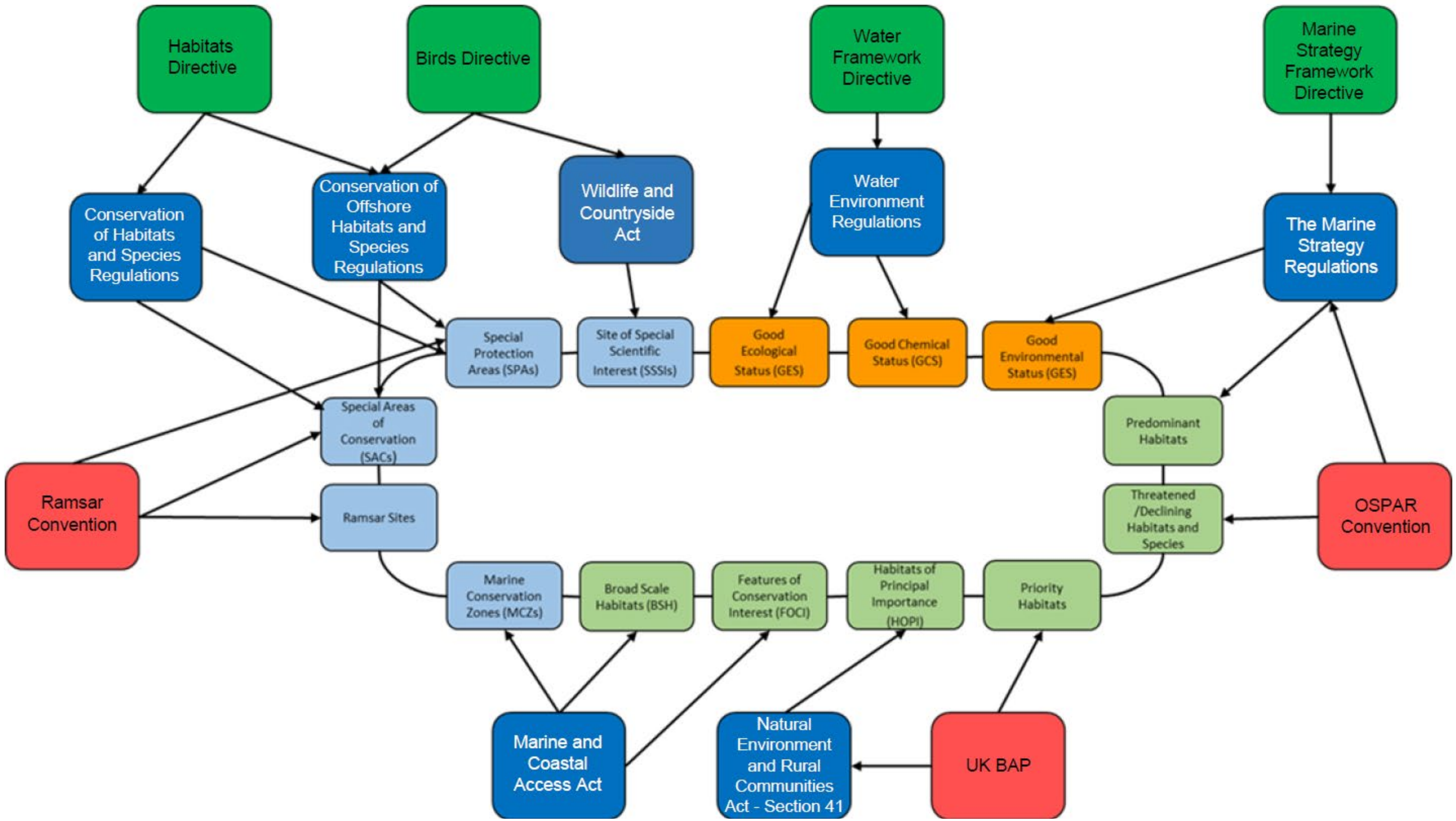

Figure 5: Policy map illustrating current marine policy and legislation that protects English marine habitats.

MPAs are defined areas of the marine environment which are established to achieve long term conservation and sustainable use. The network of legally protected MPAs protecting habitats and conservation features within the UK has grown in the past decade (Rush and Solandt, 2017). Within the UK there are multiple different types of MPAs, including Special Protection Areas (SPAs), Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs), Ramsar Sites and Marine Conservation Zones (MCZs) as represented in the policy map.

Birds Directive is a European Union (EU) Directive which aims to protect wild birds and their nests, in order to protect these wild birds from threats such as habitat loss and degradation protection was afforded through the selection of Special Protection Areas (SPAs) which would protect bird species listen in Annex I of the directive. The Wildlife and Countryside Act 1981 (as amended) is a piece of primary legislation that implemented the EU Birds Directive into the United Kingdom. The establishment of SPAs in the marine environment is still ongoing and by 2020, there were 123 SPAs with marine components in the UK (EC website). The Wildlife and Countryside Act also provided the legislation for the selection and designation of Sites of Special Scientific Interest. The criteria states that a site will become an SSSI if it is ‘of special interest by reason of any of its flora, fauna, or geological or physiological features’.

The EU Conservation of Natural Habitats and of Wild Fauna and Flora 1992 (also referred to as the Habitats Directive) has been transposed UK primary legislation as The Conservation of Habitats and Species Regulations 2017. The Habitats Directive required the implementation of a network of Special Areas of Conservation which would protect habitats listed in Annex I of the directive that are considered to be of ‘community interest’ in order to maintain and/or achieve “Favourable Conservation Status” (Trouwborst and Dotinga 2011). The habitats listed in Annex I must achieve Favourable Conservation Status under the directive, the conservation status is the combined influences acting on a natural habitat and its species that may have long term effects on natural distribution, structure, functions and the survival of species that live in a particular habitats. Within the UK there are 116 SACs in UK marine waters (JNCC website 2020).

The Conservation of Offshore Marine Habitats and Species 2017 (as amended) implemented the protection requirements of the Habitats and Birds Directive in the UK offshore marine area, this is waters more than 12 nautical miles in the UK Exclusive Economic Zone and the seabed in the UK Extended Continental Shelf. There are 25 marine SACs out of the 116 which are within the offshore waters. Both SPAs and SACs create a network of protected areas described as Natura 2000.

The Convention on Wetlands of International Importance especially as Waterfowl Habitat (also referred to as the Ramsar Convention) provided an international framework that protected globally important sites that are of key conservation significance, specifically covering wetland conservation and the ‘wise use’ of them. The convention generated Ramsar sites which are wetlands of international importance and many of them are considered to be a type of MPA and these habitats are protected for the purpose of conserving the biological diversity at the site. The UK designated its first Ramsar sites in 1976 and within the UK, these sites have the same protection as Special Areas of Conservation (SAC) and Special Protection Areas (SPAs) at a policy level.

Lists of habitats that are of conservation interest have been highlighted in other forms of UK and international legislation, these have helped to identify and implement the legal protection of many marine habitats. The UK Biodiversity Action Plan 1994 (UK BAP) created a list of UK BAP Priority Habitats, which included a range of threatened semi - natural habitats types that required conservation action. In 2007 the list was revised and listed 65 priority habitats based on international obligations, habitat threat and how important the habitat is for key species. Despite the fact that the UK BAP was succeeded by the UK Post 2010 Biodiversity Framework 2012, the list of UK BAP priority habitats is still an important source used in decision making and contributed to statutory lists of conservation interest habitats (JNCC website).

The UK BAP Priority Habitats identified in England as requiring action was used in Section 41 of the Natural Environment and Rural Communities Act 2006 (NERC). In this section a list of living organisms and habitat types, which were considered to be principally important for conserving biodiversity, was published by the Secretary of State. The Habitats of Principal Importance (HOPI) list included 16 marine habitats.

The Convention for the Protection of the Marine Environment of the Northeast Atlantic 1972 (also referred to as the OSPAR Convention) is an international convention that involves the cooperation of 15 governments to protect the Northeast Atlantic marine environment. OSPAR unified the Oslo Convention against waste dumping and the Paris Convention which covered land based sources of marine pollution and offshore industry (OSPAR website). In Annex 5 of the OSPAR convention a strategy for the Protection and Conservation of Ecosystems and Biological Diversity required the OSPAR Commission to identify and assess species and habitats in need of protection and which human activities are likely to have adverse effects on these habitats and ecological processes that occur at the habitat. To implement Annex 5 the OSPAR list of Threatened and/or Declining Species and Habitats was developed in 2004 and revised in 2008 (Trouwborst and Dotinga 2011).

The Marine and Coastal Access Act (2009) is another UK primary legislation which provides framework for the designation and protection of a network of Marine Conservation Zones. These are designated Marine Nature Reserves, and will replace the existing marine nature reserves that have been designated under the Wildlife and Countryside Act (1981). The MCZs also contribute to the achievement of establishing an ecologically coherent network of MPAs under the OSPAR convention. MCZs must complement other site designations such as SACs, which exist under other primary legislation. MCZs differ from SACs and SPAs as they designate any marine feature rather than specifying individual habitat and species features that meet the criteria for protection (Lieberknecht and Jones, 2016)

The Marine and Coastal Access Act also created the Marine Management Organization (MMO), developed an integrated marine spatial planning system, and improved the system for marine activity licensing, all of which is important in the managing the protected habitats (Jones, 2012). As of 2019 there was 91 MCZs implemented in England (JNCC website).

In the process of identifying MCZs in England and Wales, the Ecological Network Guidance the MCZs marine features that are threatened, rare or declining and generated a list of Features of Conservation Interest (FOCI), also known as the Habitats of Conservation Importance (HOCI). (Marlin website). The listed habitats are made up of features from the OSPAR Threatened and/or Declining Species and Habitats, protected species from the Wildlife and Countryside Act and the UK BAP list of priority habitats and species. It is recommended that 22 HOCI should be protected within MPAs in each regional MCZ project area but excludes habitats which are sufficiently protected under the Habitats and Birds Directive, or habitats that are not known to exist in the MCZ regional area (JNCC and NE, 2016). The ecological network guidelines for selecting MCZs also suggested a list of 23 Broad Scale Habitats (BSHs) that should be conserved within MPAs in each regional MCZ. The BSHs are easier to identify compared to finer scale habitats and these habitats are more representative, showing differences in the marine communities (JNCC and NE, 2010). The lists of FOCIs and BSHs have been included in the policy map.

European directives such as The Marine Strategy Framework Directive (MSFD) created targets and conservation objectives for conserving the marine environment and these were transposed into The Marine Strategy Regulations 2010. The main target of the MSFD is to maintain and/or achieve “good environmental status” (GES) in the marine environment by 2020, this good status will mean that UK oceans and seas are ecologically diverse, clean, healthy and productive (Trouwborst and Dotinga 2011). Within the UK regulations a 3 stage framework, which is reviewed every 6 years, was created to achieve GES in 11 descriptors. Descriptor 1 (Biodiversity), Descriptor 4 (Food Webs) and Descriptor 6 (Sea – Floor integrity) are the main indictors and targets for marine habitats and focus on habitat distribution, condition, physical damage to the seabed and benthic community composition.

The Water Framework Directive (WFD) also sets conservation targets and objectives in a framework to analyse, plan and manage water resources and protect all aquatic ecosystems. The Water Environment (England and Wales) Regulations 2003/2015/2017 implemented the requirements of the WFD, which was amended and replaced in 2017. Within the regulations previsions were created for certain protected areas (Collins and others, 2012). One of the key aims of the WFD sets a target deadline for achieving “good status” in all waters and marine environments. In surface waters there is a requirement to achieve or maintain ecological protection and minimum chemical standards. This lead to the introduction of “good ecological status” (GES) targets which are defined in the WFD as the quality of the biological community, hydrological and chemical characteristics, and the introduction of “good chemical status” (GCS) targets that aims to maintain quality chemical standards that have been established at a European level. The targets aim to conserve and protect the quality of all surface water bodies including ones that are protected in SPAs and SACs, the targets highlight that WFD member states must implement and achieve targets in compliance with any objectives or standards specified in the legislation that establish protection to the individual habitats.

Table 18: Review of legislation and policy applicable to habitats that score highly against irreplaceability criteria (>40) (Blank cells indicate that the policy or legislation is not relevant in that instance).

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A1.127 *Ceramium* sp. and piddocks on eulittoral fossilised peat		Peat and clay exposures [N. Ireland, England, Wales]	Peat and clay exposures	
A1.2143 *Fucus serratus* and piddocks on lower eulittoral soft rock	Littoral chalk communities	Intertidal chalk [N. Ireland, England]	Littoral chalk communities	
A1.223 *Mytilus edulis* and piddocks on eulittoral firm clay		Peat and clay exposures [N. Ireland, England, Wales]	Peat and clay exposures	
A1.4114 *Cystoseira* spp. in eulittoral rockpools				
A3.2113 *Laminaria digitata* and piddocks on sublittoral fringe soft rock		Subtidal chalk [N. Ireland, England]	Subtidal chalk	
A3.217 *Hiatella arctica* and seaweeds on		Subtidal chalk [N.	Subtidal chalk	

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
vertical limestone / chalk		Ireland, England]		
A3.362 *Cordylophora caspia* and *Electra crustulenta* on reduced salinity infralittoral rock		Estuarine rocky habitats		Low or variable salinity habitats
A3.363 *Hartlaubella gelatinosa* and *Conopeum reticulum* on low salinity infralittoral mixed substrata		Estuarine rocky habitats		Low or variable salinity habitats
A4.12 Sponge communities on deep circalittoral rock				Northern seafan and sponge communities
A4.121 *Phakellia ventilabrum* and axinellid sponges on deep, wave-exposed circalittoral rock		Fragile sponge and anthozoan communities on subtidal rocky habitats	Fragile sponge and anthozoan communities	Northern seafan and sponge communities
A4.1311 *Eunicella verrucosa* and *Pentapora foliacea* on wave-exposed circalittoral rock		Fragile sponge and anthozoan communities on subtidal rocky habitats	Fragile sponge and anthozoan communities	
A4.23 Communities on soft circalittoral rock		Subtidal chalk / Peat and clay exposures	Subtidal chalk / Peat and clay exposures	

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
		(N. Ireland, England, Wales)		
A4.231 Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay		Subtidal chalk / Peat and clay exposures [N. Ireland, England, Wales]	Peat and clay exposures	
A4.232 Polydora sp. tubes on moderately exposed sublittoral soft rock		Subtidal chalk [N. Ireland, England]	Subtidal chalk	
A4.233 Hiatella-bored vertical sublittoral limestone rock		Subtidal chalk [N. Ireland, England]	Subtidal chalk	
A4.71 Communities of circalittoral caves and overhangs				
A4.711 Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock				
A5.51 Maerl beds	Maerl beds	Maerl beds	Maerl beds	Maerl beds
A5.511 *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	Maerl beds	Maerl beds	Maerl beds	Maerl beds

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
A5.512 *Lithothamnion glaciale* maerl beds in tide-swept variable salinity infralittoral gravel	Maerl beds	Maerl beds	Maerl beds	Maerl beds
A5.513 *Lithothamnion corallioides* maerl beds on infralittoral muddy gravel	Maerl beds	Maerl beds	Maerl beds	Maerl beds
A5.5343 *Ruppia maritima* in reduced salinity infralittoral muddy sand		Seagrass beds	Seagrass beds	Seagrass beds
A5.6 Sublittoral biogenic reefs				
A5.621 *Modiolus modiolus* beds with hydroids and red seaweeds on tide-swept circalittoral mixed substrata	Modiolus modiolus beds	Horse mussel beds	Horse mussel beds	Horse mussel beds
A5.622 *Modiolus modiolus* beds on open coast circalittoral mixed sediment	Modiolus modiolus beds	Horse mussel beds	Horse mussel beds	Horse mussel beds
A5.623 *Modiolus modiolus* beds with fine hydroids and large solitary ascidians on very sheltered	Modiolus modiolus beds	Horse mussel beds	Horse mussel beds	Horse mussel beds

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
circalittoral mixed substrata				
A5.624 *Modiolus modiolus* beds with *Chlamys varia*, sponges, hydroids and bryozoans on slightly tide-swept very sheltered circalittoral mixed substrata	Modiolus modiolus beds	Horse mussel beds	Horse mussel beds	Horse mussel beds
A5.63 Circalittoral coral reefs	Lophelia pertusa reefs	Cold-water coral reefs [Scotland]	Cold-water coral reef	Cold-water coral reefs
A5.631Circalittoral [Lophelia pertusa] reefs	Lophelia pertusa reefs	Cold-water coral reefs [Scotland]	Cold-water coral reef	Cold-water coral reefs
A5.7 Features of sublittoral sediments				
A5.71 Seeps and vents in sublittoral sediments		Carbonate reef (Wales) / carbonate mounds [Scotland)		Submarine structures made by leaking gases
A5.711 Bubbling reefs in the sublittoral euphotic zone		Carbonate reef [Wales) / carbonate mounds [Scotland)		Submarine structures made by leaking gases
A5.712 Bubbling reefs in the aphotic zone		Carbonate reef [Wales) / carbonate		Submarine structures made by

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
		mounds [Scotland)		leaking gases
A6 Deep-sea bed				
A6.1 Deep-sea rock and artificial hard substrata	Coral gardens		Coral gardens	Coral Gardens
A6.11 Deep-sea bedrock				
A6.14 Boulders on the deep-sea bed				
A6.2 Deep-sea mixed substrata	Coral gardens		Coral gardens	Coral gardens
A6.3 Deep-sea sand	Coral gardens		Coral gardens	Coral gardens / Offshore subtidal sands and gravels
A6.4 Deep-sea muddy sand	Coral gardens		Coral gardens / seapens and burrowing megafauna	Coral gardens
A6.5 Deep-sea mud	Coral gardens		Coral gardens / mud habitats in deep water / seapens	Coral gardens / Offshore

Habitats	OSPAR	HPI	MCZ HOCI	PMF (Scotland)
			and burrowing megafauna	deep sea mud
A6.6 Deep-sea bioherms				
A6.61 Communities of deep-sea corals	*Lophelia pertusa* reefs	Cold-water coral reefs [Scotland)	Cold-water coral reef	
A6.611 Deep-sea *Lophelia pertusa* reefs	Lophelia pertusa reefs	Cold-water coral reefs [Scotland)	Cold-water coral reef	Cold-water coral reefs
A6.62 Deep-sea sponge aggregations	Deep-sea sponge aggregations	Deep-sea sponge communities [Scotland)	Deep-sea sponge aggregations	Deep-sea sponge aggregations

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